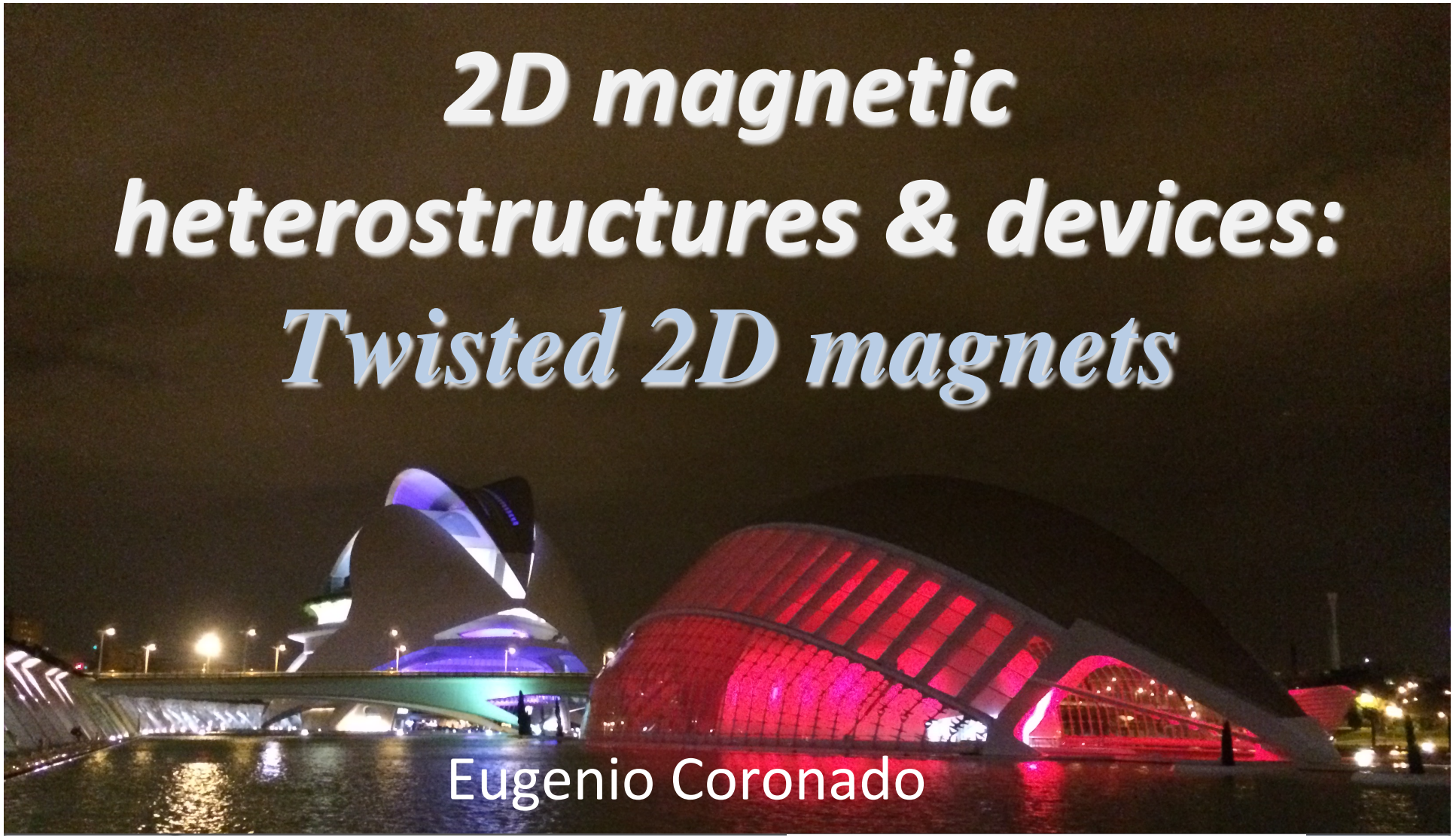
# 2D magnetic heterostructures & devices: *Twisted 2D magnets*



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ARTICLE

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doi:10.1038/nature26160

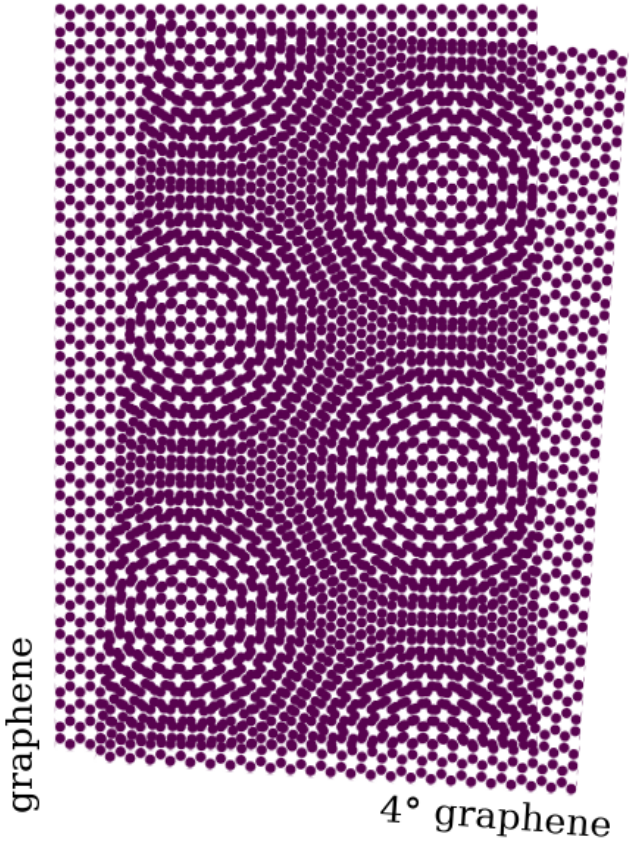
# Unconventional superconductivity in magic-angle graphene superlattices

Yuan Cao[1], Valla Fatemi[1], Shiang Fang[2], Kenji Watanabe[3], Takashi Taniguchi[3], Efthimios Kaxiras[2,4] & Pablo Jarillo-Herr

2018

**Twistronics**

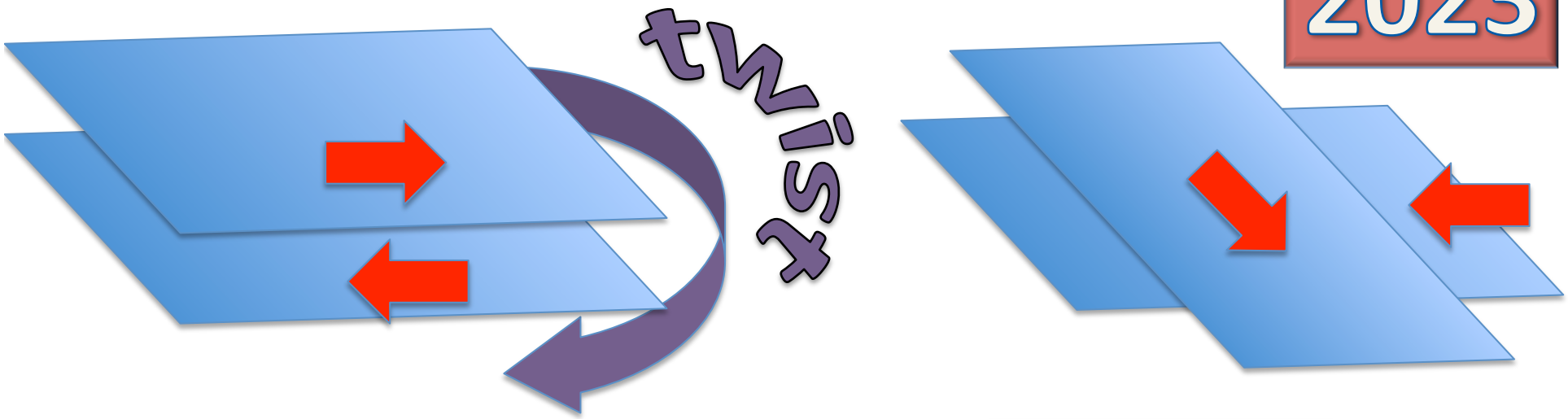
***Moiré superlattice***



# Twisted 2D magnets
## (beyond Moiré)

*Nat. Mater.* **2023**, *doi: 10.1038/s41563-023-01735-6*

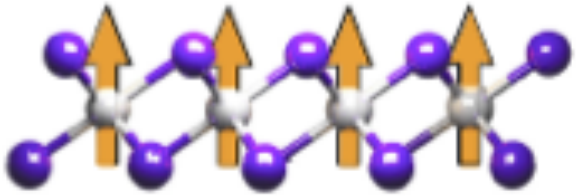
2023




***Natural magnet***

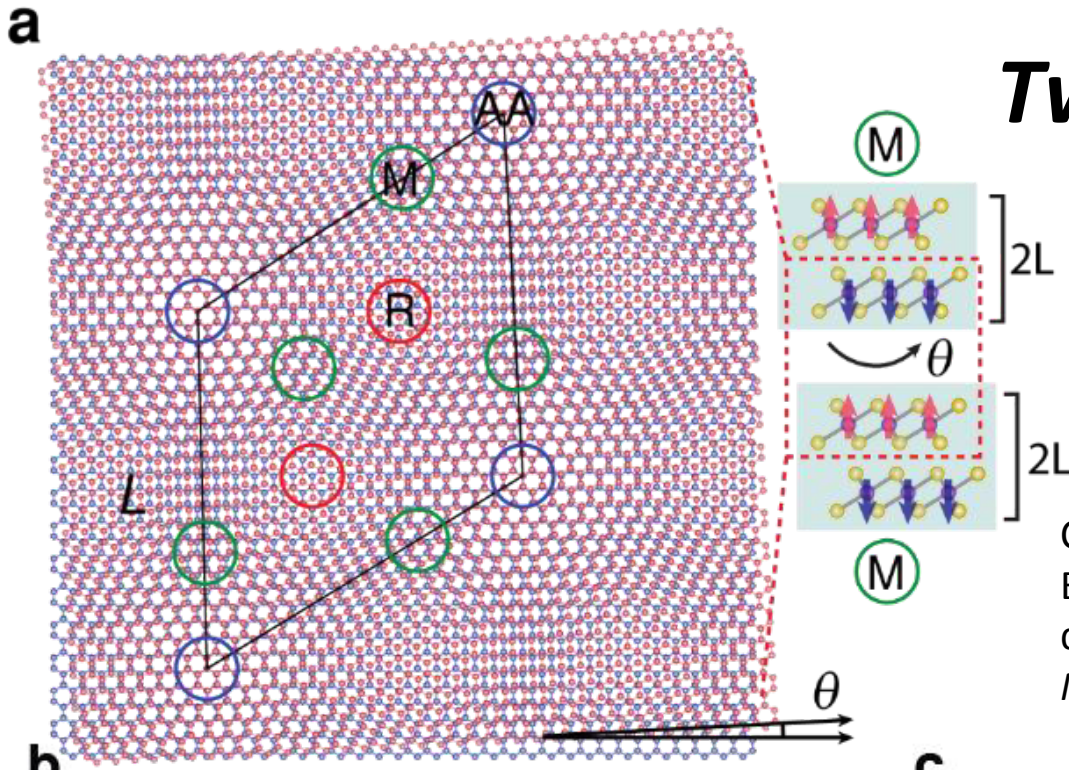
***Twisted magnet***

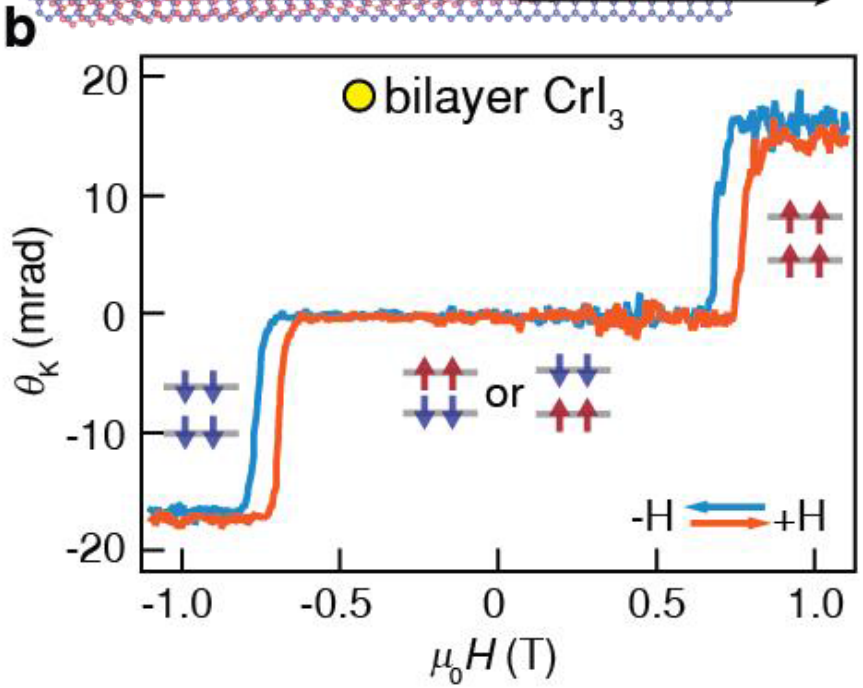
# *Twistronics with $CrI_3$*

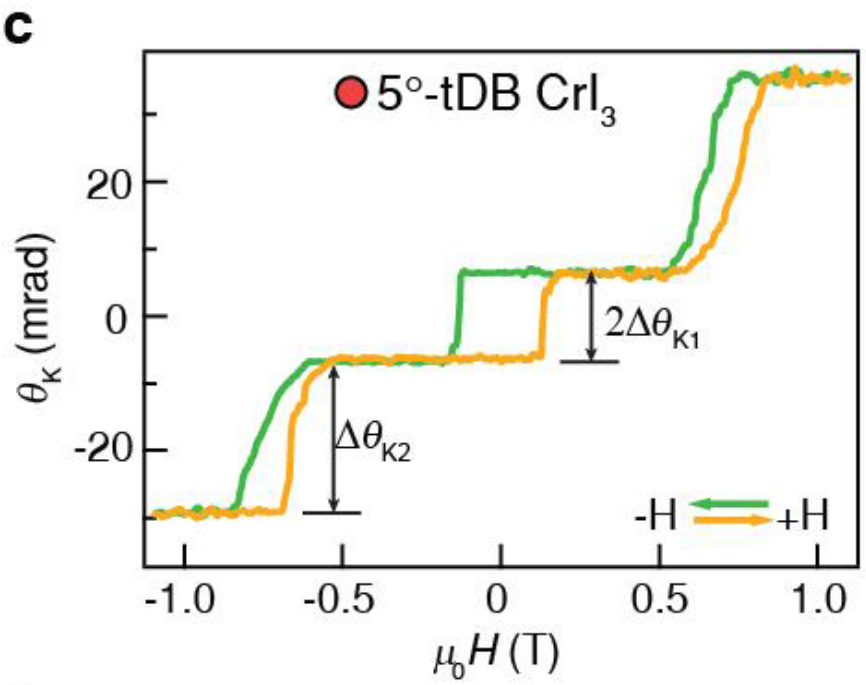


Ising ferromagnet

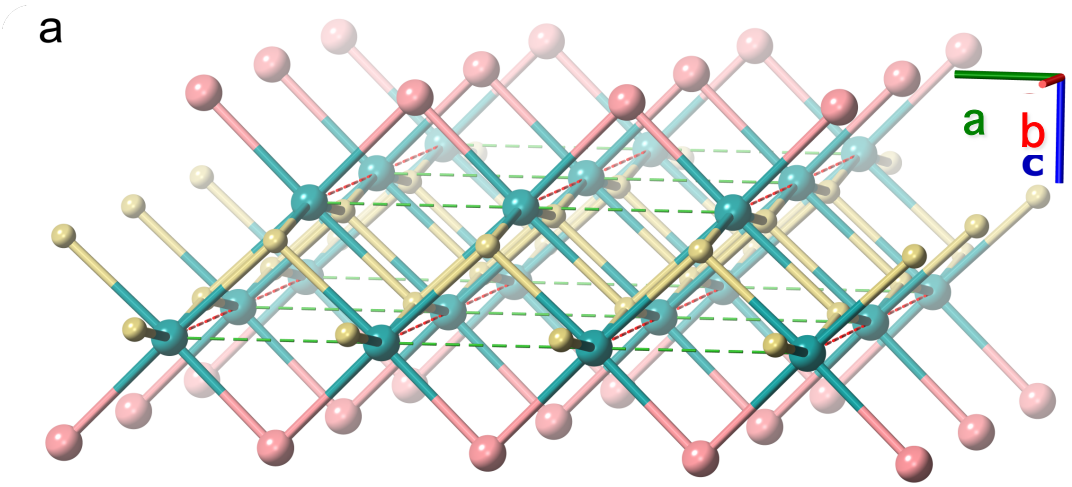
Cheng, G., Rahman, M.M., Allcca, A.L. *et al.* Electrically tunable moiré magnetism in twisted double bilayers of chromium triiodide. *Nat Electron* **6**, 434–442 (2023).



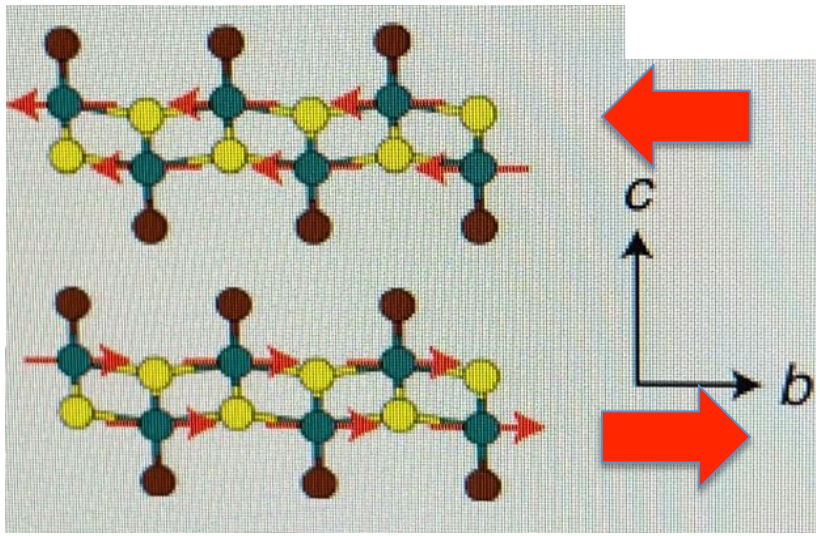



# *Magnetic semiconductor CrSBr*




***Natural magnet***



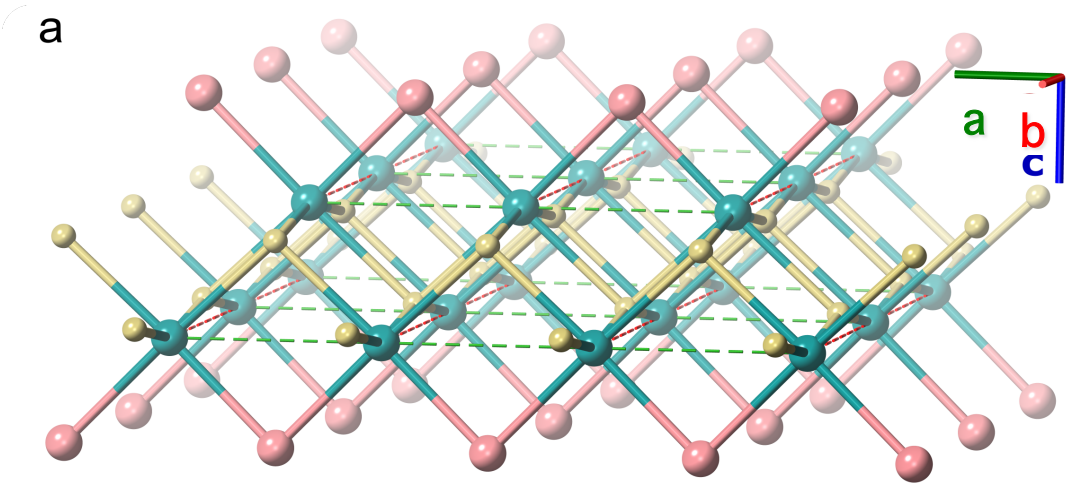

**Ferromagnetic monolayer** ($T_C$ = 150 K)

with in-plane Ising anisotropy (along *b*)

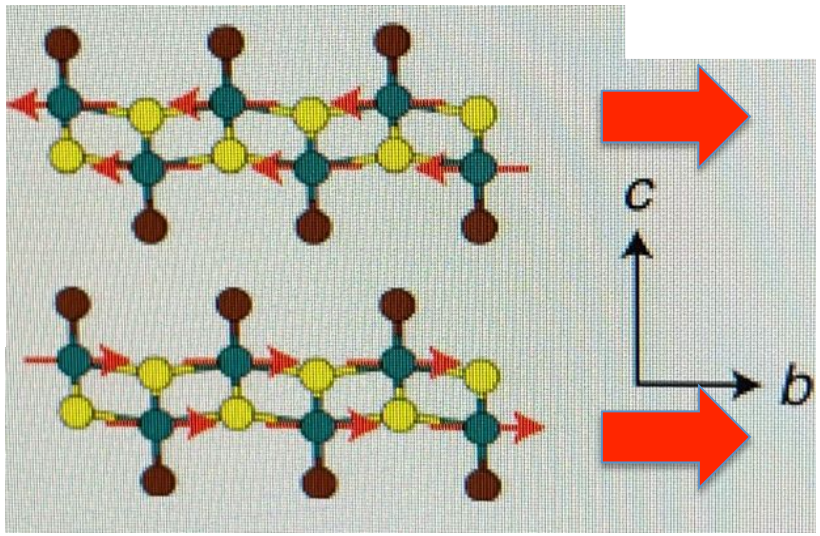
**Metamagnetic bilayer** with a field-induced spin switching at 0.2 T

C. Boix, S. Mañas-Valero *et al.* ***Adv. Mater. 2022,*** 34, 2204940

# *Magnetic semiconductor CrSBr*




***Natural magnet***

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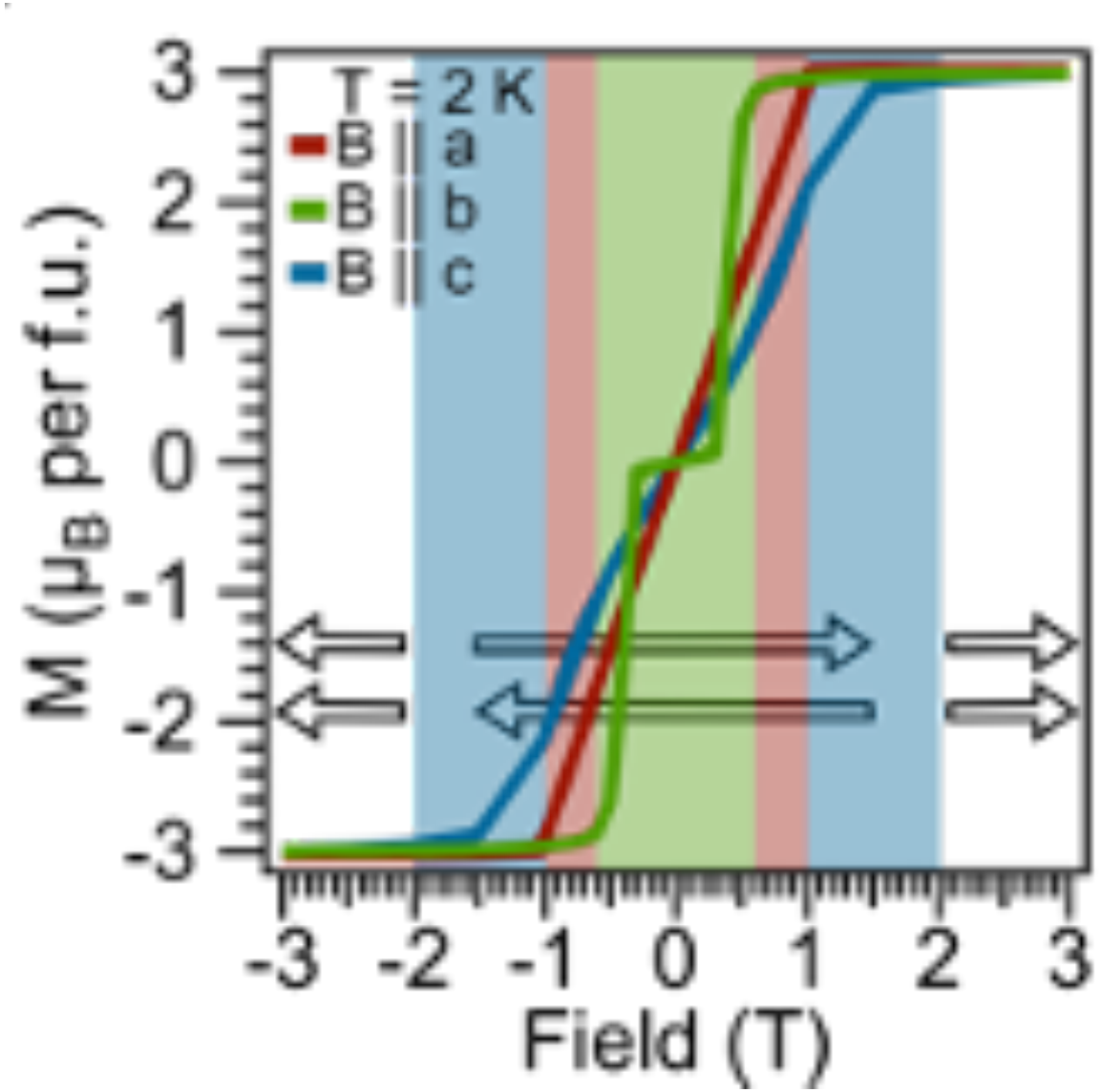
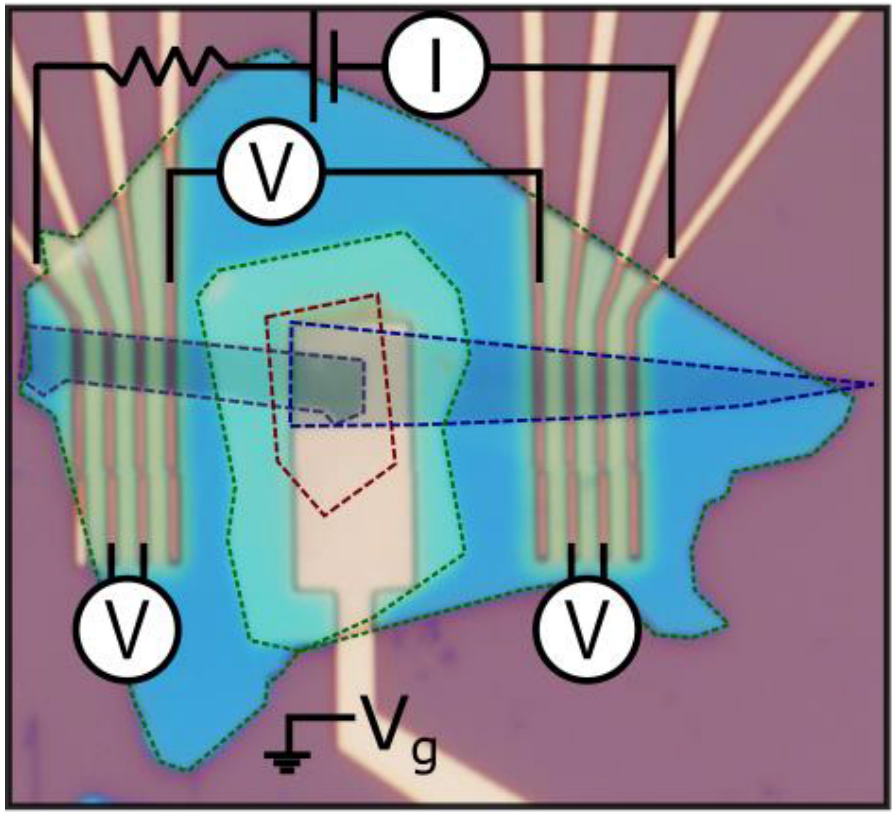
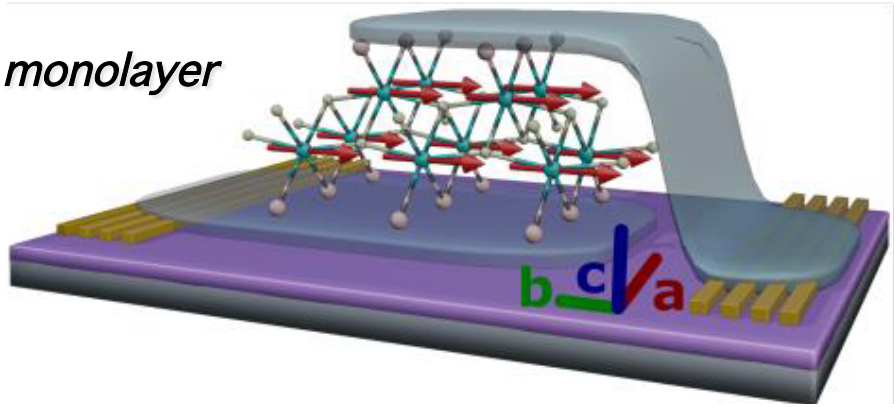
# *2D MAGNET CrSBr. Magnetism*

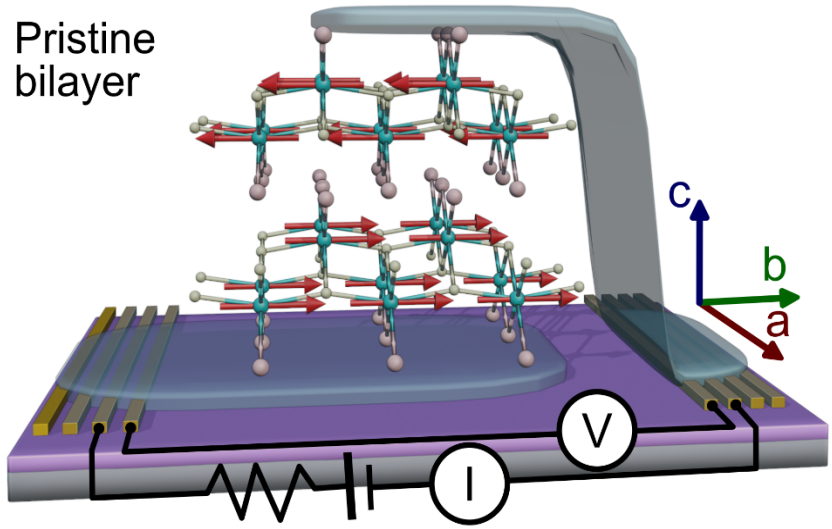



**Bulk: metamagnet with $T_N$ =138 K**

# *Magneto-transport properties in the 2D limit*

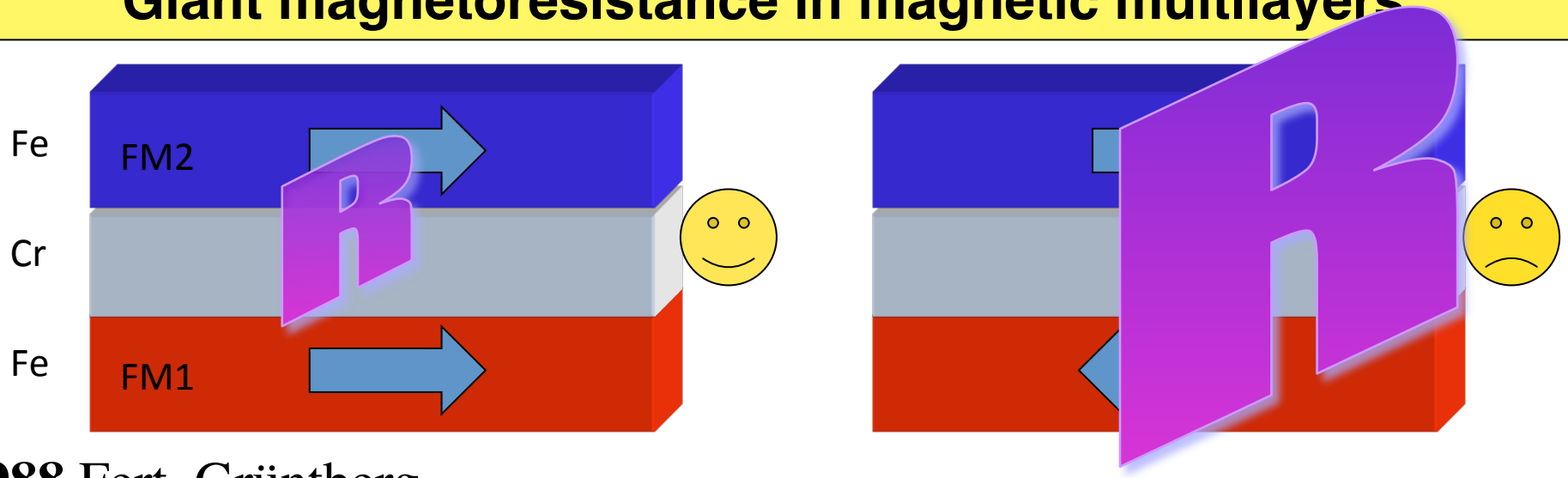


# SPINTRONICS: SPIN VALVES

**Giant magnetoresistance in magnetic multilayers**




**1988** Fert, Grüntberg

**van der Waals spin valve**

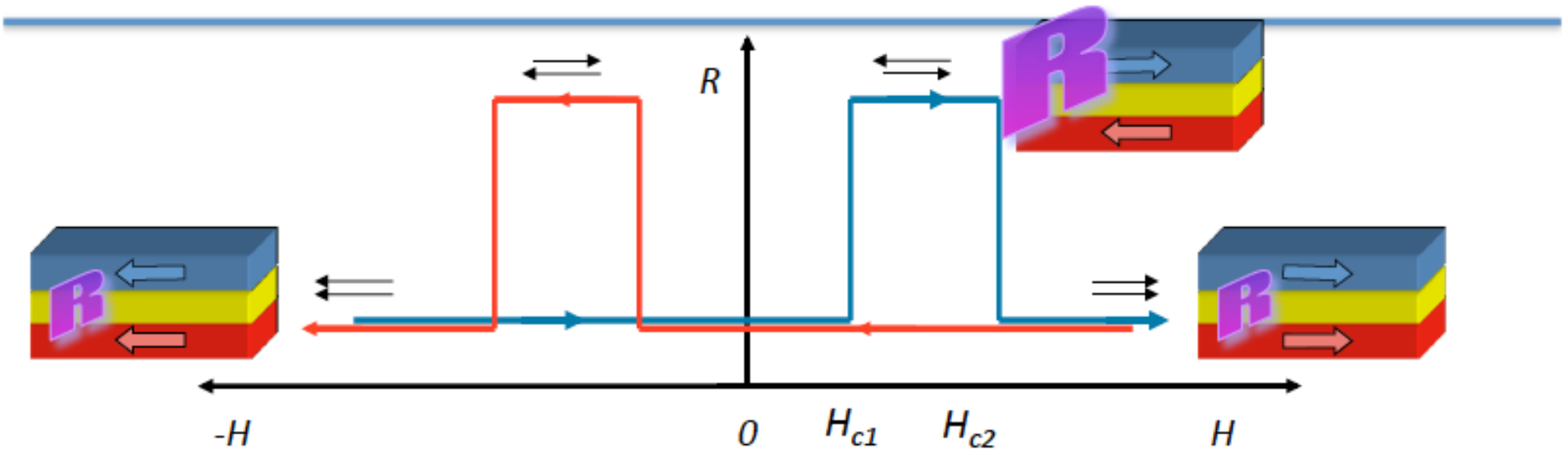
2D magnet

Van der Waals gap

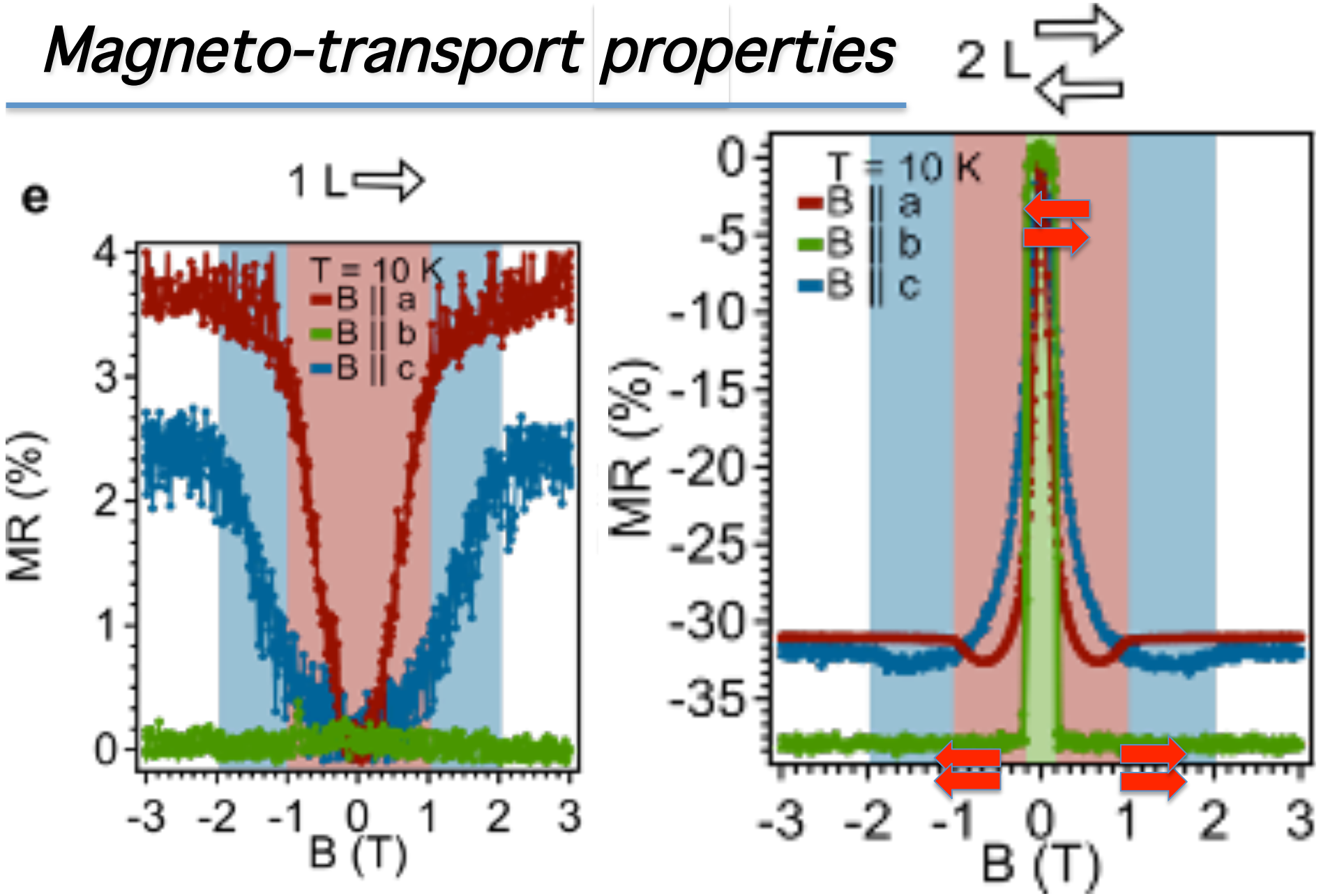
2D magnet

# SPINTRONICS: SPIN VALVES

**Giant magnetoresistance in magnetic multilayers**



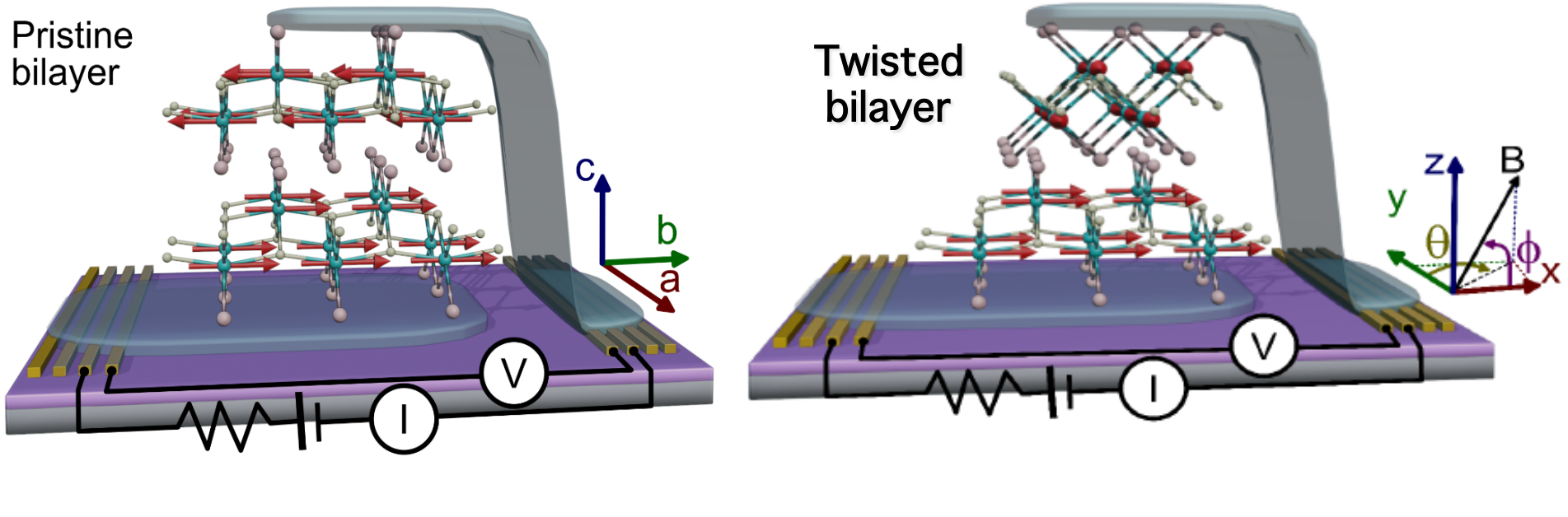
# *Magneto-transport properties*

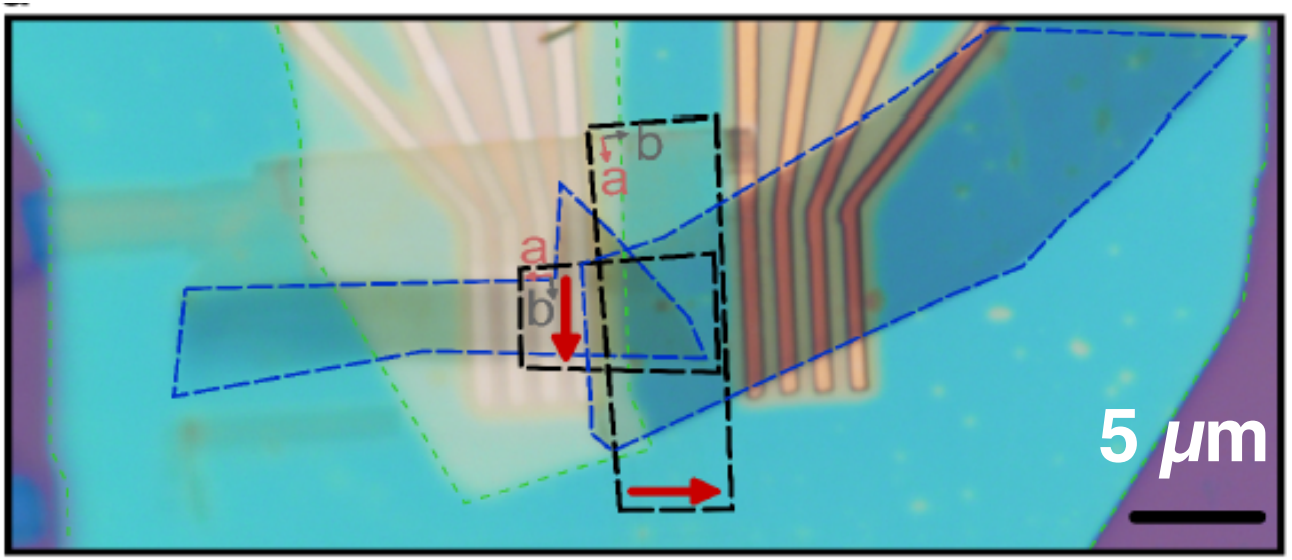



Spin reorientation
(magnetic anisotropy)

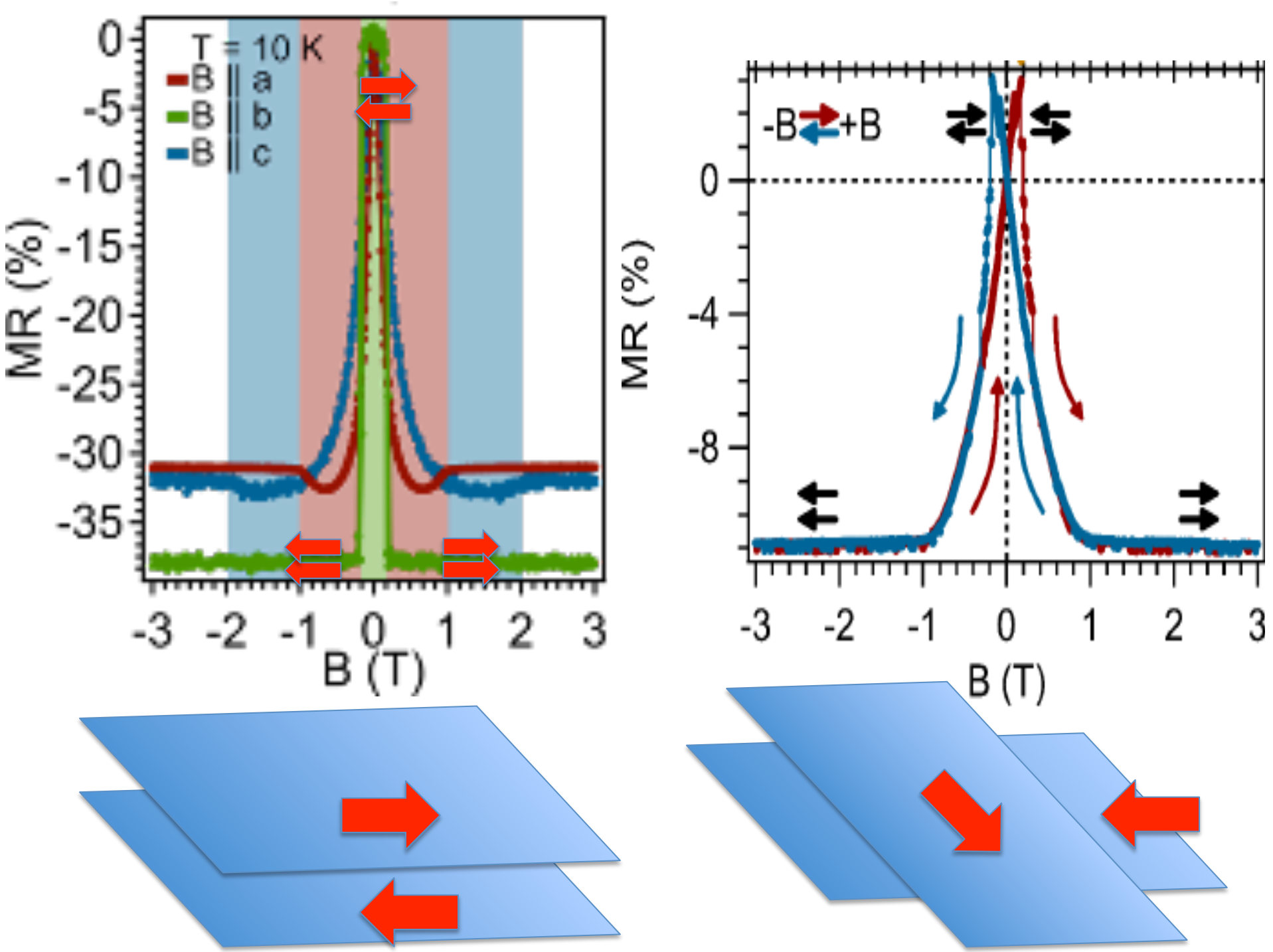
Spin valve effect
(AF interlayer coupling)

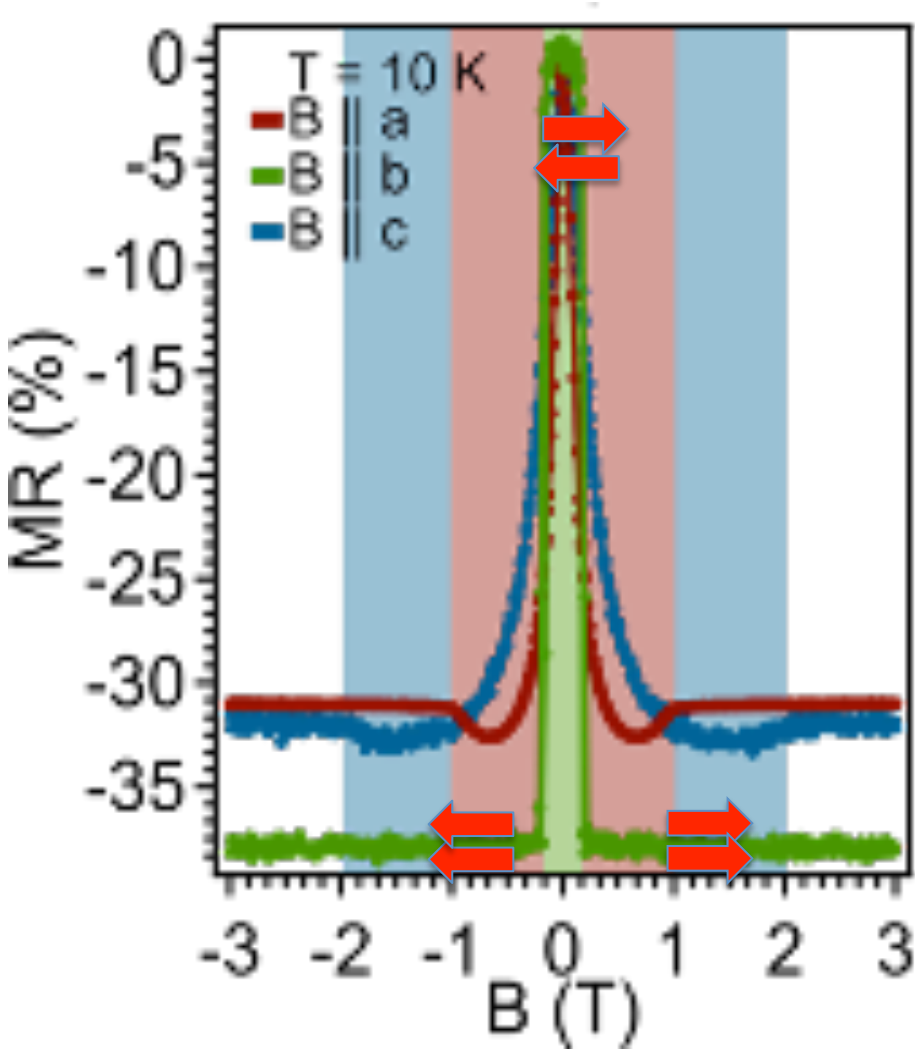
# Twisted 2D magnets

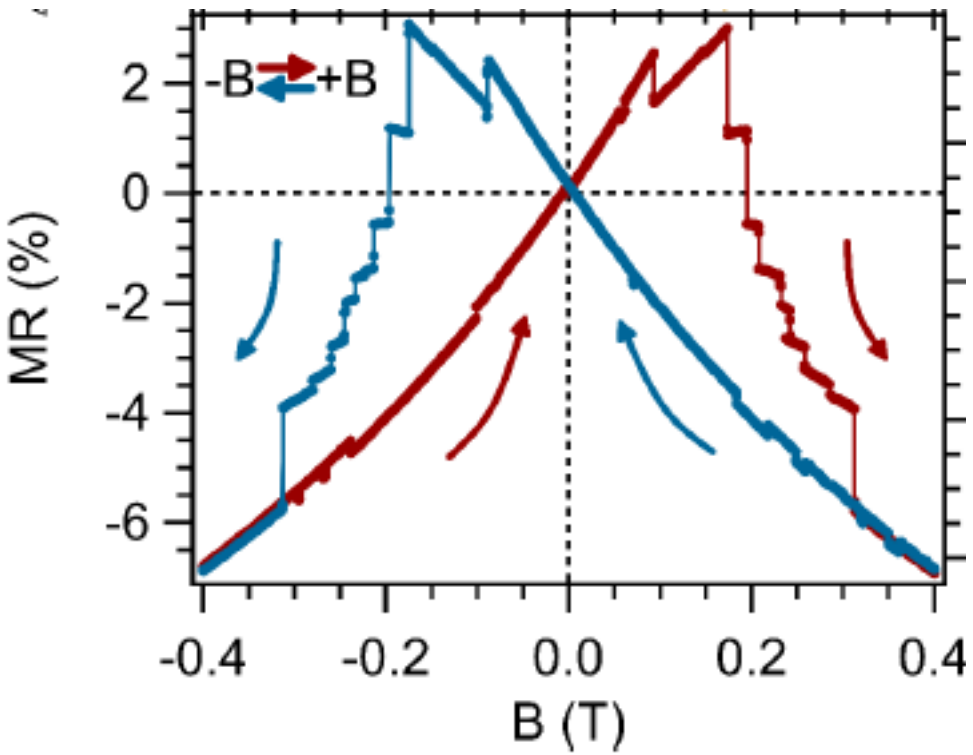



C. Boix, S. Mañas-Valero, E. Coronado, *Nat. Mater.* **2023**, *doi: 10.1038/s41563-023-01735-6*

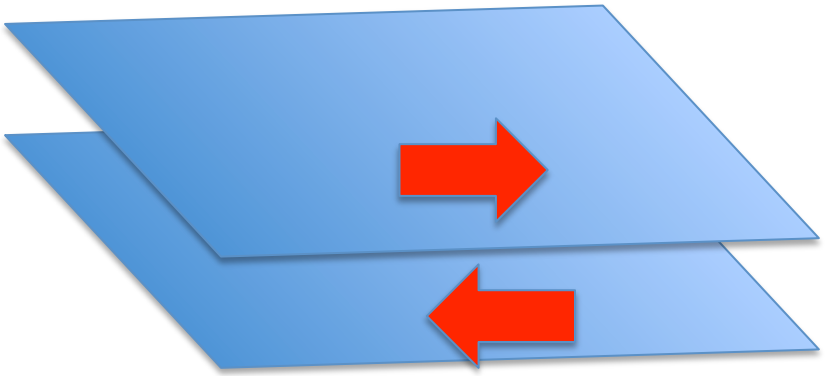

T = 10 K
B || a
B || b
B || c
MR (%)
B (T)
-B +B
MR (%)
B (T)

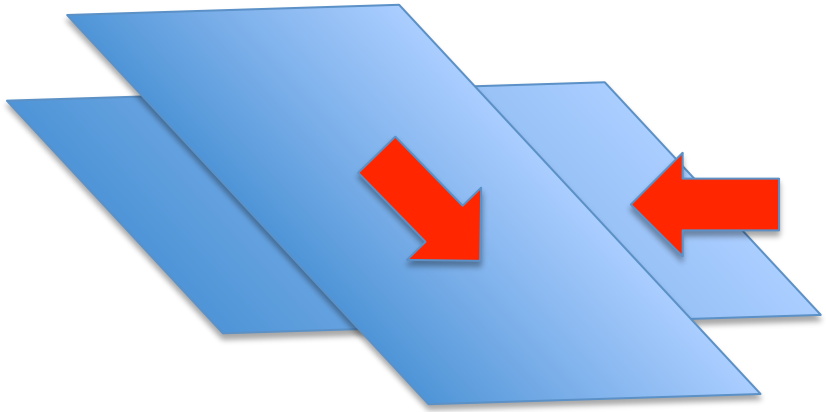


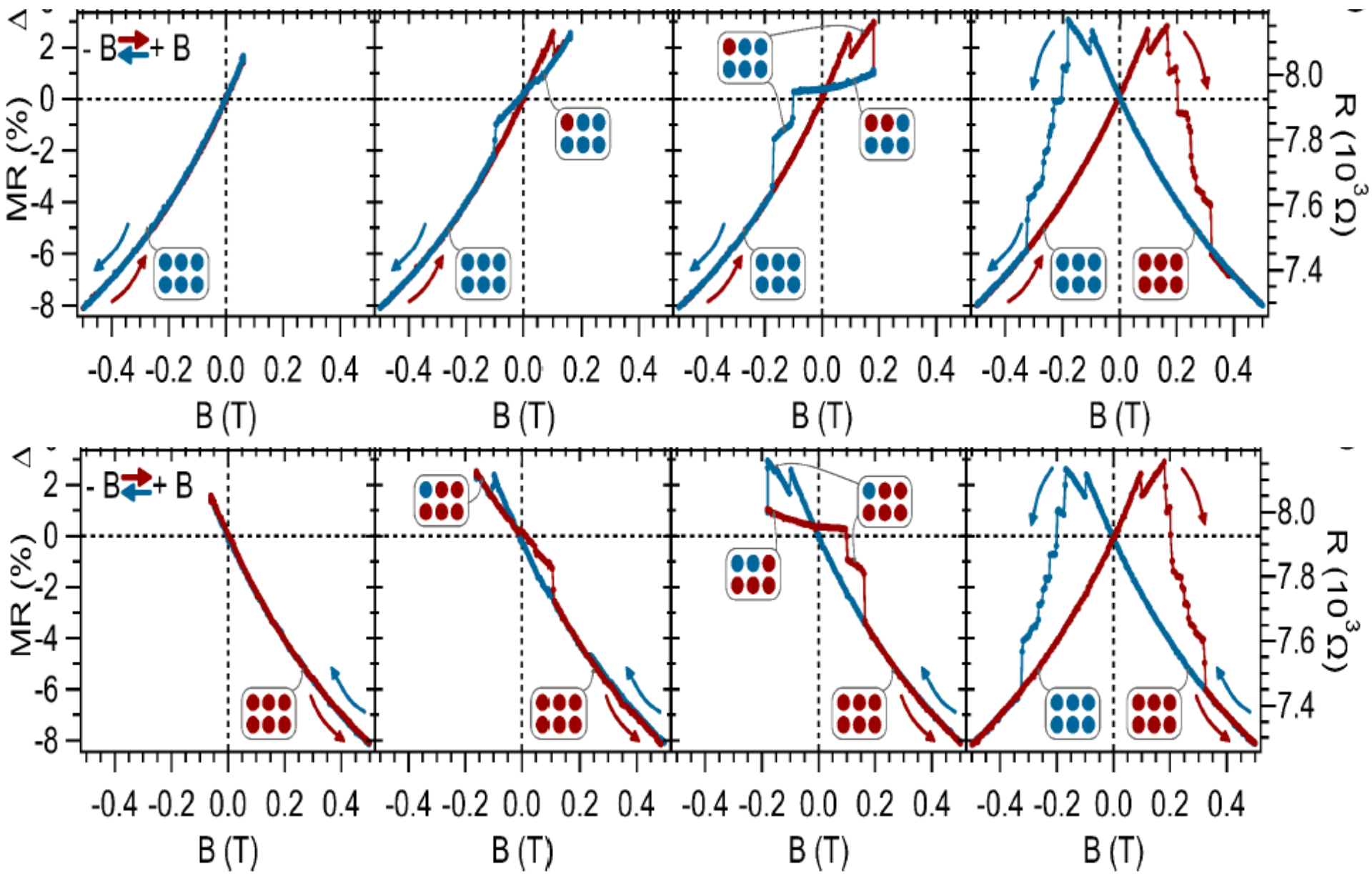




***Multiple spin switching with hysteresis:***

**MAGNETIC MULTISTABILITY**

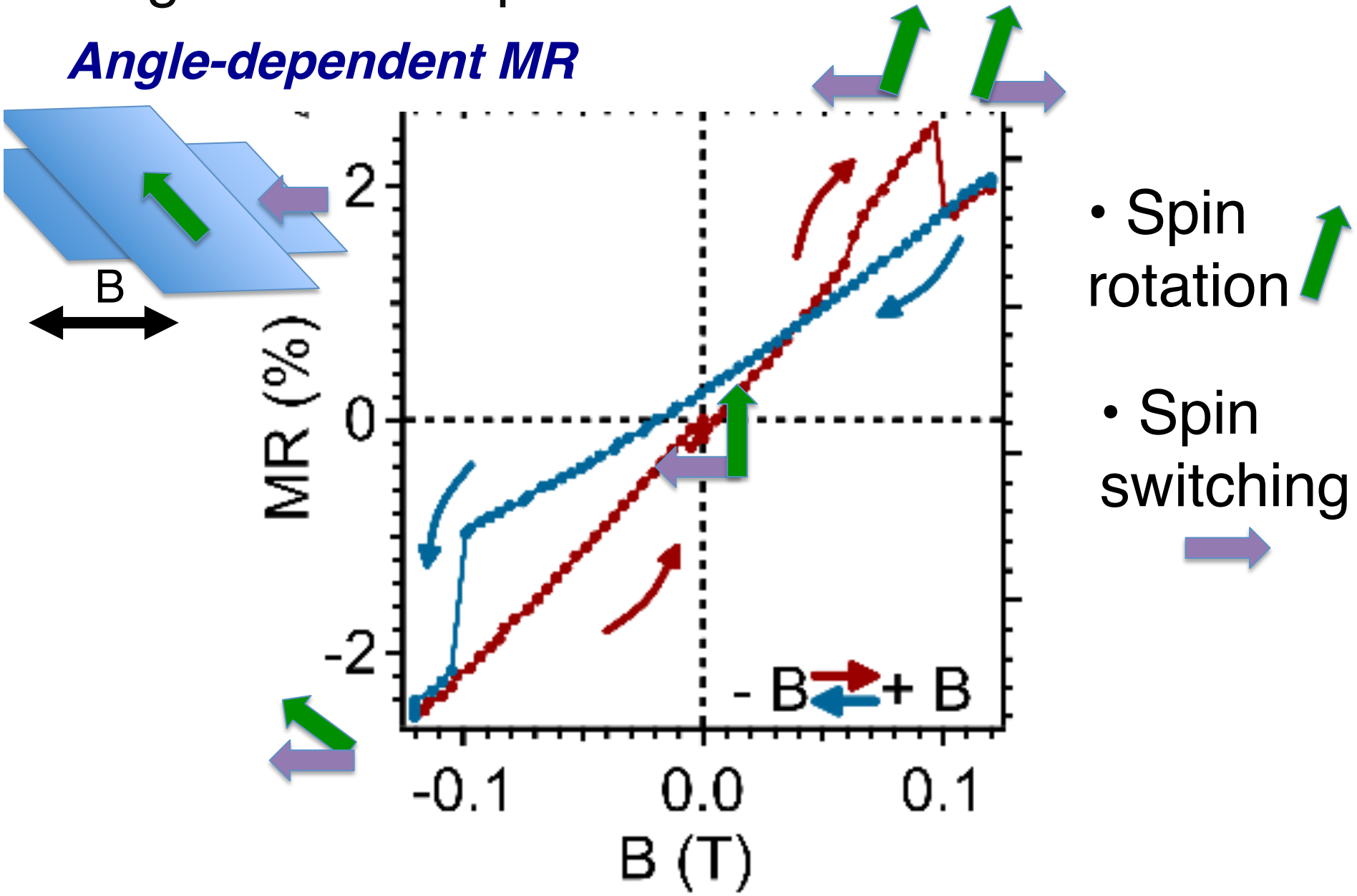




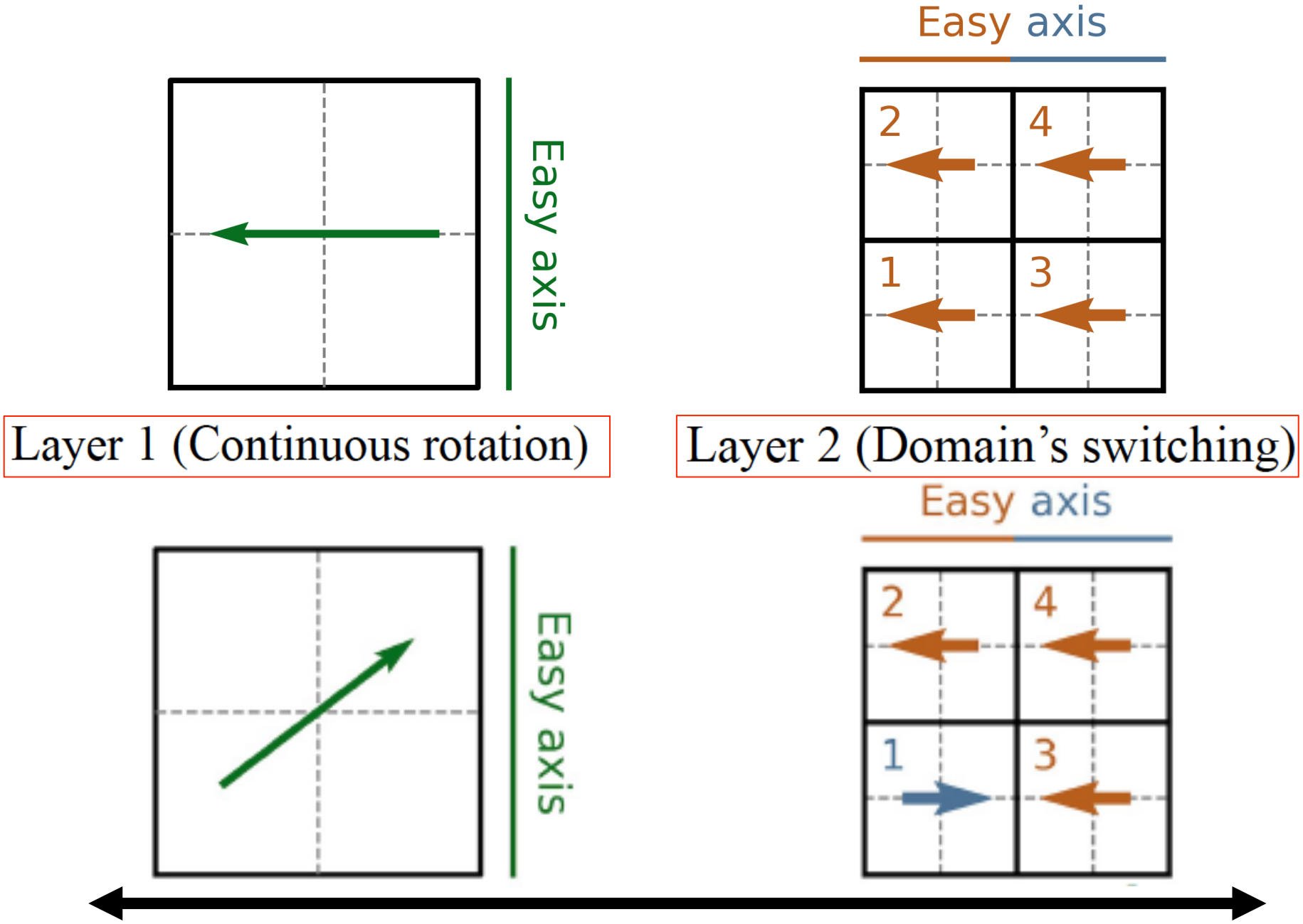

- B
+ B
MR (%)
R (10^3 Ω)
B (T)
-0.4 -0.2 0.0 0.2 0.4
2
0
-2
-4
-6
-8
8.0
7.8
7.6
7.4

# Origin of the steps:

***Angle-dependent MR***



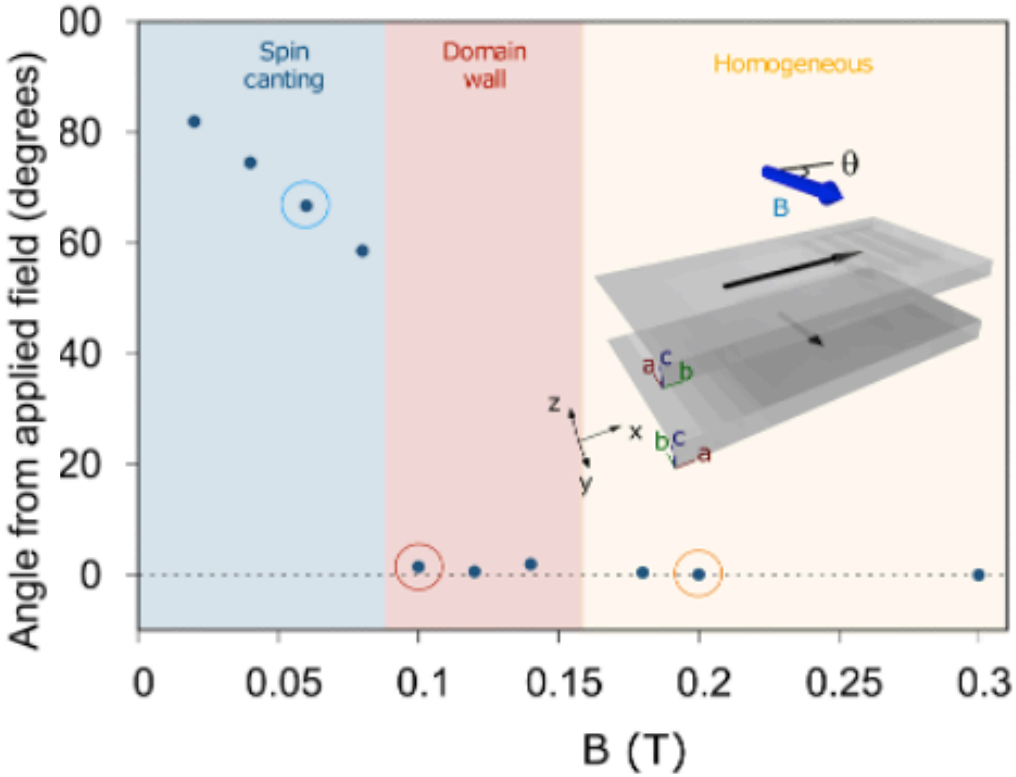

- Spin rotation
- Spin switching

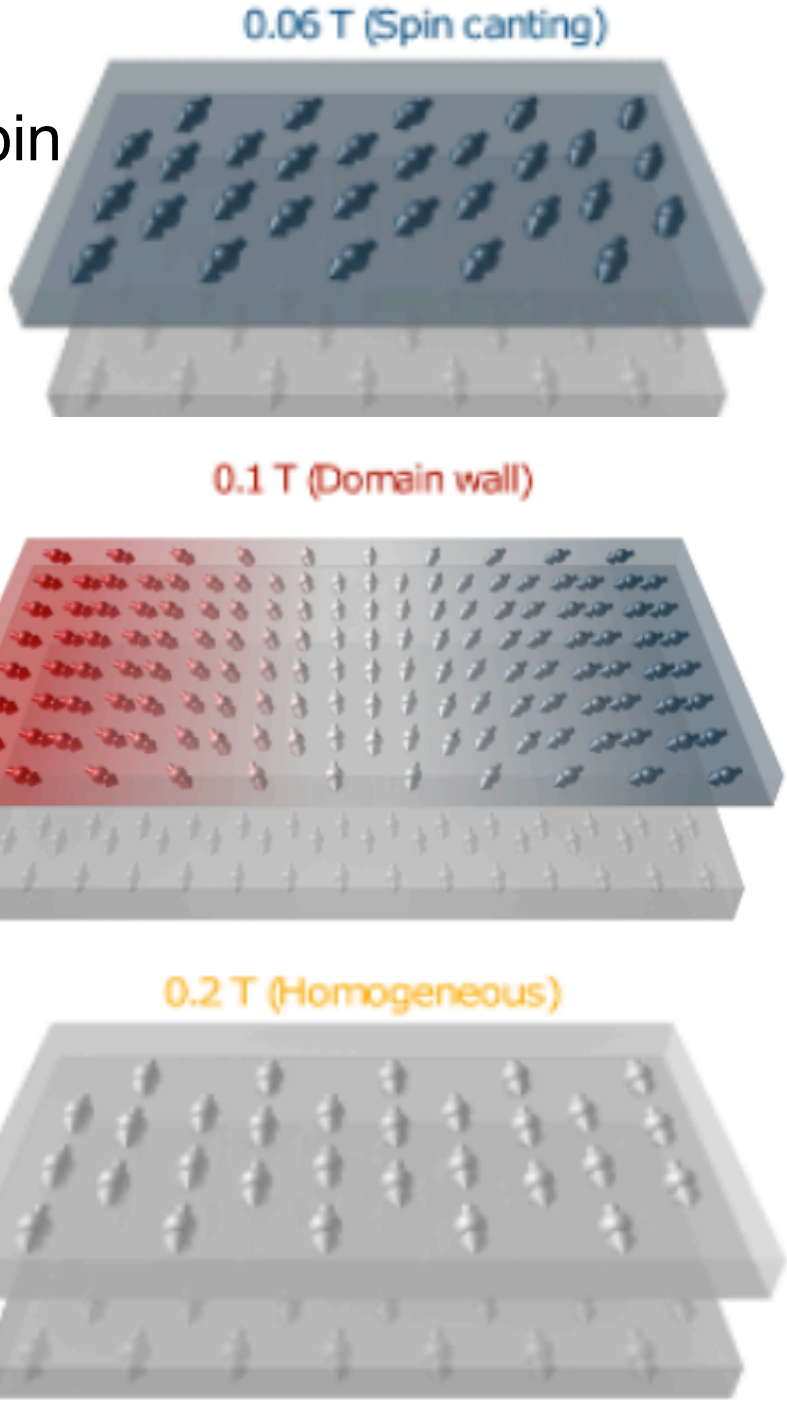



A. Ribakov, J. Ferrer

# Origin of the hysteresis:

## different domain configurations and spin textures

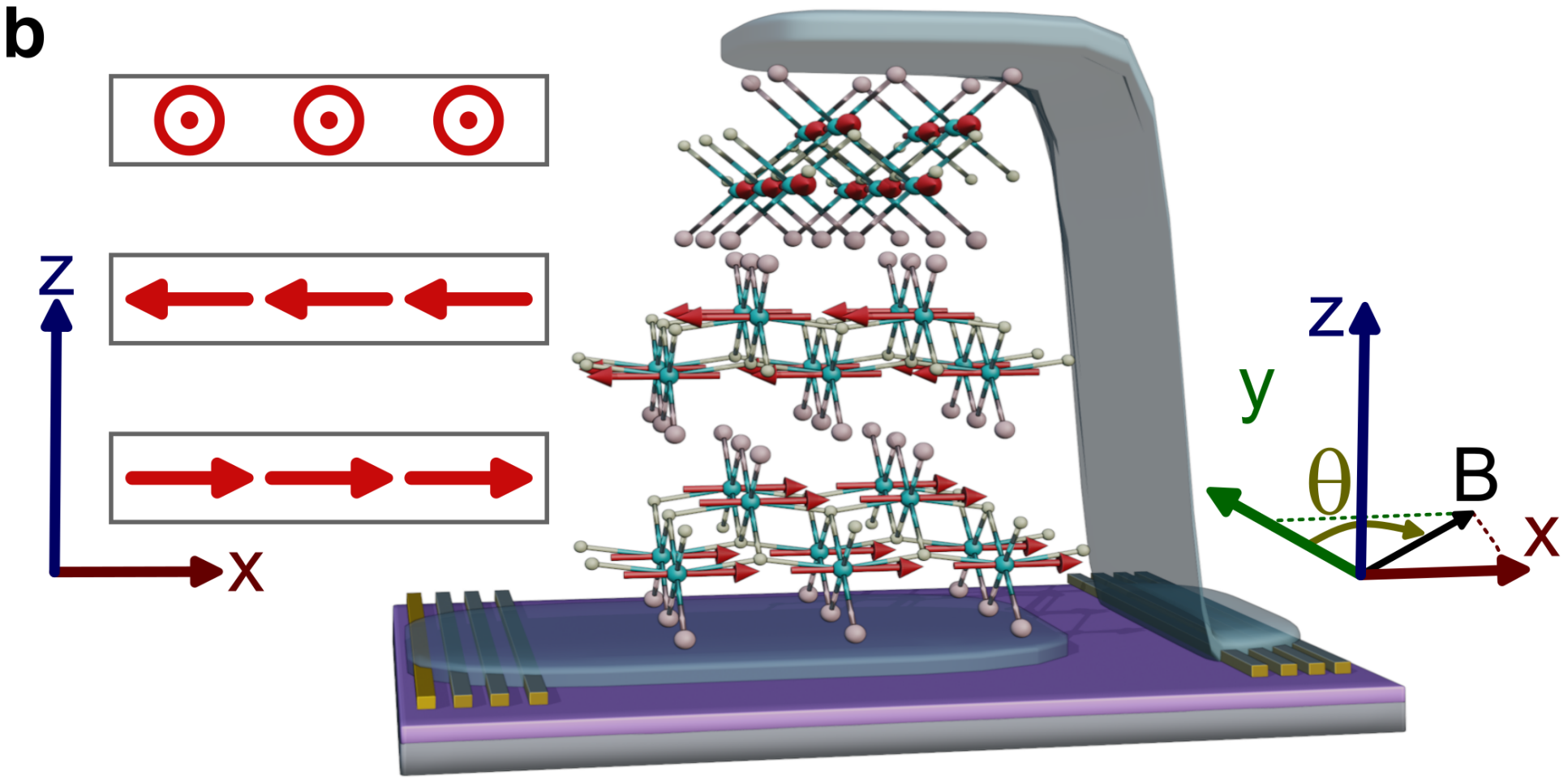



Atomistic calculations by E. Santos

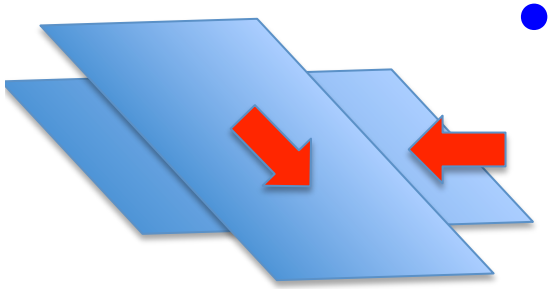
*Non-conlinear spin configurations emerge in the form of hybrid domain walls (Bloch-type) when DM interactions are taken into account*

# *Increasing the complexity*



# *Take home message*

## *TWISTED 2D MAGNETS*



- **Artificial 2D magnets with emergent properties (useful in spintronics)**

**Next: vary the angles, vary the number of layers, vary the 2D magnets**

# Acknowledgment


**Univ. Valencia (ICMol)**

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- Josep Canet
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- Elton Santos

**Univ. Oviedo**

- Jaime Ferrer


- European Union:


***4D-NMR***

***FATMOLS***

***SINFONIA***

***SPINMol***

**MoI-2D**

- Spanish MINECO



***Molecular Nanoscience***

Unit of Excellence **María de Maeztu**

- Generalitat Valenciana

***PROMETEO*** *Program of Excellence*