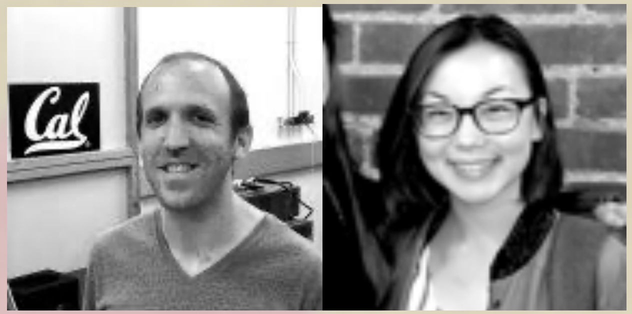
Collective dynamics of coexisting spin textures: the antiferromagnetic switching of Fe_xNbS_2

Eran Maniv, Nityan Nair, Shannon Haley
Shan Wu, Robert Birgeneau
Caolan John, Spencer Doyle
Yaroslav Tserkovnyak
James G. Analytis



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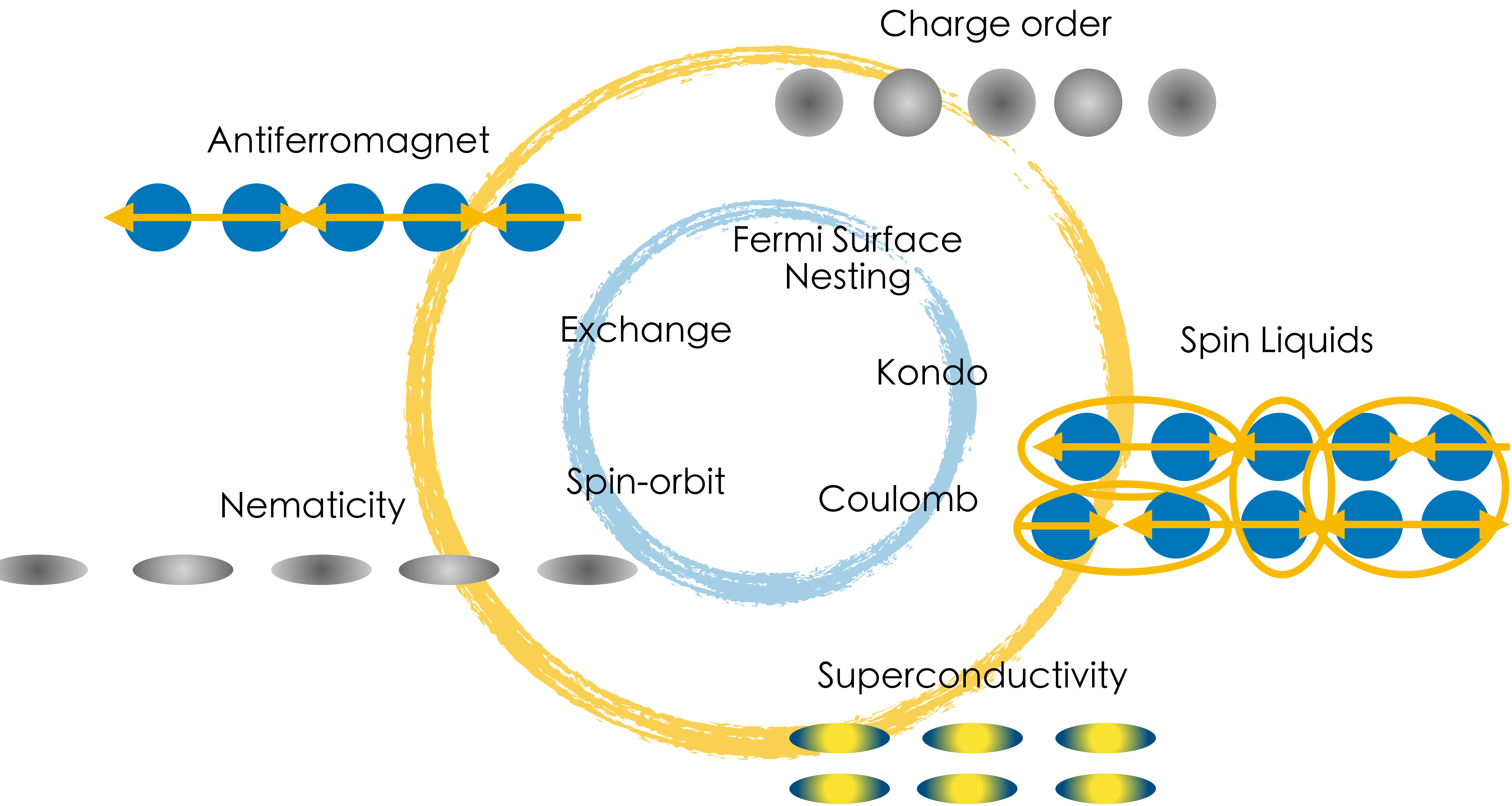
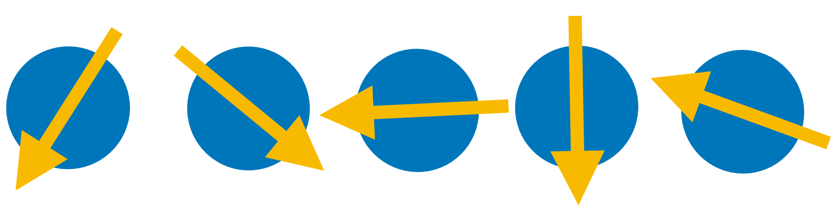
Berkeley UNIVERSITY OF CALIFORNIA

Frustration, Rigidity and Disorder

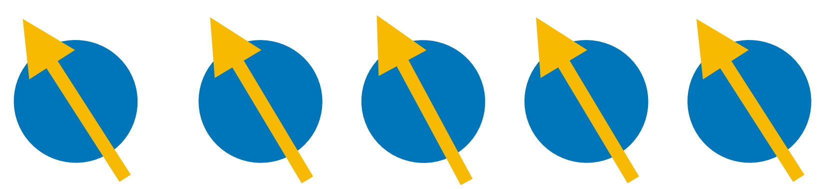


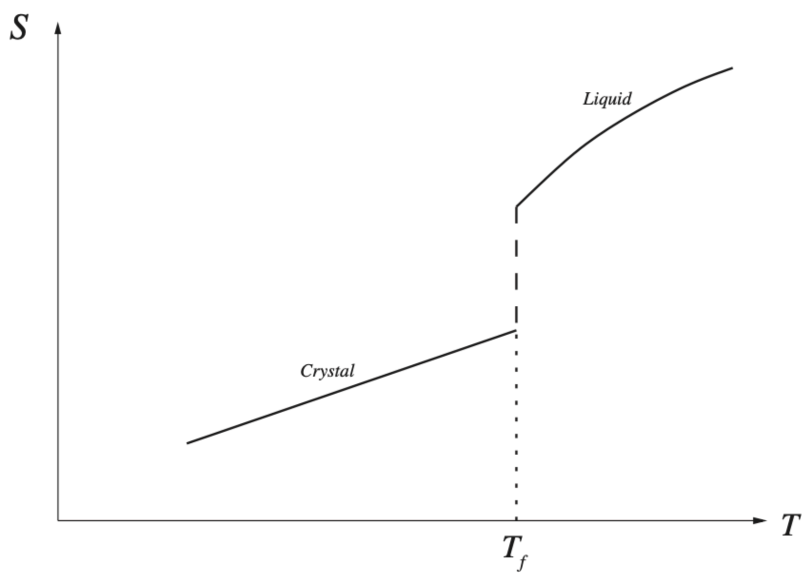
Frustration, Rigidity and Disorder

Paramagnet



Magnetic order

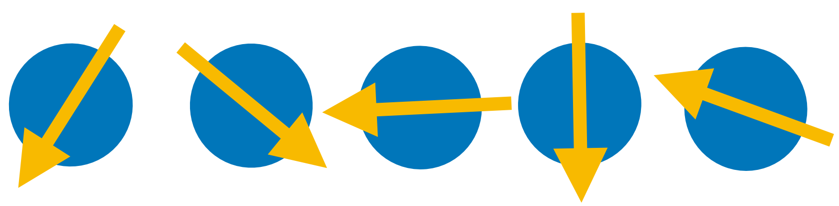


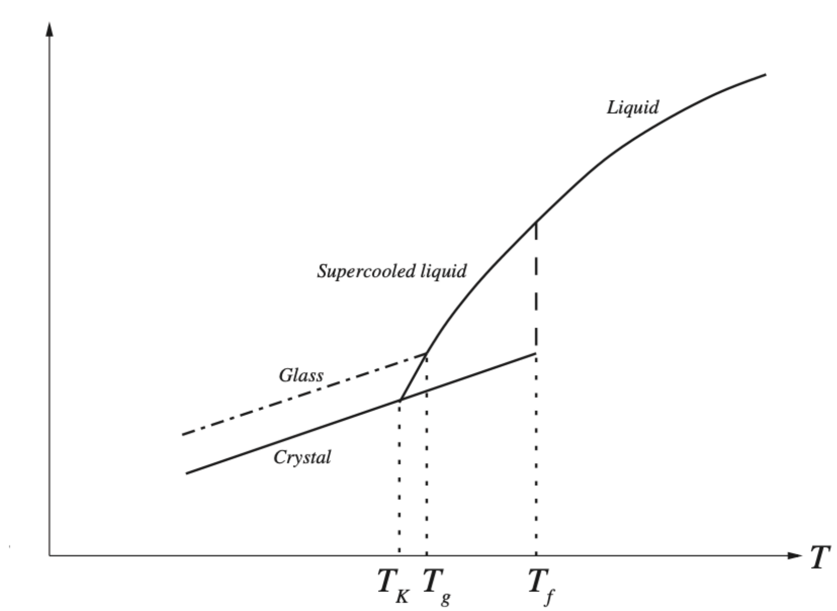


T>Tc T<Tc

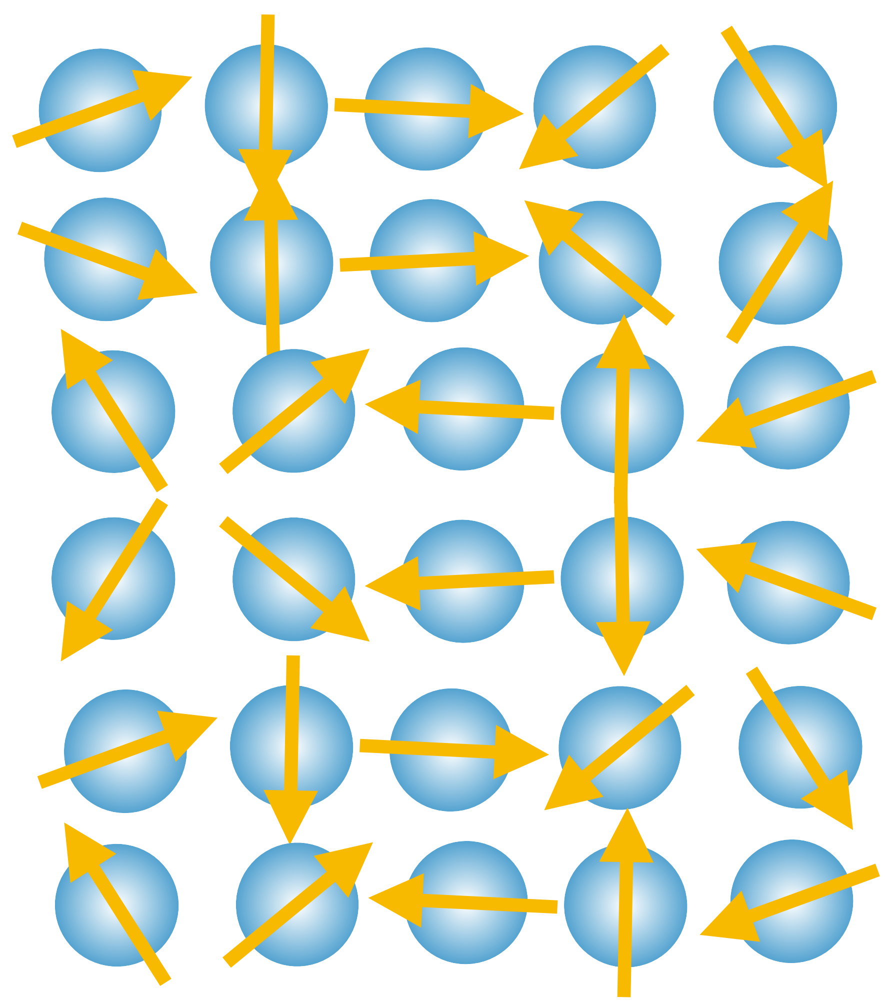
Frustration, Rigidity and Disorder

Paramagnet





Quenched disorder



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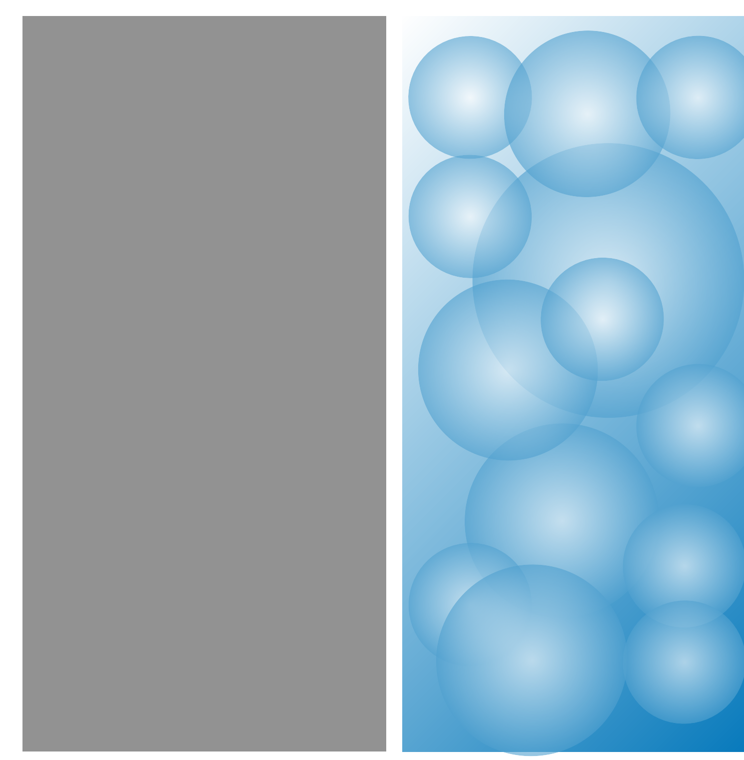
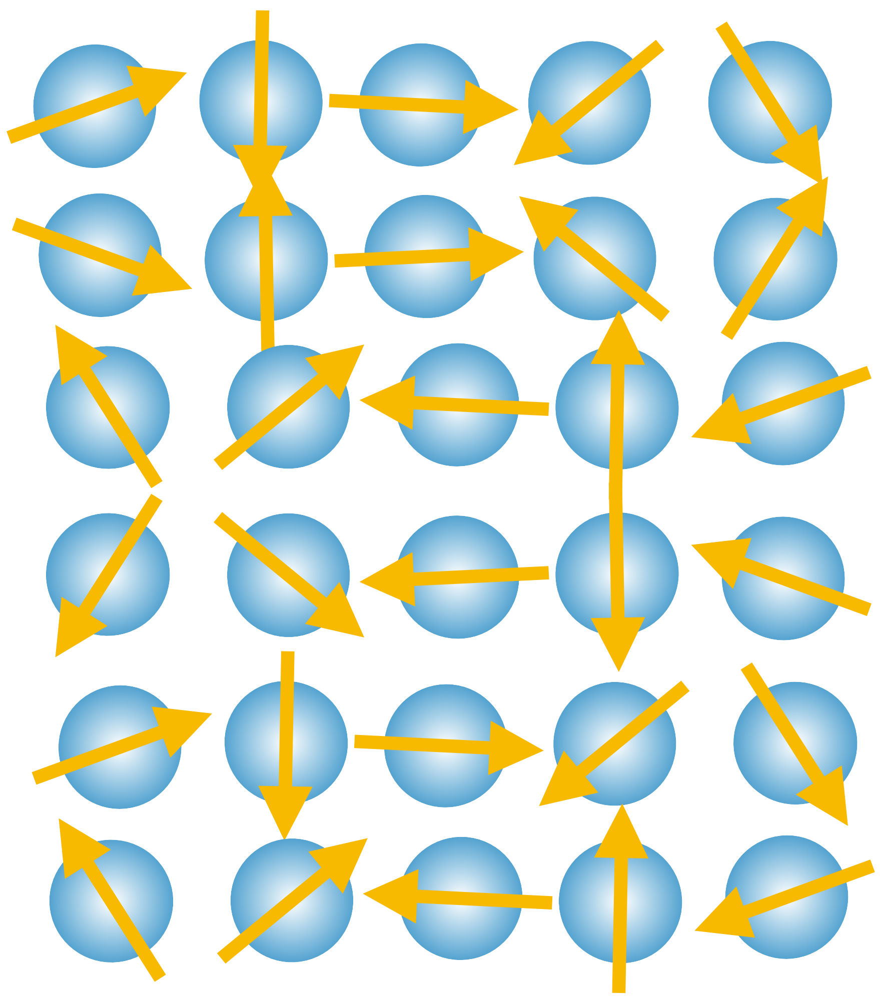


Frustration, Rigidity and Disorder



Spin susceptibility

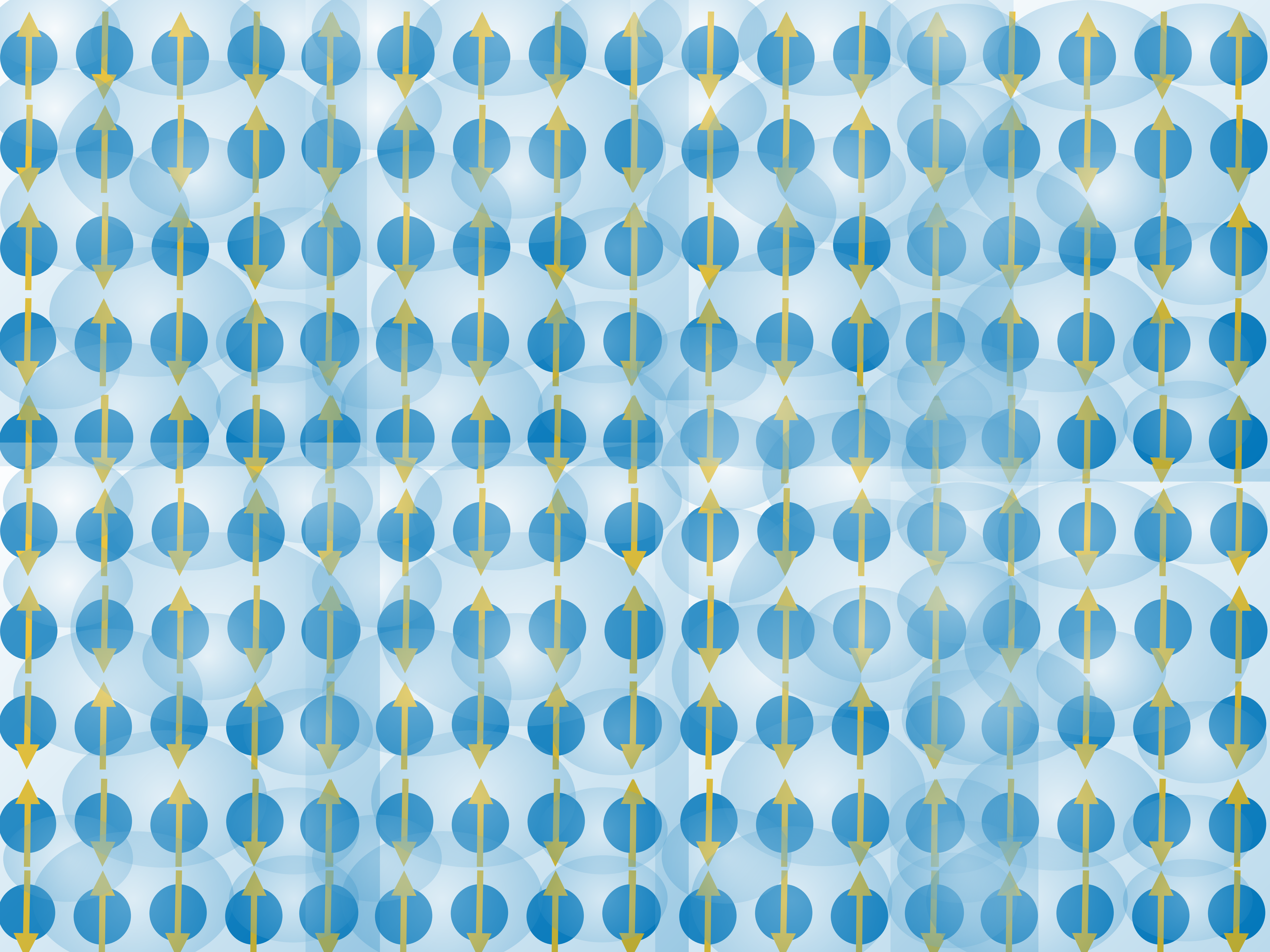
Local rotation

$$[m_{\alpha}^{2}\chi^{-1} + \rho_{s}(\nabla\theta_{\alpha})^{2}]$$

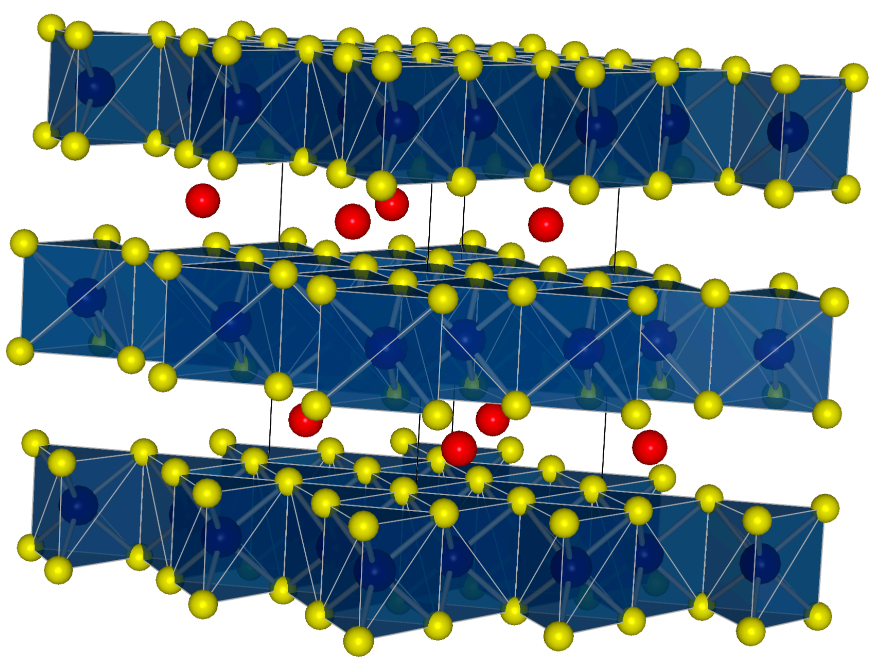
Stiffness

Local magnetization density

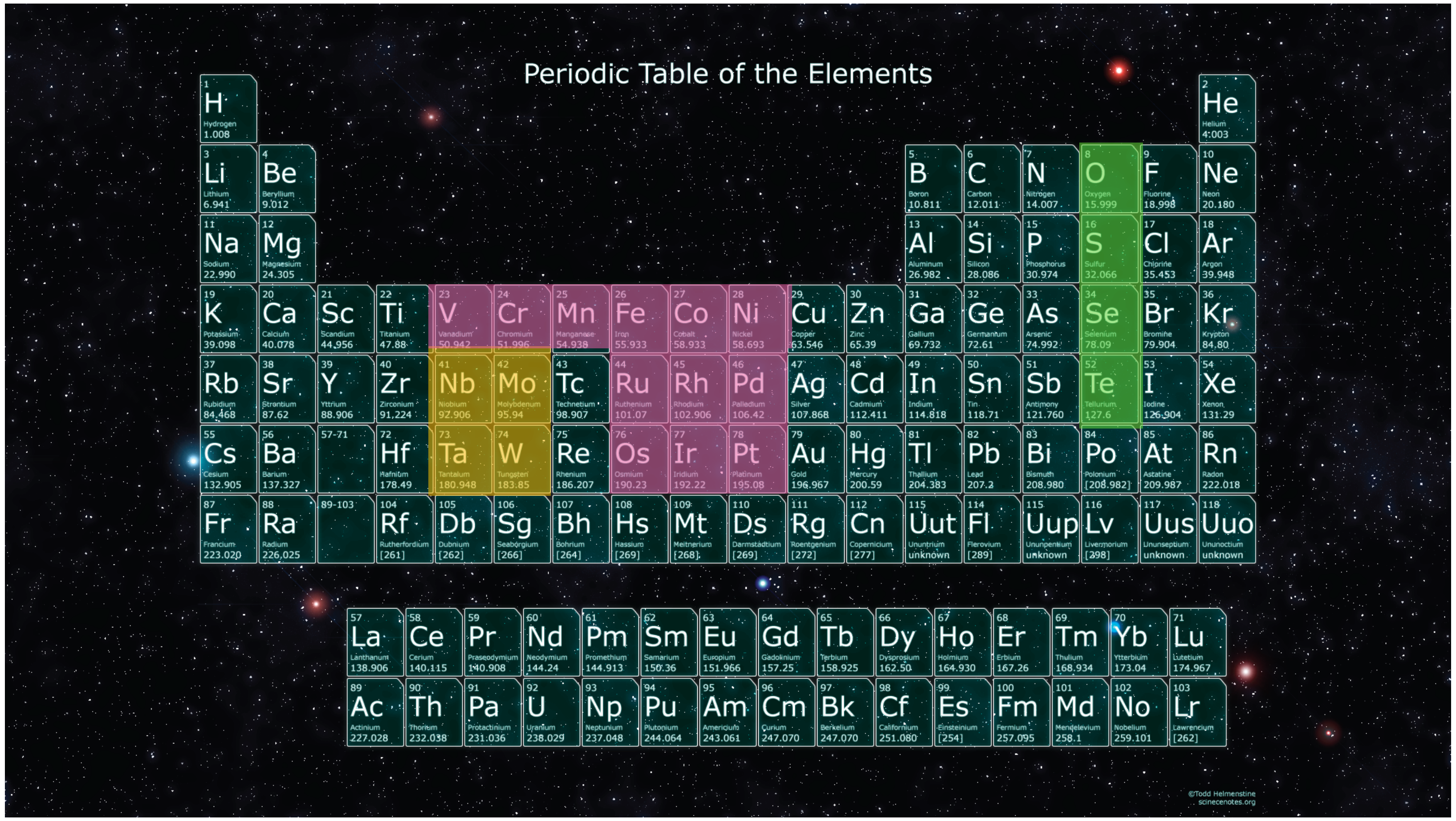
Halperin & Saslow, PRL 16, 2154 (1977)



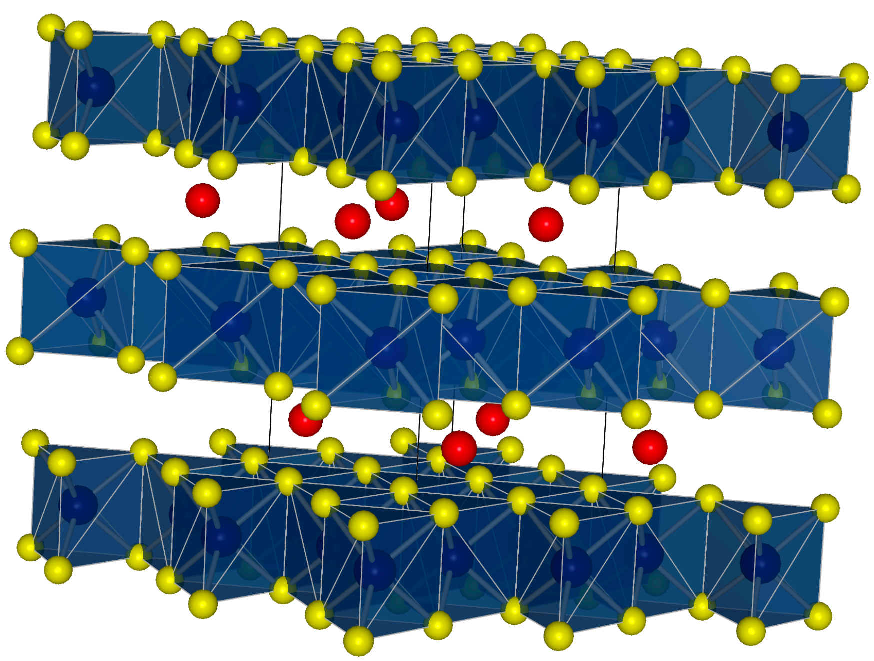
Intercalated TMDs - M_xNbS_2



Layered 2H-NbS_2
Centrosymmetric at 1/4 filling
Becomes chiral at 1/3 filling



Intercalated TMDs - Fe_xNbS_2



Layered 2H-NbS_2
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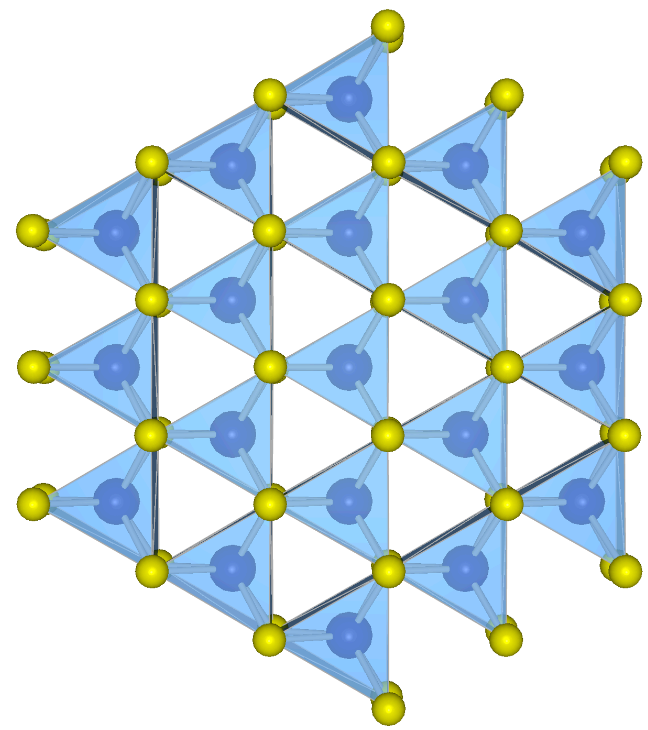
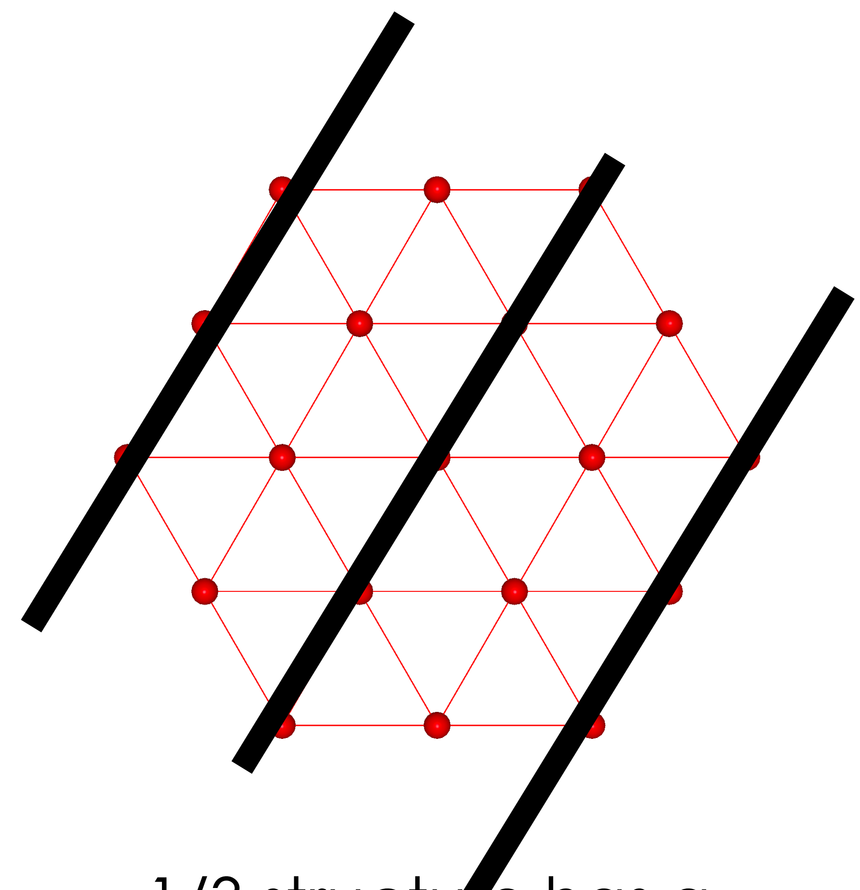


Triangular prism co-ordination of Nb
Octahedral co-ordination of Fe



1/3 structure has a triangular lattice of Fe

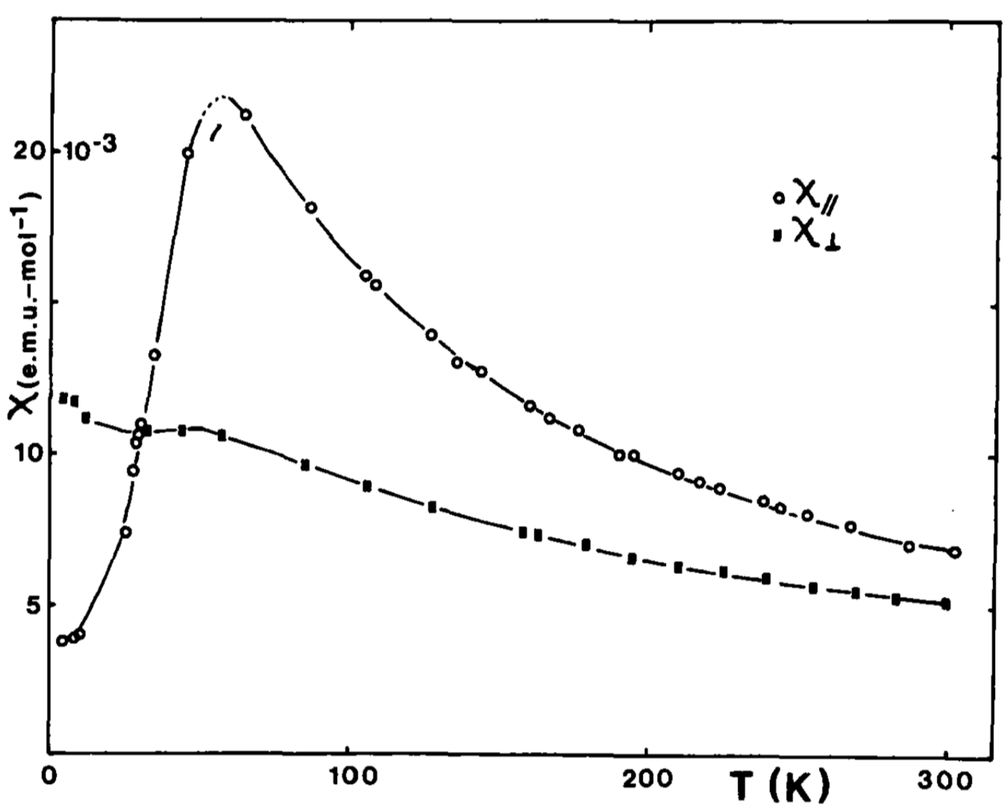
Magnetic structure

PHILOSOPHICAL MAGAZINE B, 1980, VOL. 41, NO. 1, 65–93

3*d* transition-metal intercalates of the niobium and tantalum dichalcogenides
I. Magnetic properties

By S. S. P. PARKIN and R. H. FRIEND
Cavendish Laboratory, Madingley Road, Cambridge, England

Fig. 3



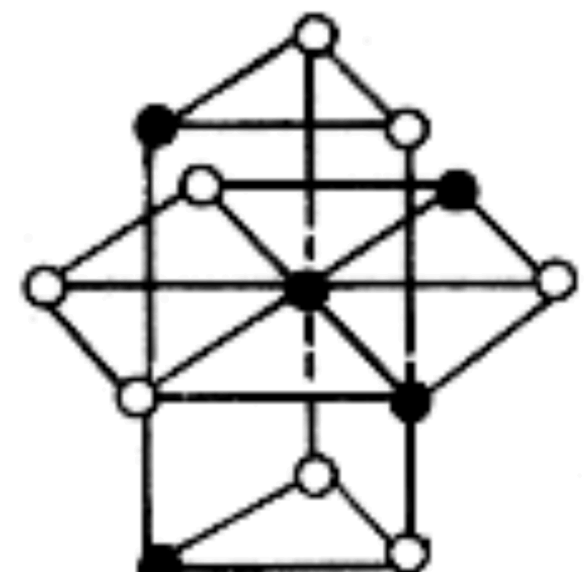
Magnetic susceptibility of a single crystal of $Fe_{0\cdot33}NbS_2$ versus temperature. Black squares : $\chi \perp c$ axis. Open circles : $\chi \parallel c$ axis.

JOURNAL OF SOLID STATE CHEMISTRY 3, 154–160 (1971)

Magnetic and Crystallographic Structures of Me_xNbS_2 and Me_xTaS_2

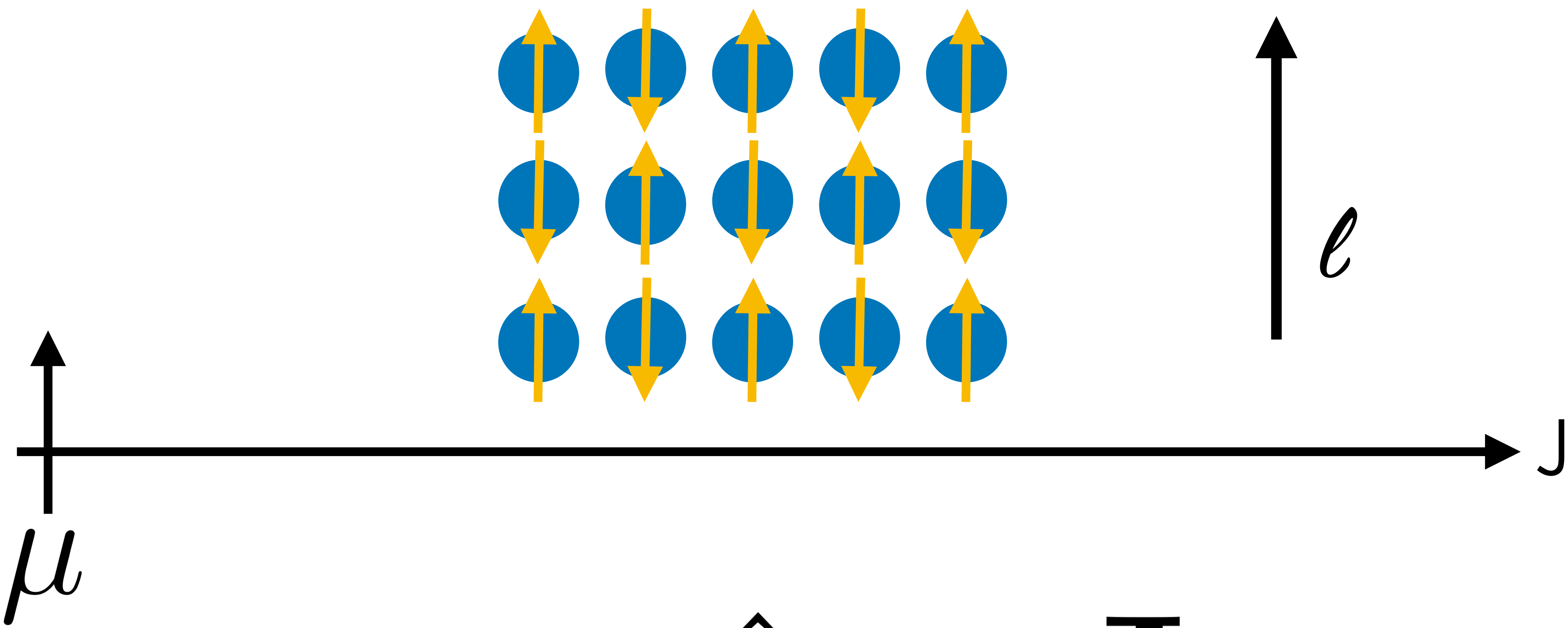
B. VAN LAAR, H. M. RIETVELD
Reactor Centrum Nederland, Petten, The Netherlands

Wurtzite



Aside: What is an antiferromagnetic switch?

What is an antiferromagnetic switch?

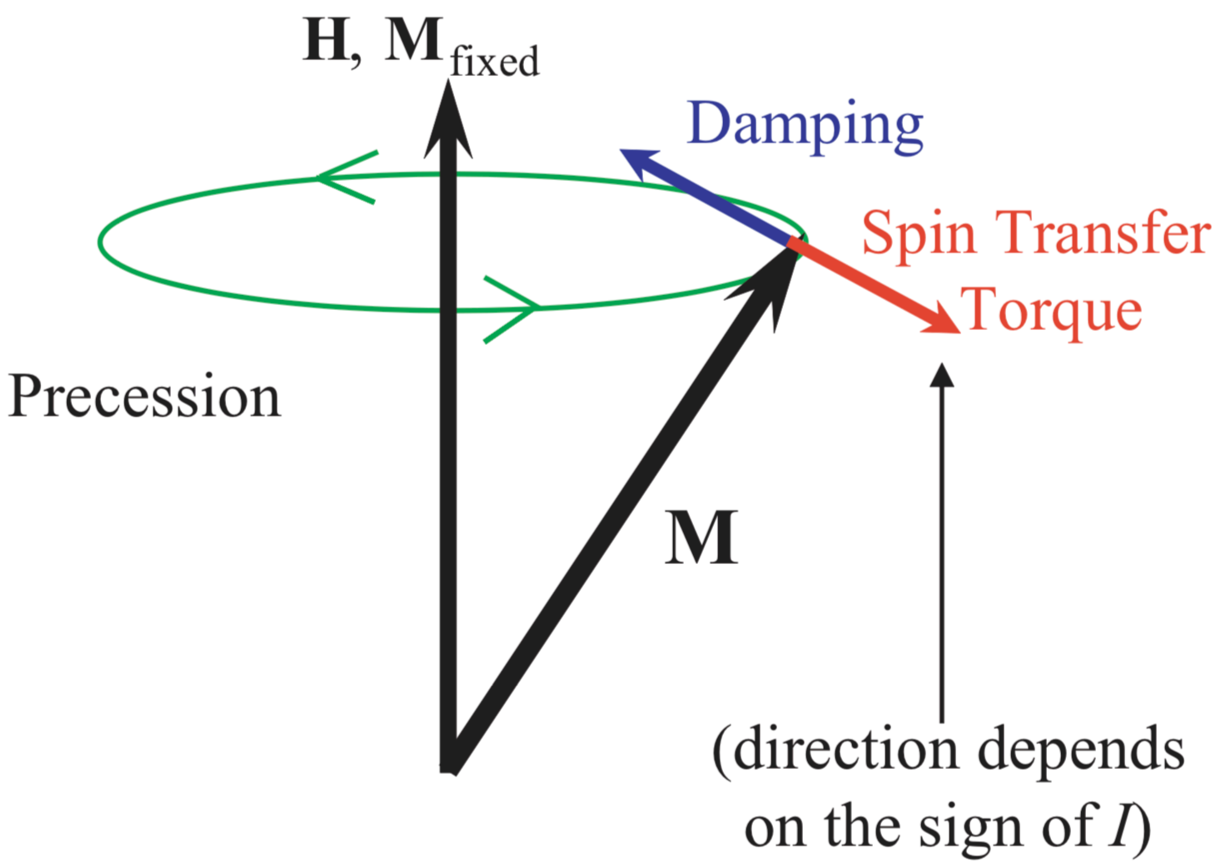


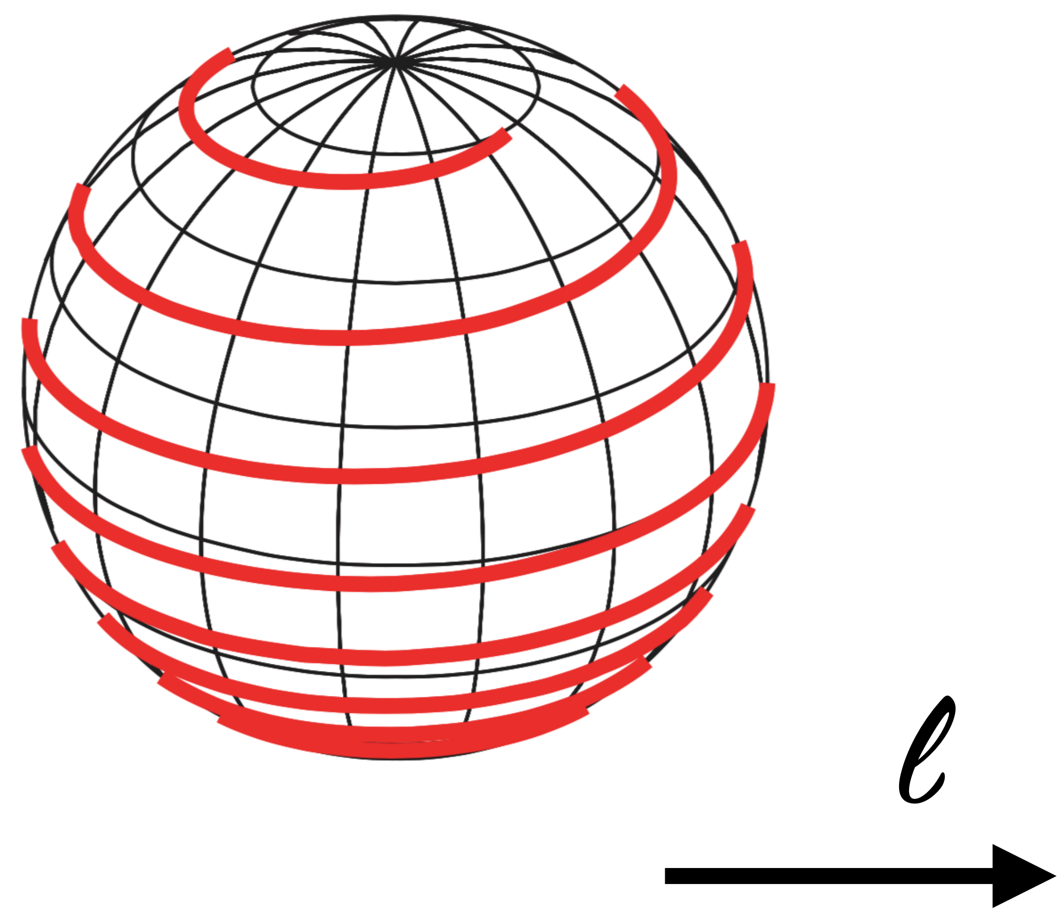
$$\mu = \hat{\mathbf{z}} \times \mathbf{J}$$

In the presence of spin orbit coupling and broken inversion symmetry, an applied current can attain a partial spin polarization due to the Edelstein/Spin Hall effect

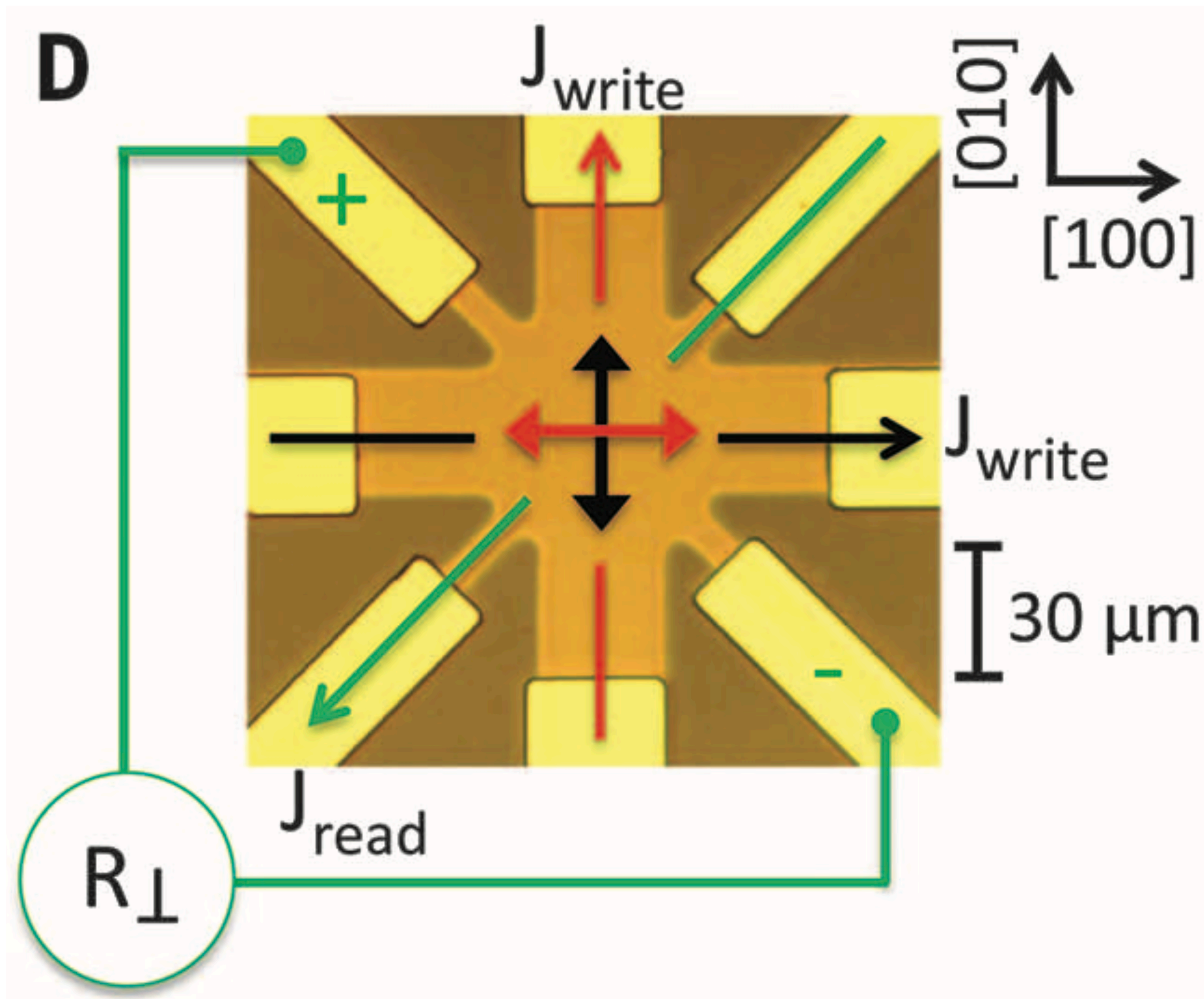
Landau-Lifshitz-Gilbert

$$d\mathbf{M}/dt = -\gamma_0 \mathbf{M} \times \mathbf{H}_{\text{eff}} + \frac{\alpha}{M_s} \mathbf{M} \times d\mathbf{M}/dt$$



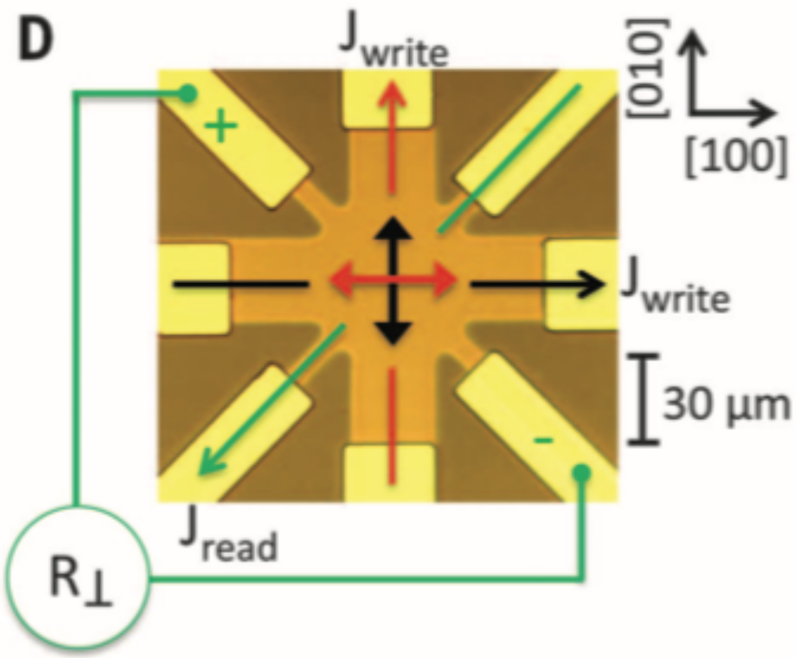


What is an antiferromagnetic switch?

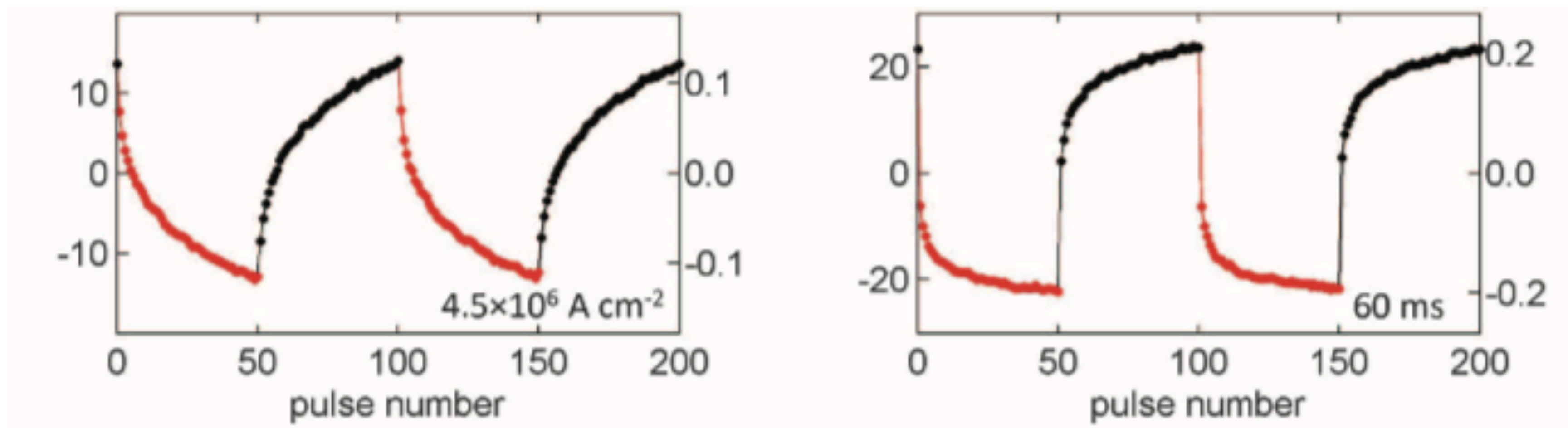


CuMnAs (Wadley et al. Science 2016)

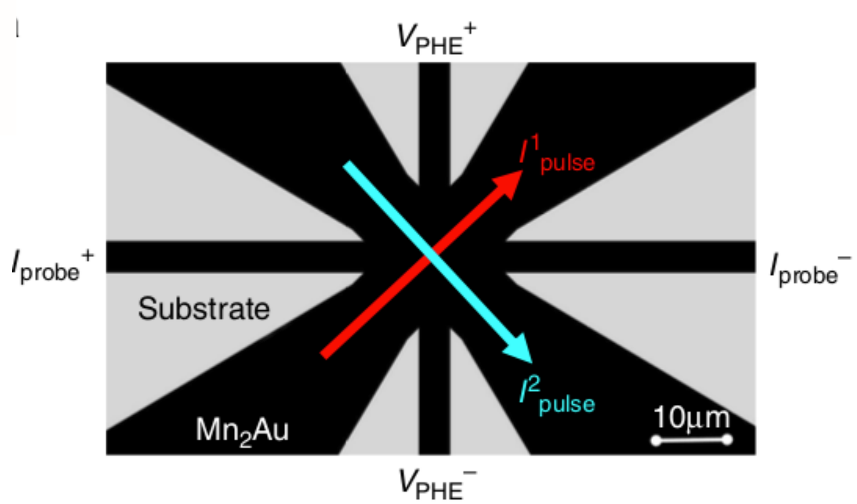
What is an antiferromagnetic switch?

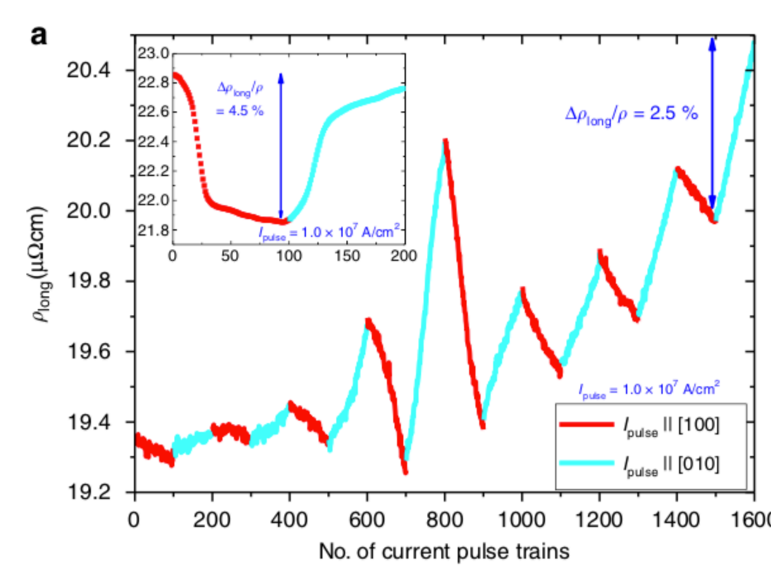


Mn2Au (Bodnar et al, Nature Comm. 2018)

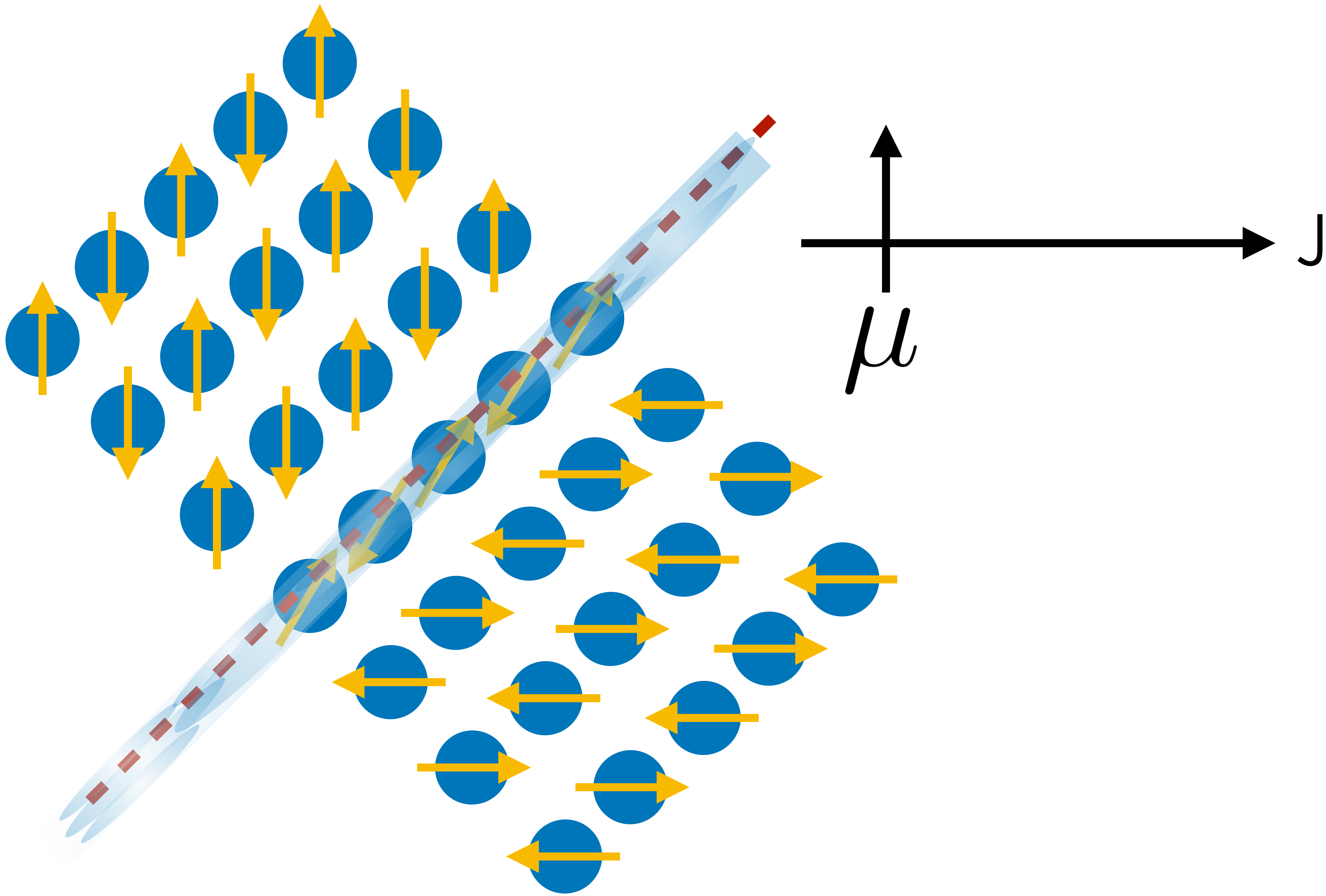


CuMnAs (Wadley et al. Science 2016)

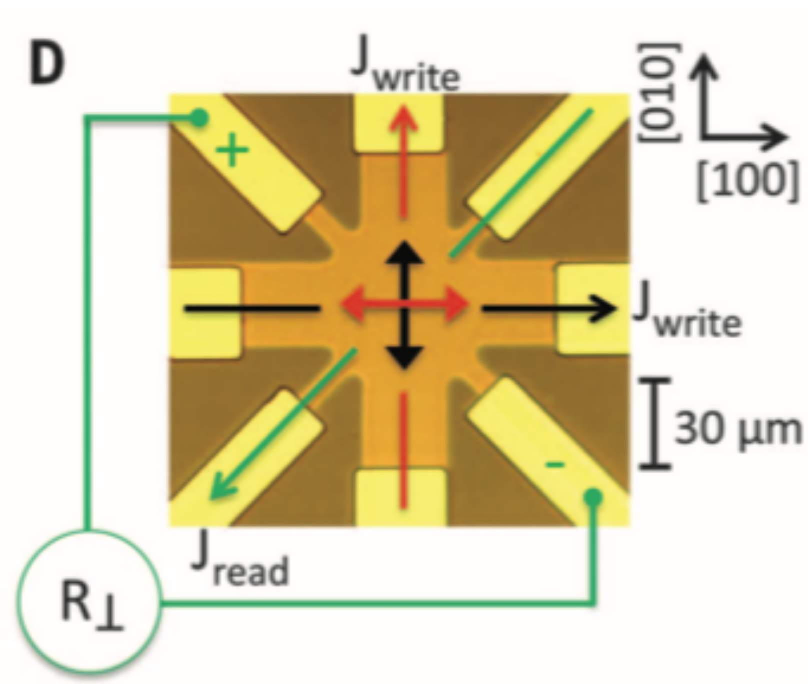


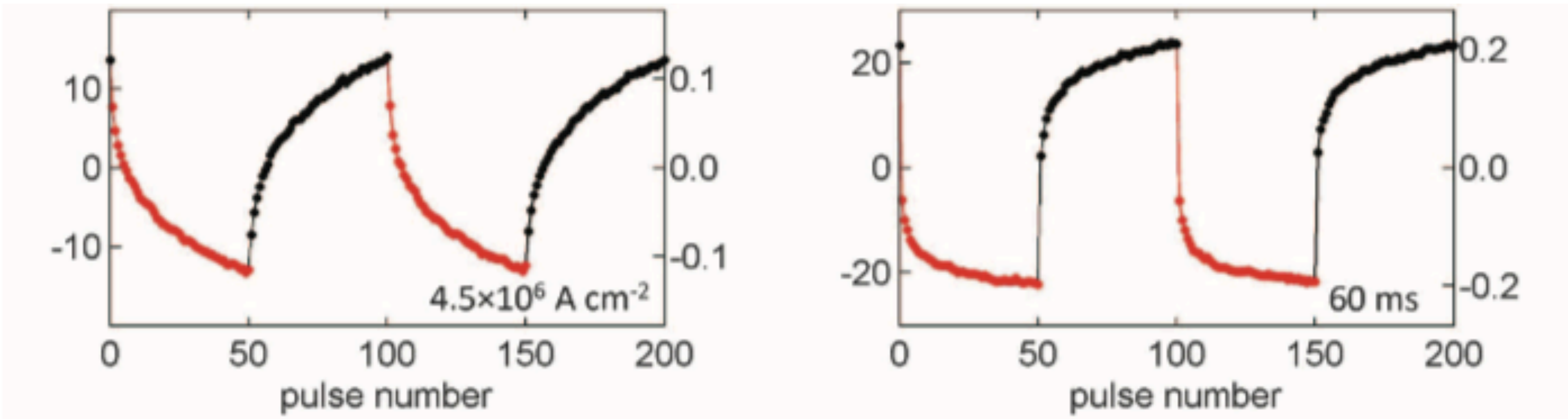


Domain boundary motion moves an average ℓ



What is an antiferromagnetic switch?





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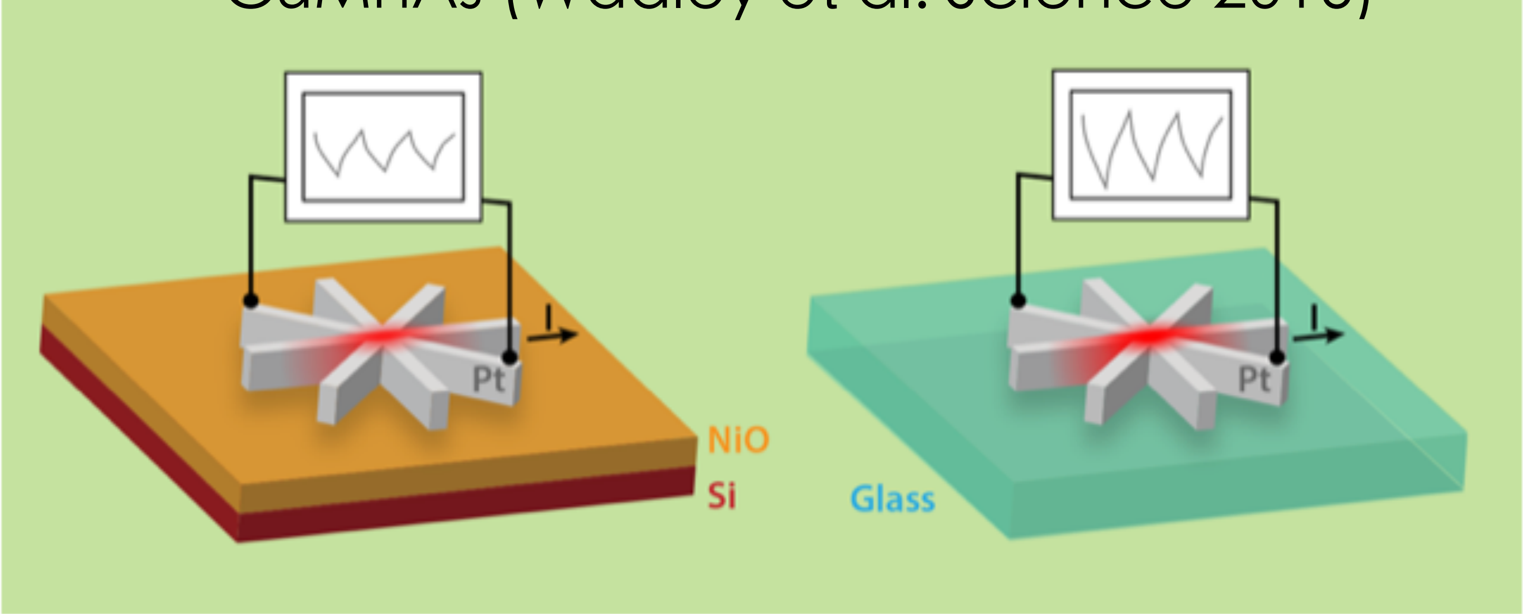
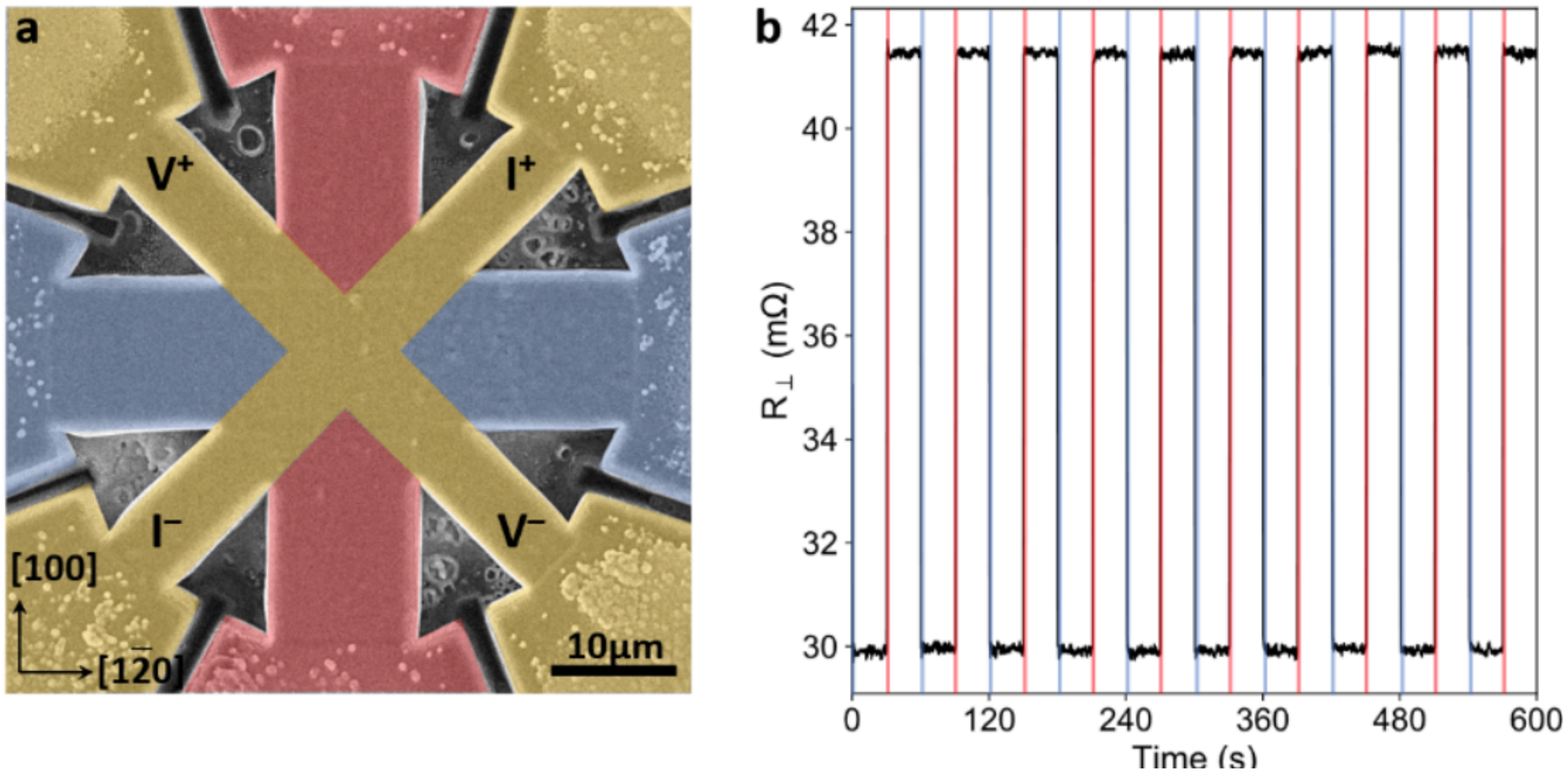


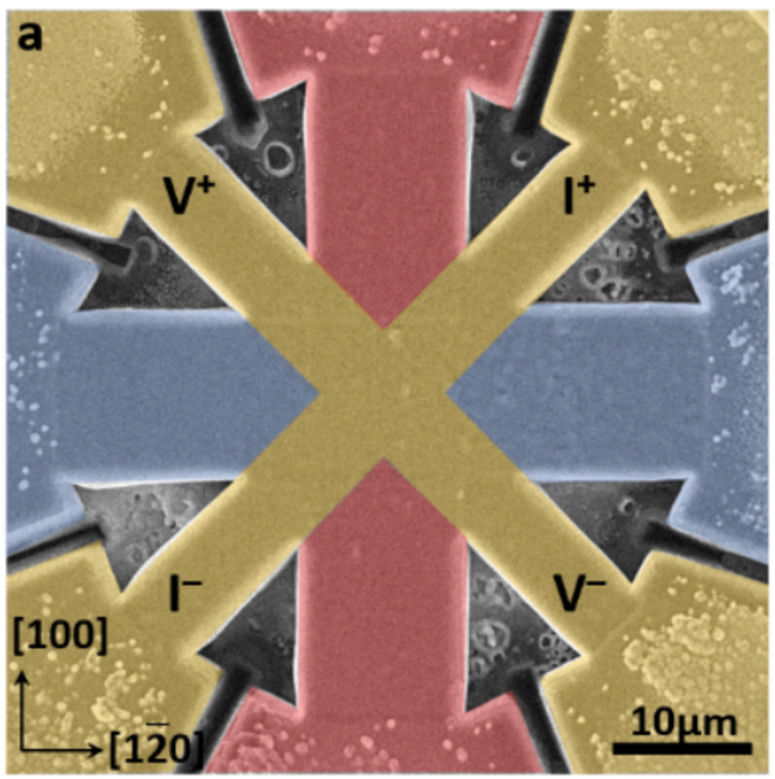
Chiang et al. Phys. Rev. Lett. 123, 227203

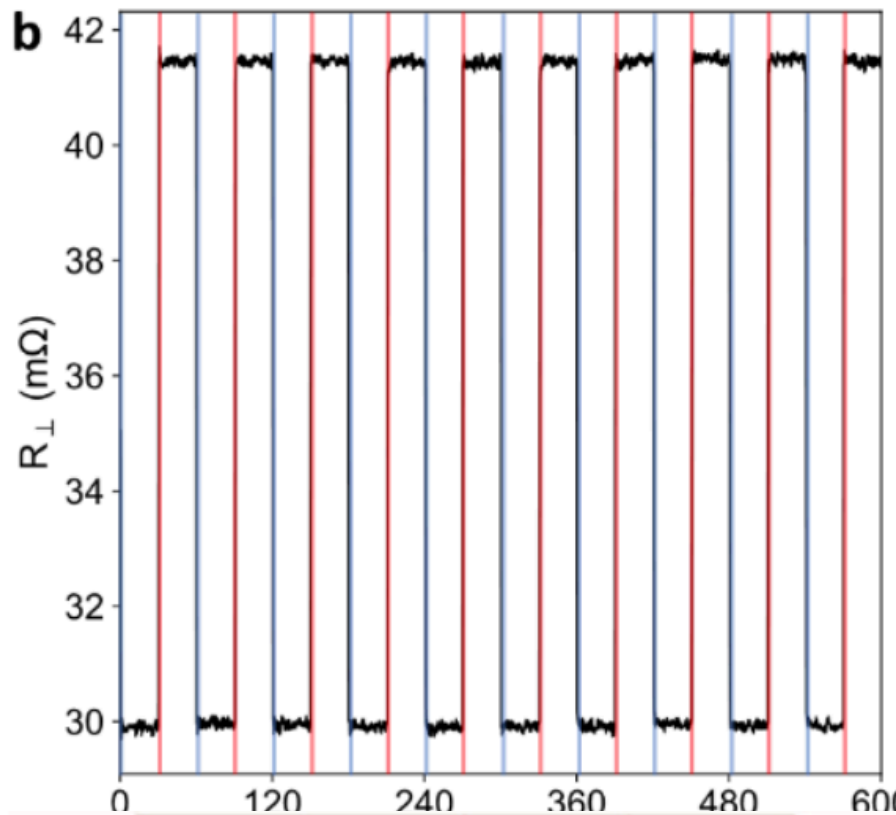
Antiferromagnetic Switching in $Fe_{1/3-\delta}NbS_2$

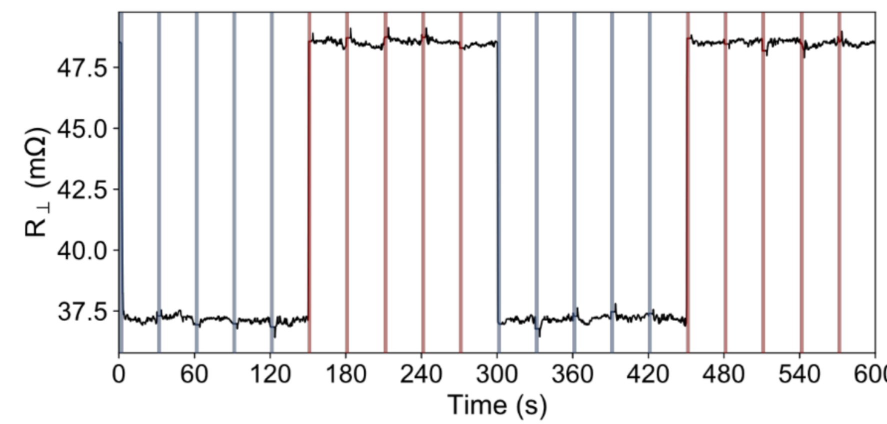


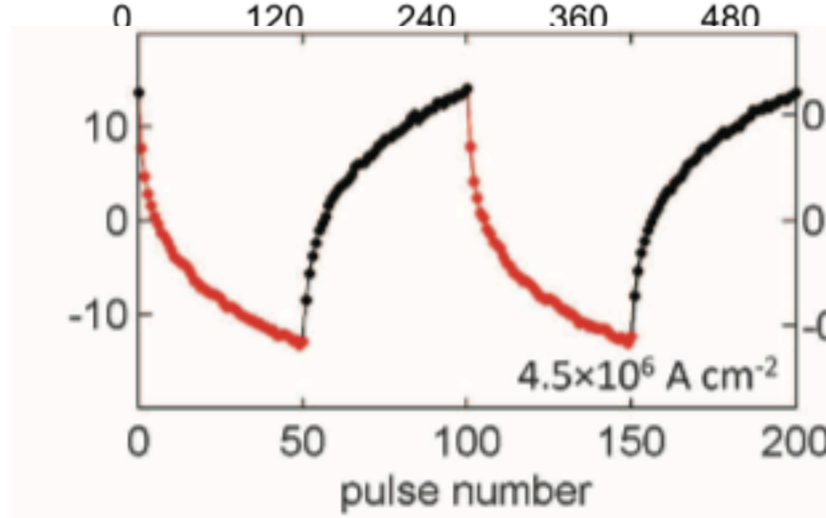
Nair, Maniv, JGA Nature Materials 2020

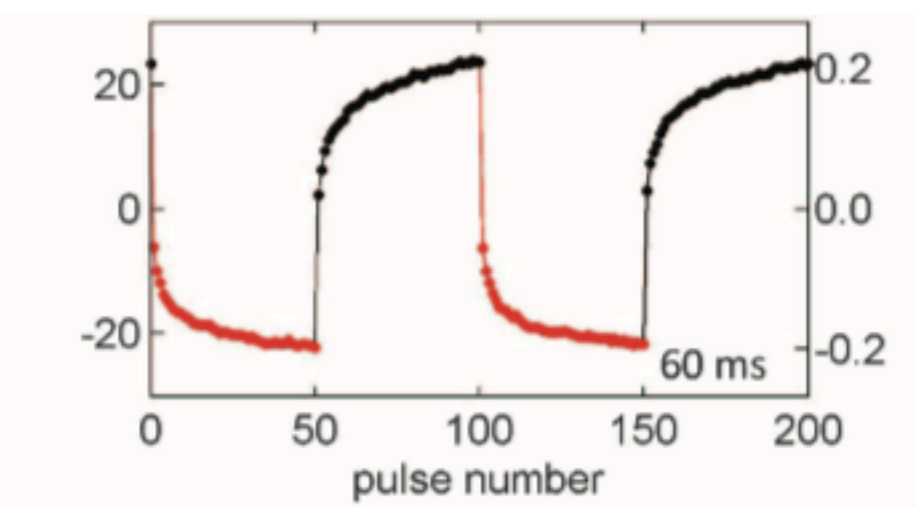
Antiferromagnetic Switching in $Fe_{1/3-\delta}NbS_2$







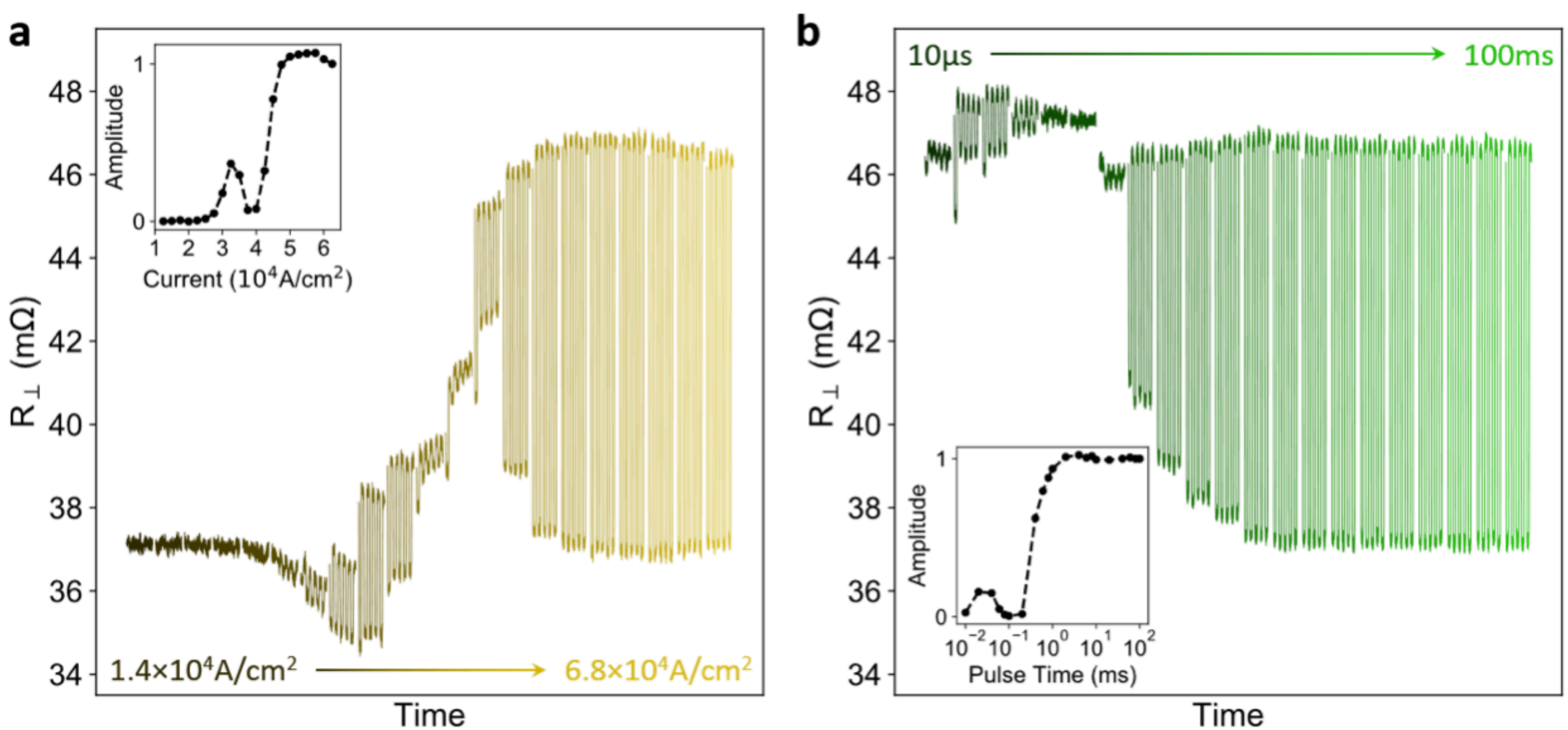




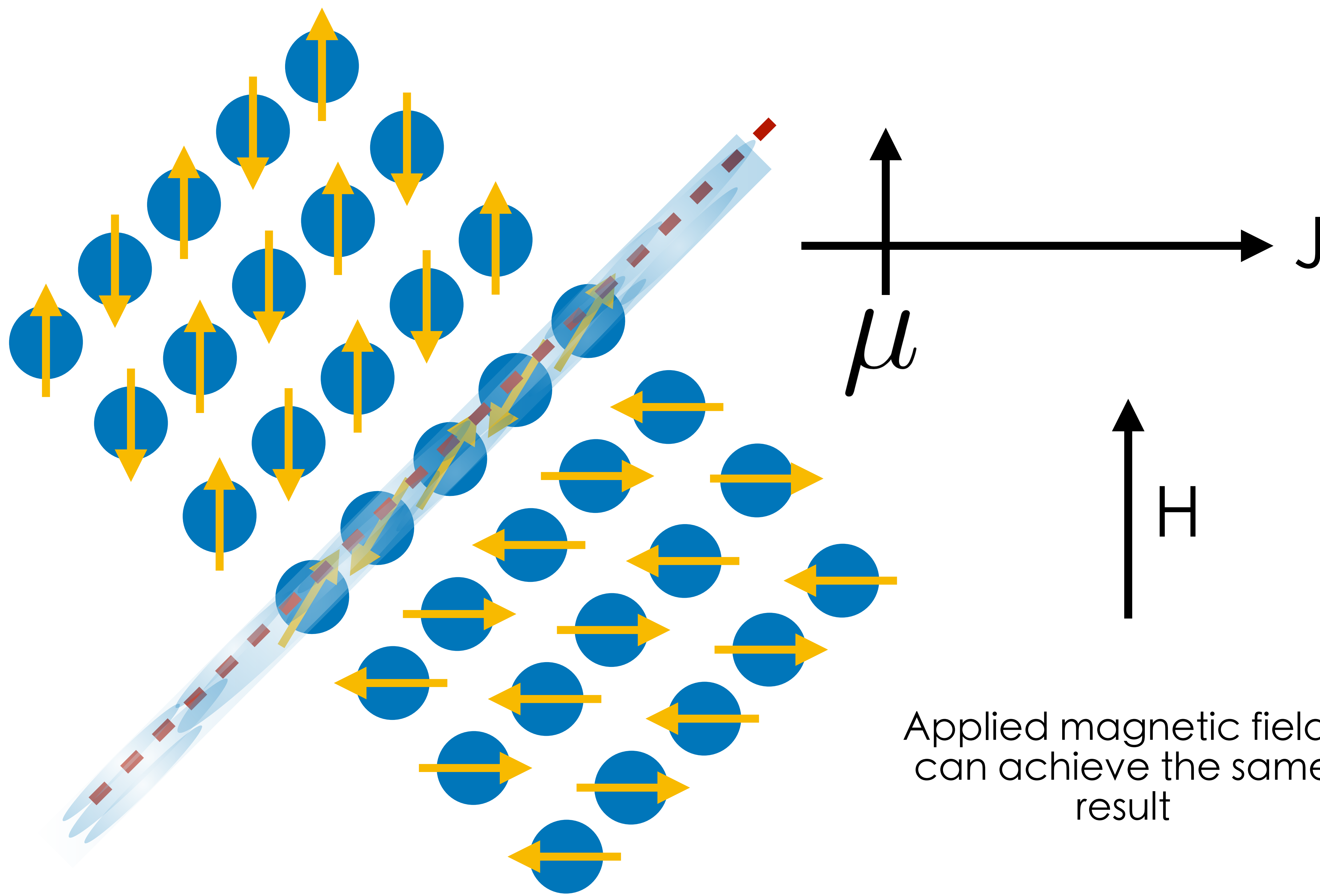
Extremely low current densities and pulse durations

$J \sim 10^4 A/cm^2$

$\Delta t \sim 1ms$

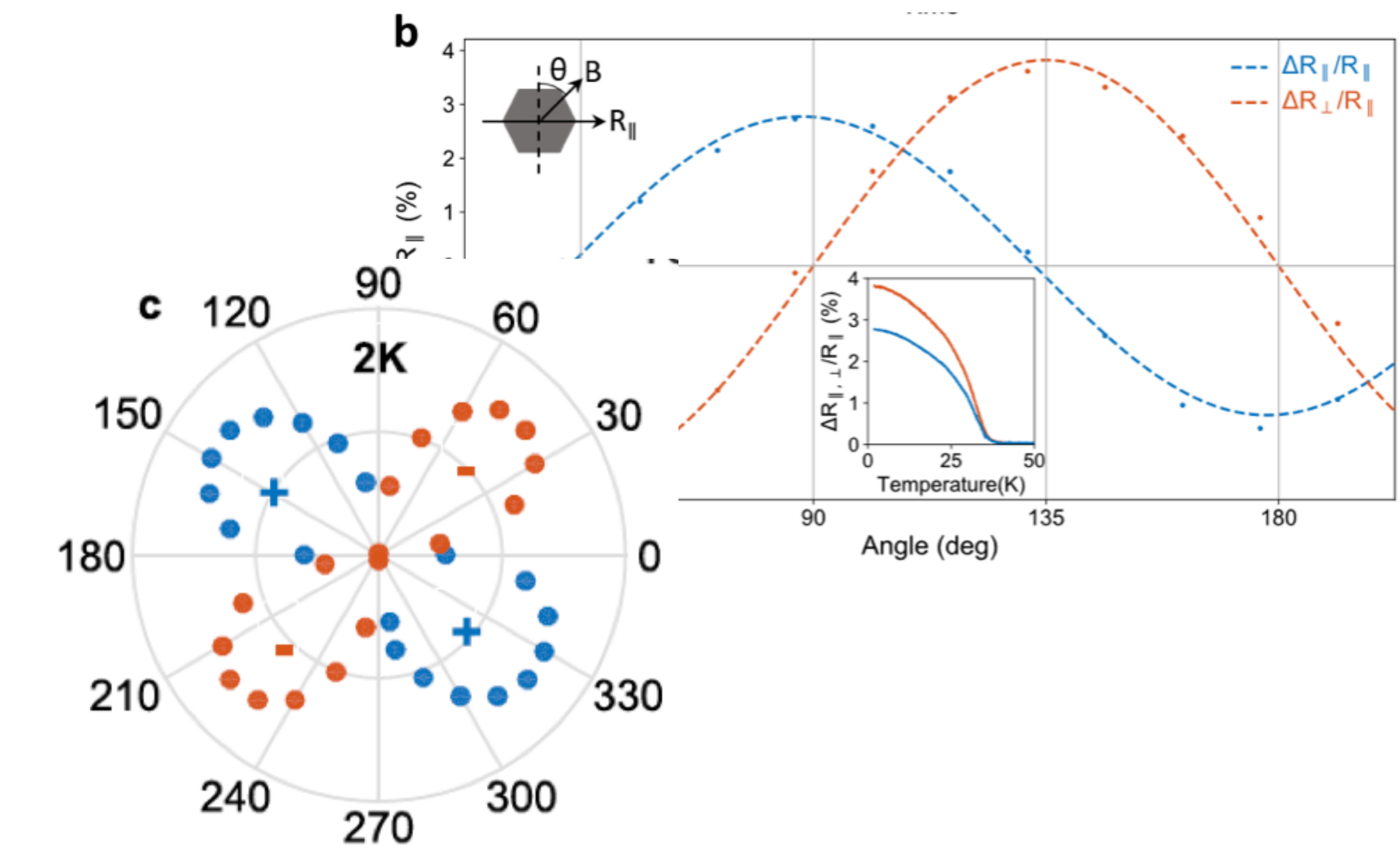


Domain boundary motion moves an average ℓ

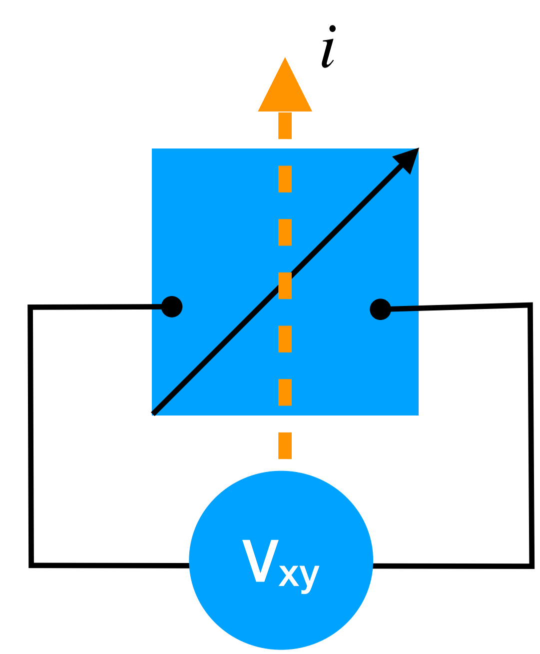


Applied magnetic fields can achieve the same result

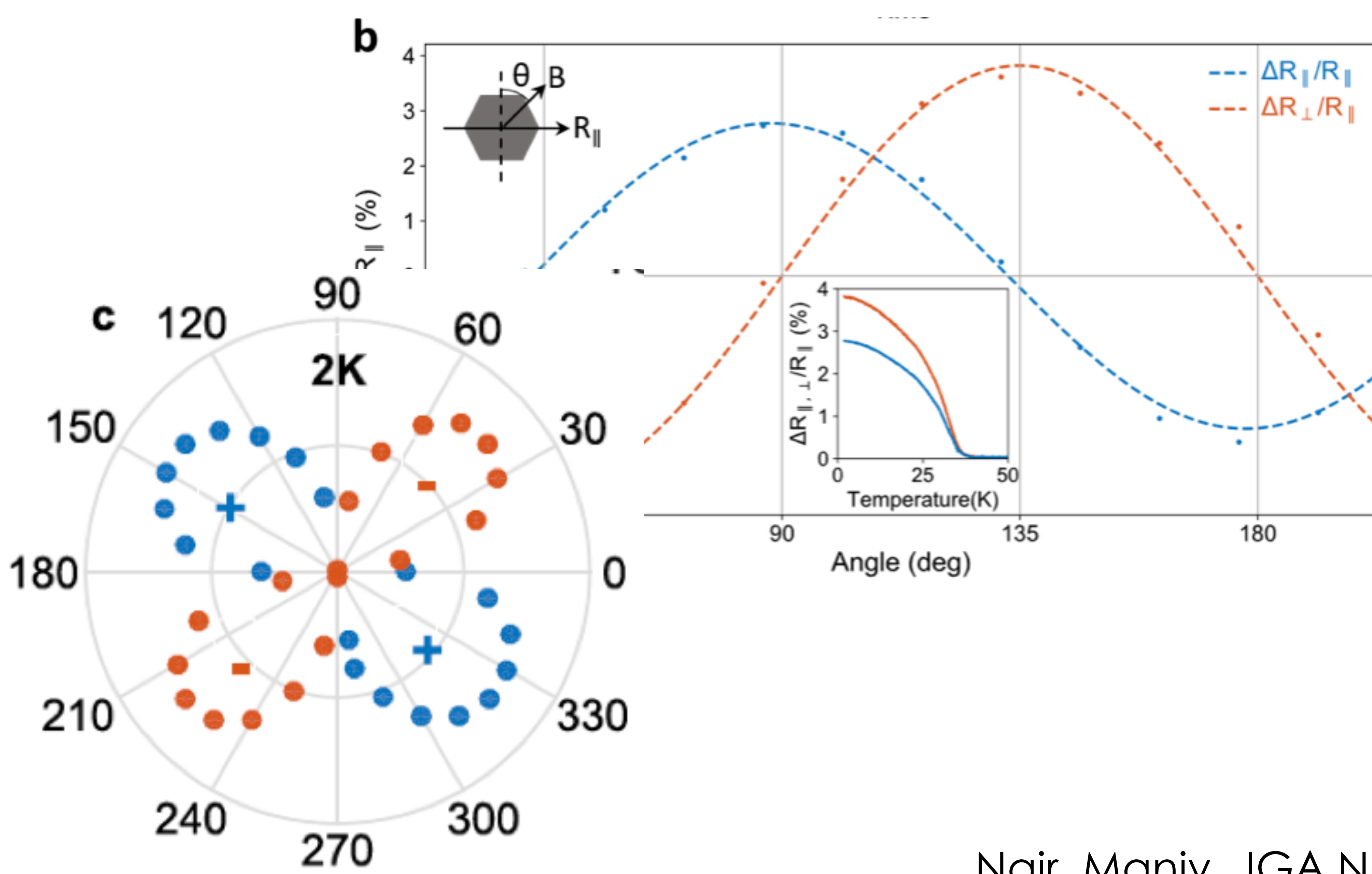
Anisotropic MagnetoResistance & switching in $Fe_{1/3+\delta}NbS_2$



AMR



Zero-Field Anisotropic MagnetoResistance & switching in $Fe_{1/3+\delta}NbS_2$



zAMR

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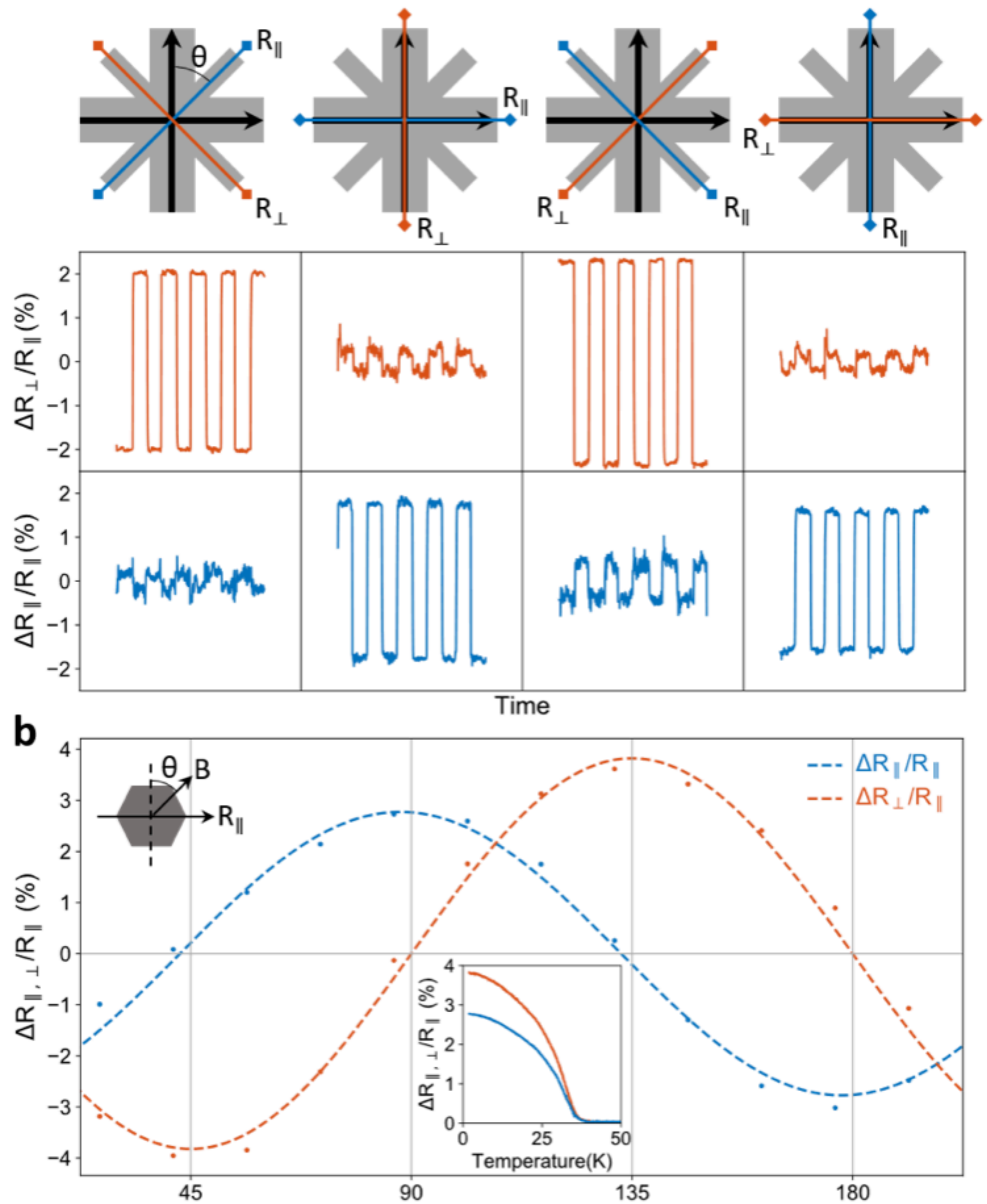
Zero-Field Anisotropic MagnetoResistance & switching in $Fe_{1/3+\delta}NbS_2$



This provides evidence that the AFM switching follows the AFM order parameter.

Or does it?

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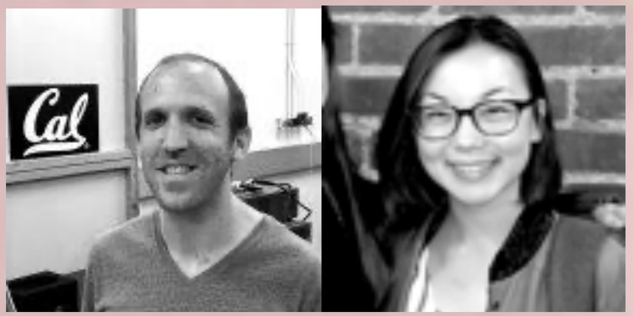
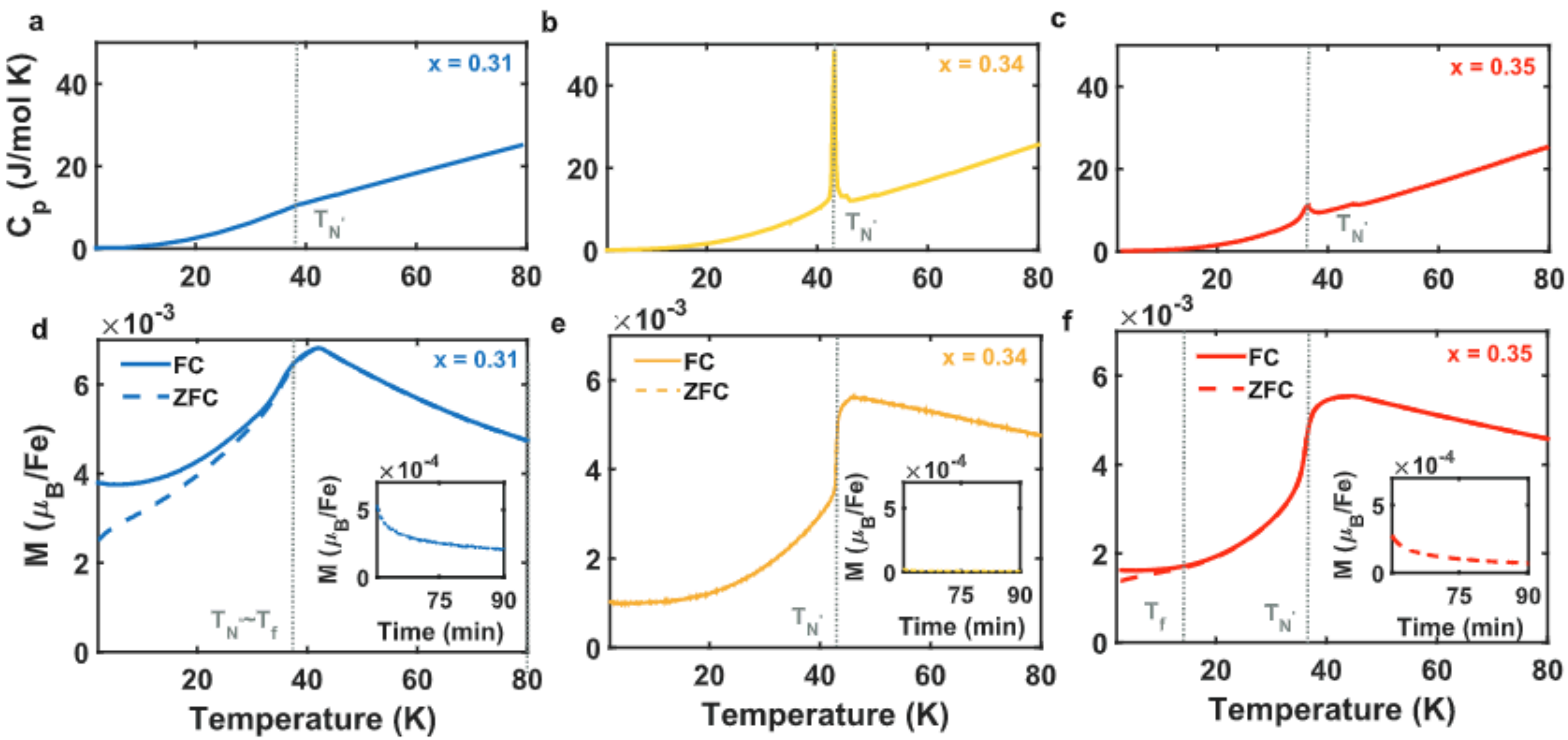
Collective dynamics of the coexisting spin glass



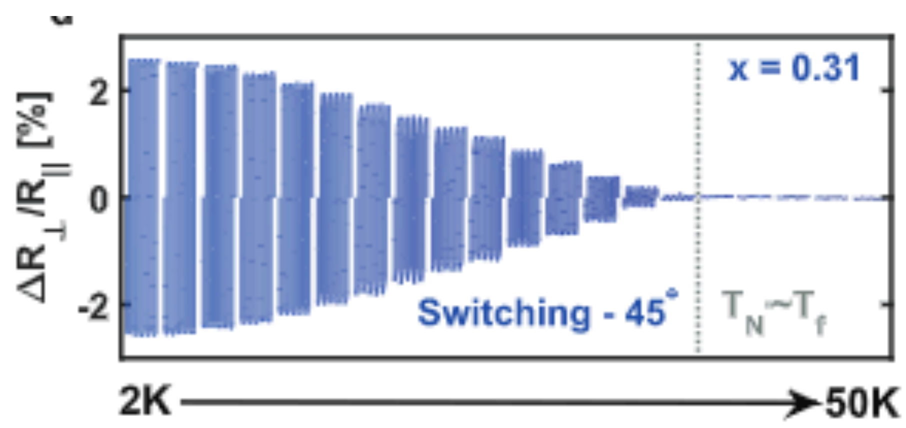
Eran Maniv, Shannon Haley

Sample “improvements”

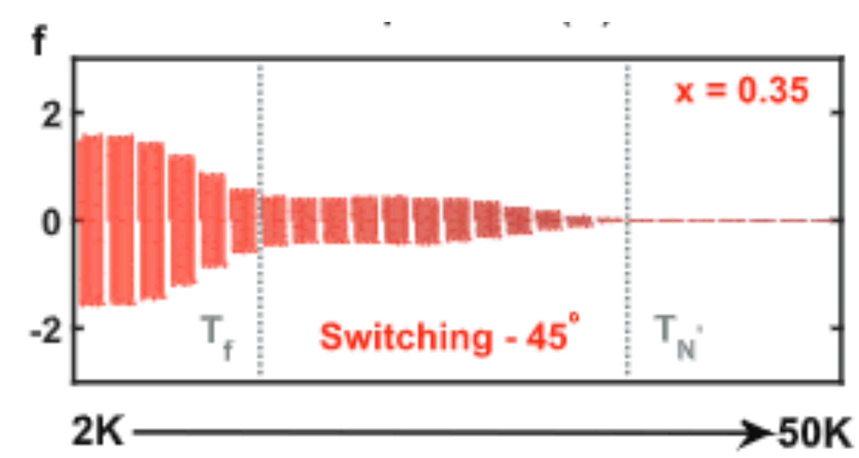


Eran Maniv, Shannon Haley

Sample “improvements”



Sample “improvements”



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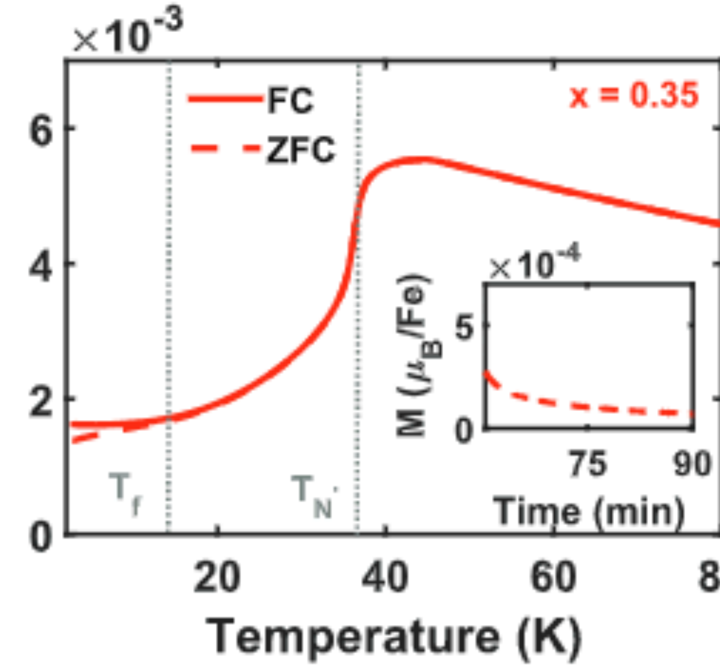
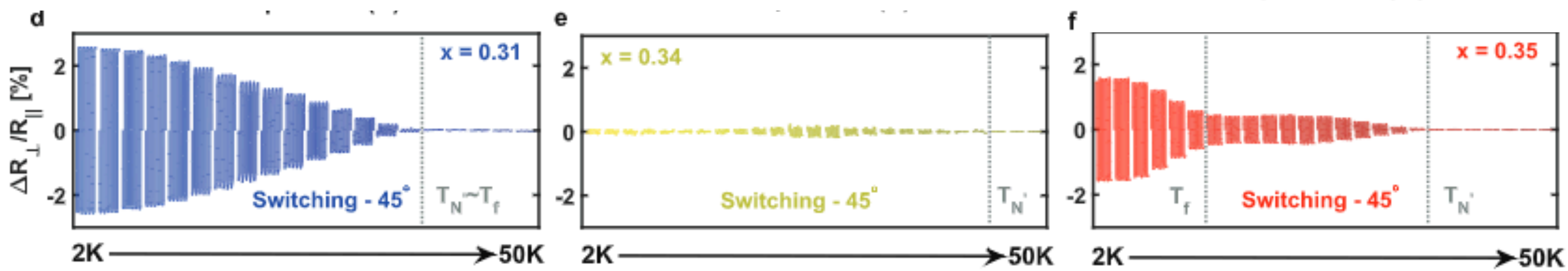
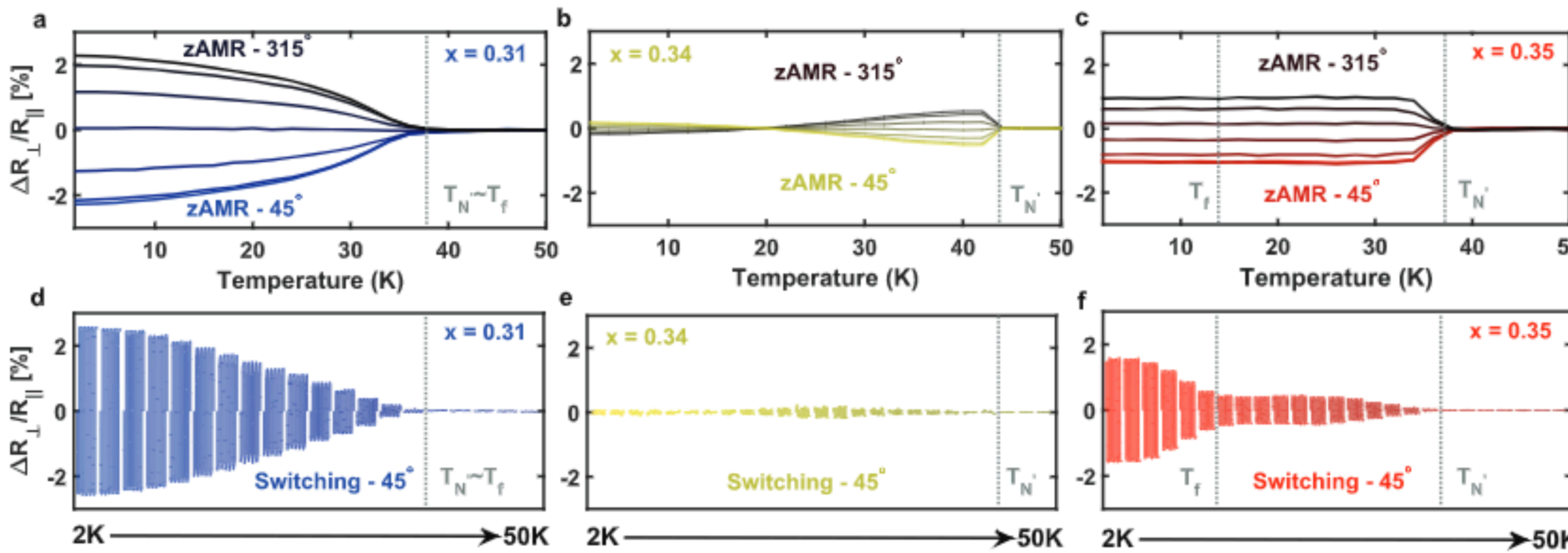




The presence of the spin glass is essential in facilitating the switching

AFM Switching and AMR

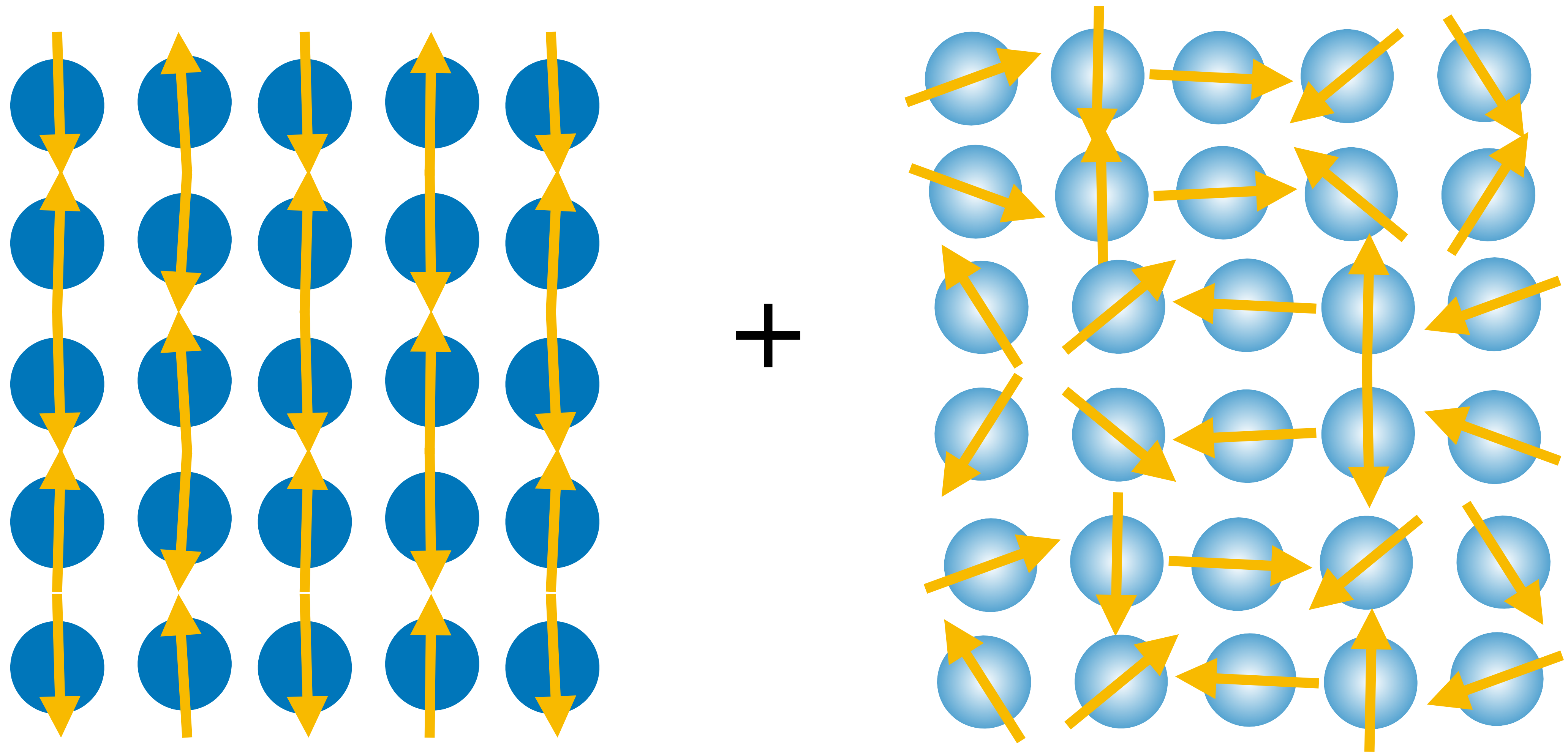


The AMR is completely indifferent to the presence of the spin glass, and the is no change of sign.

Maniv, JGA Science Advances 2020

Why?

Collective dynamics of a correlated spin glass



Glassy spin textures form hydrodynamic modes that are locked in phase

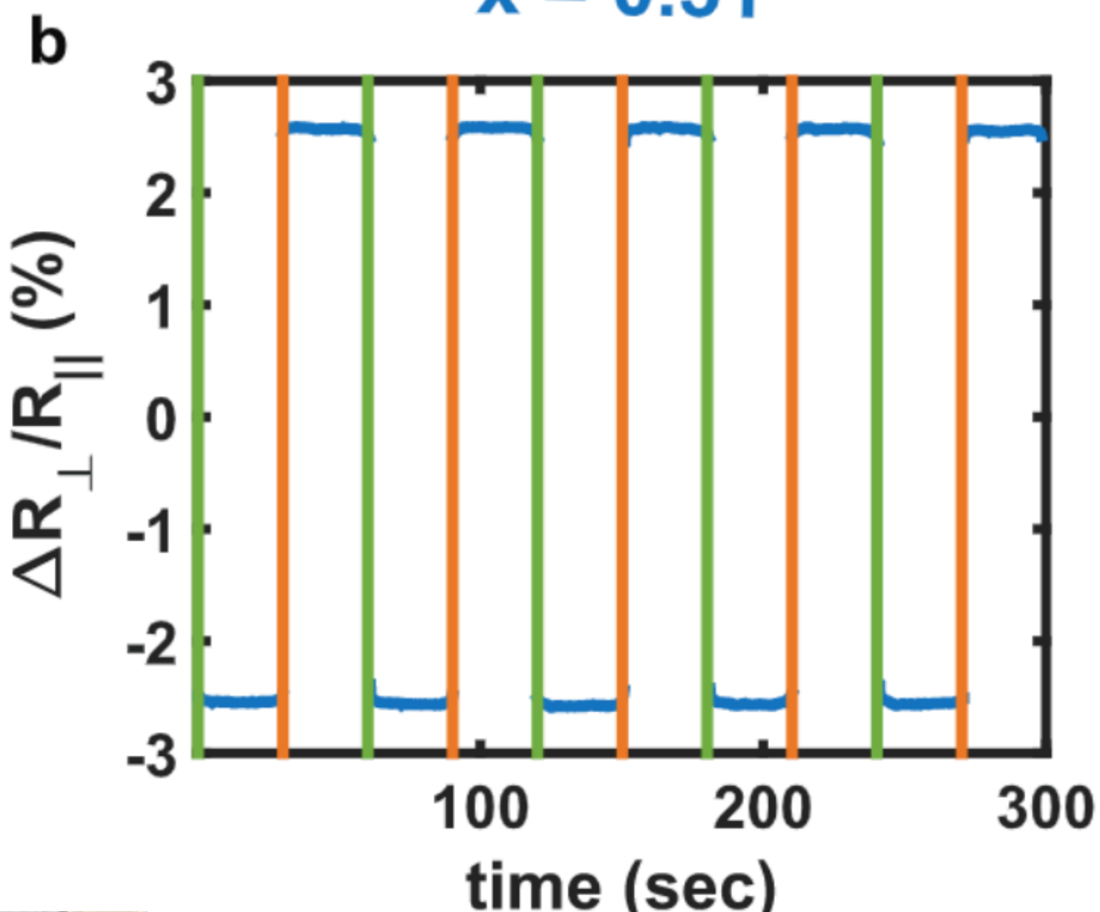
Ochoa & Tserkovnyak, PHYSICAL REVIEW B 98, 054424 (2018)
Halperin and Saslow, Physical Review Letter (1977)

Coexisting orders

Anomalous Switching

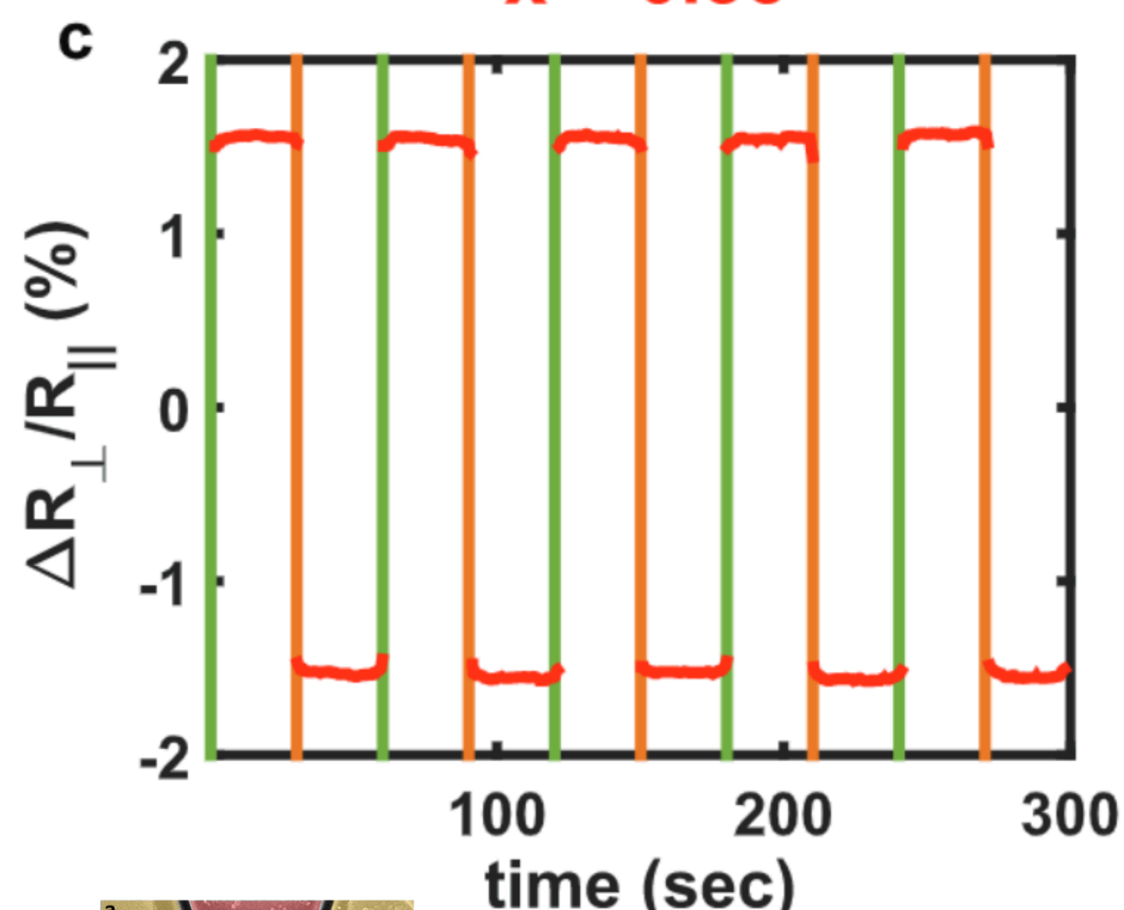
Vacancies

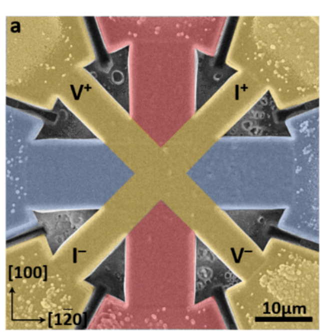
x = 0.31

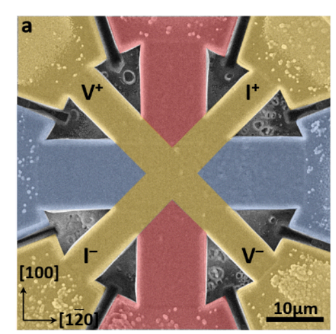


Interstitials

x = 0.35







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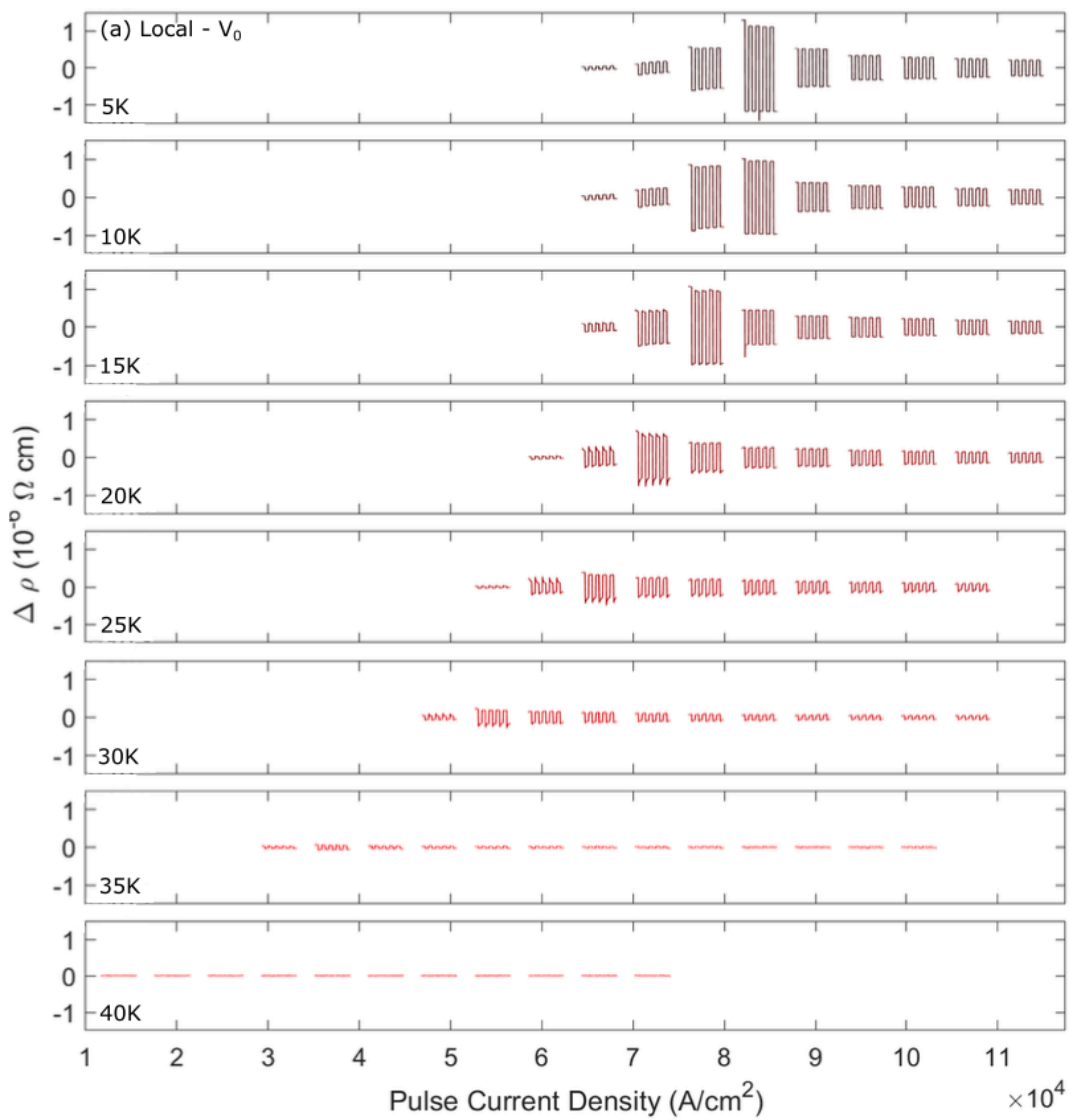
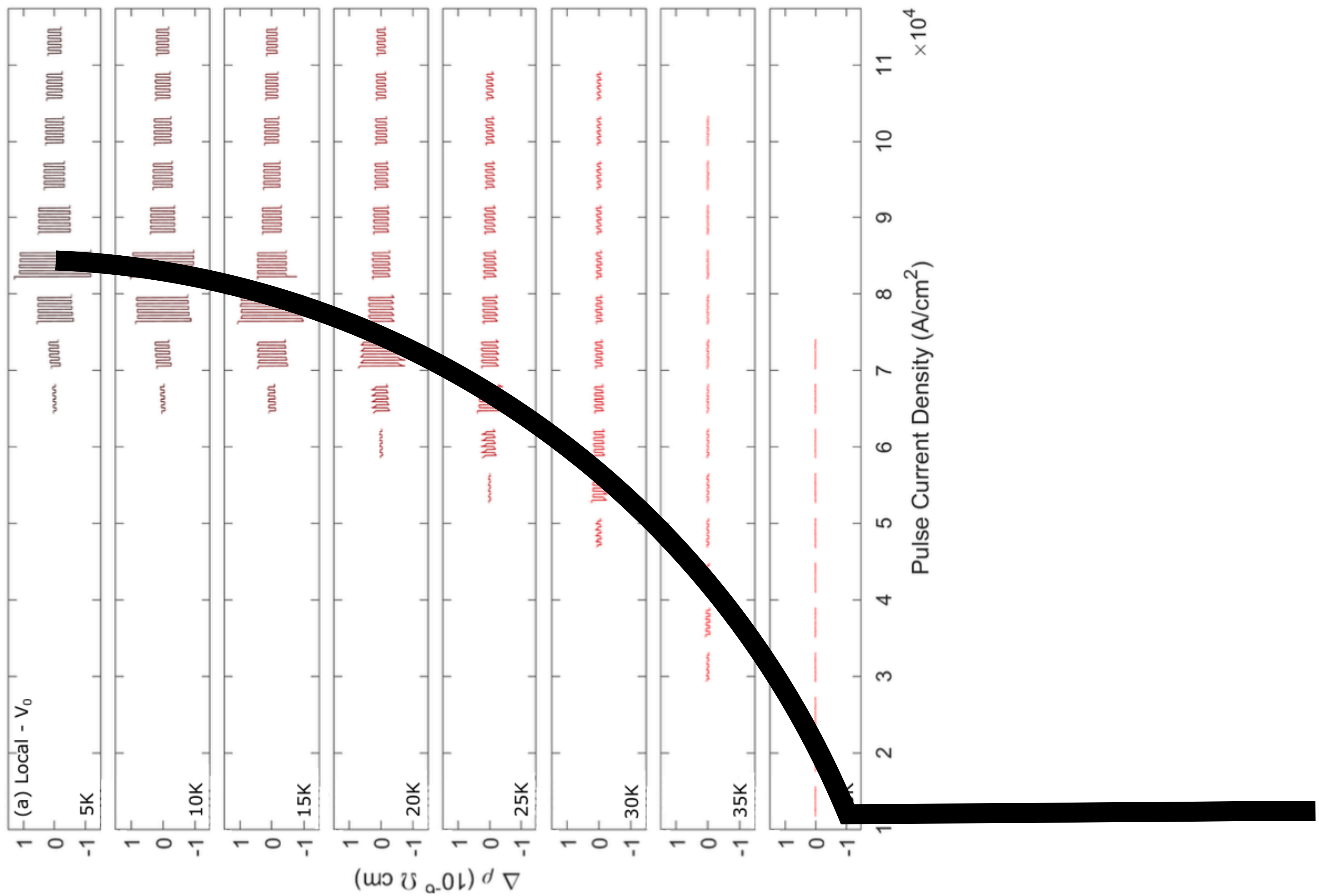
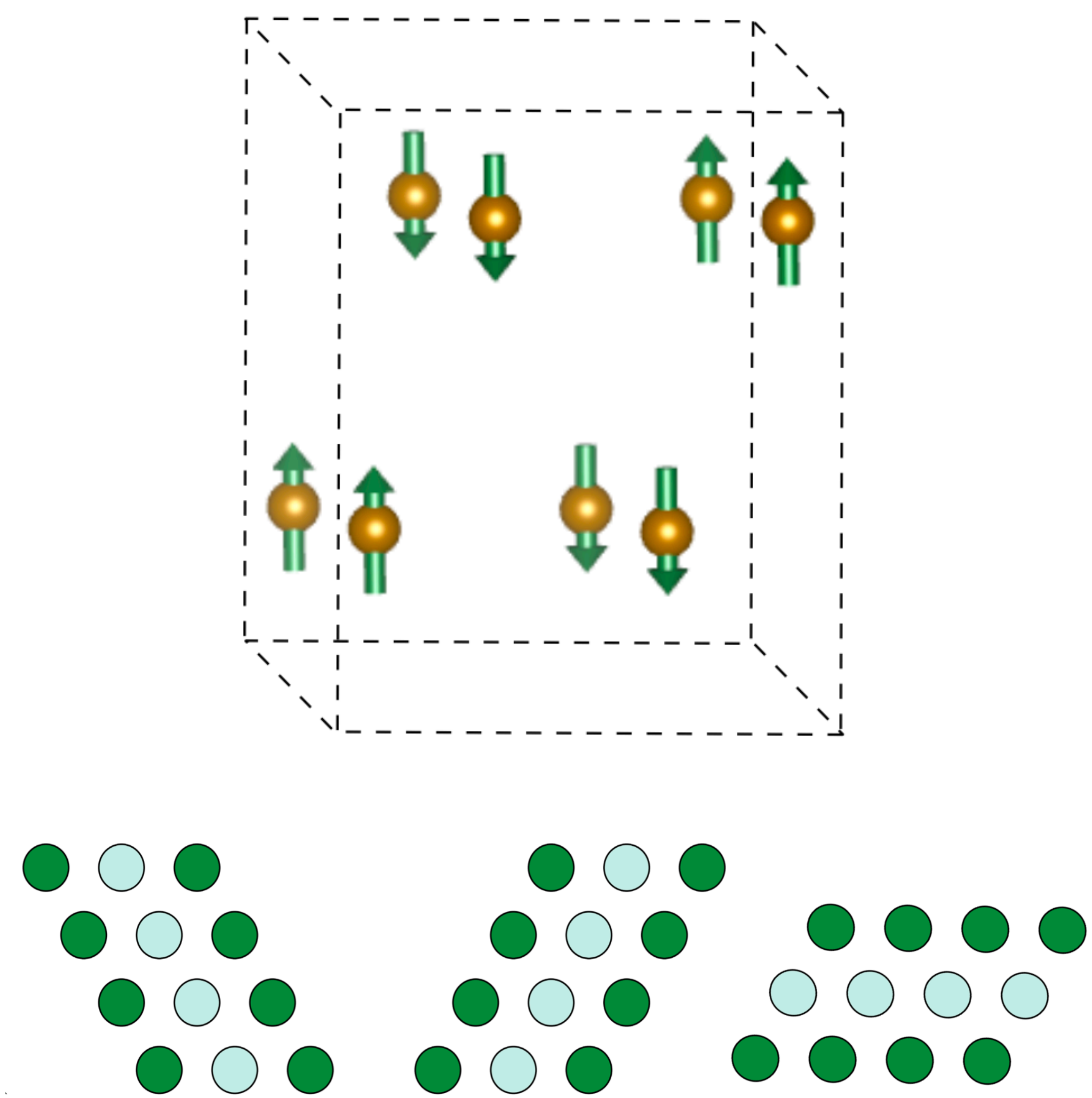
Anomalous switching



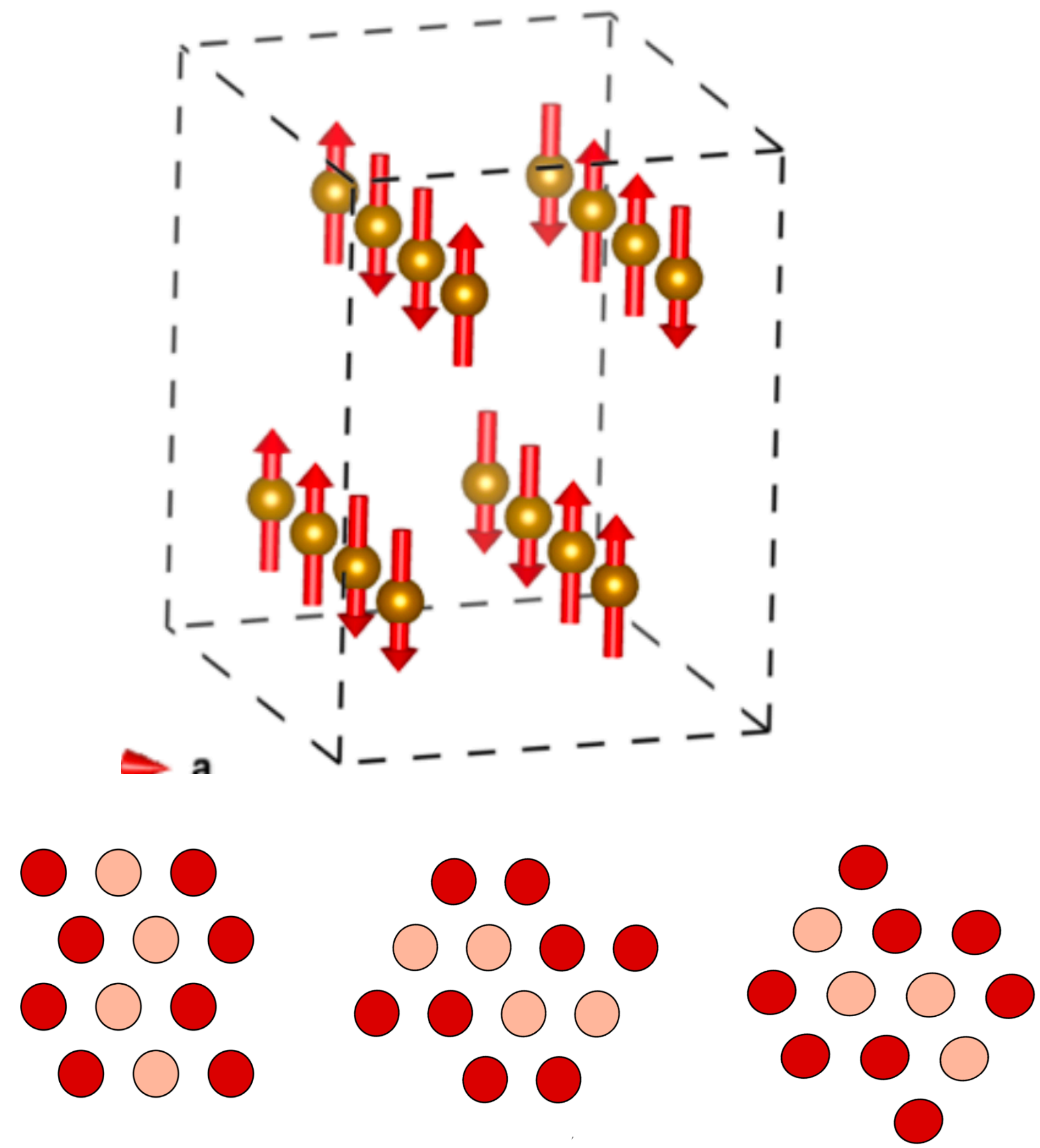
Anomalous Switching



Nearly degenerate magnetic orders

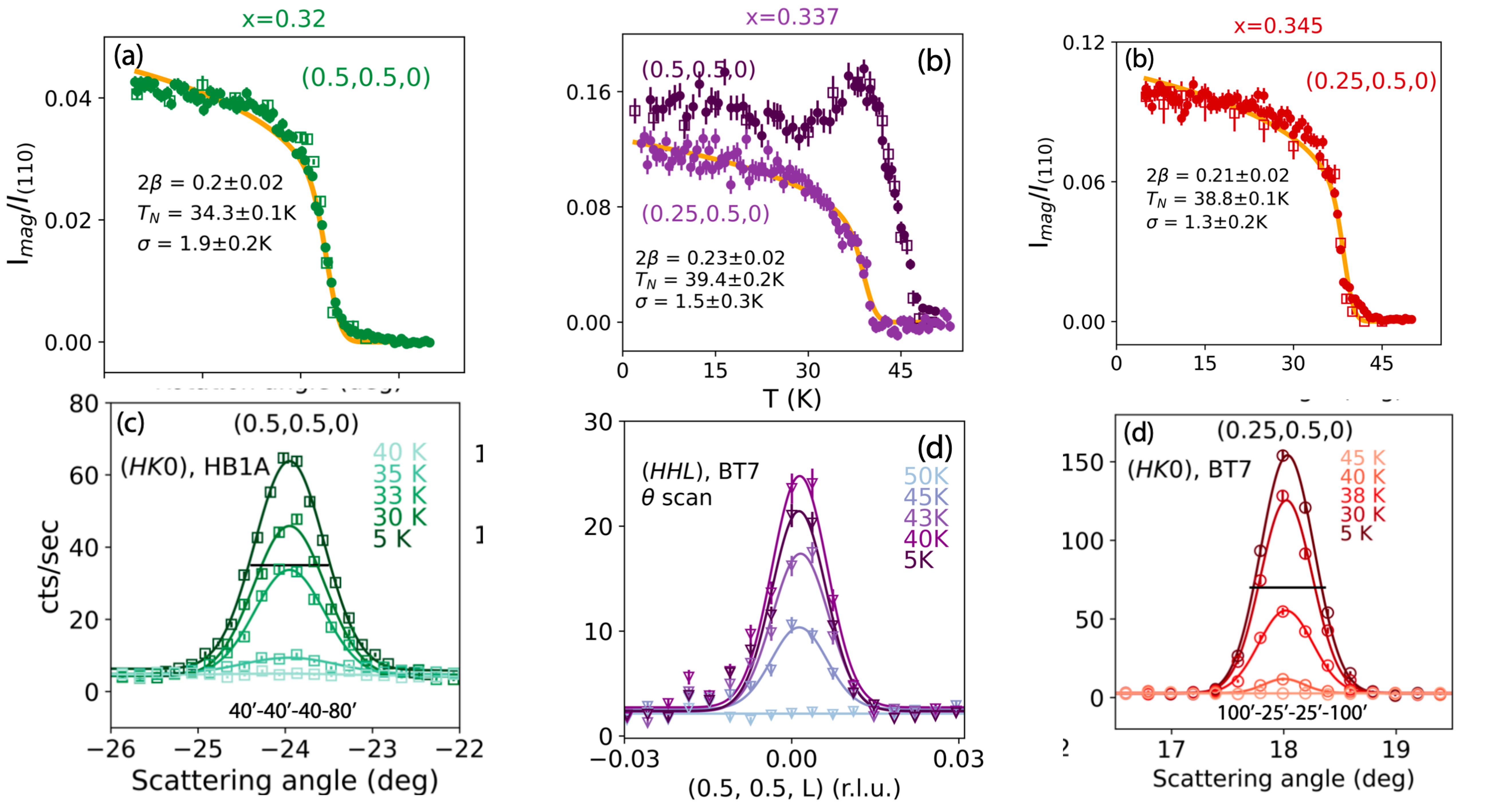


Stripe order



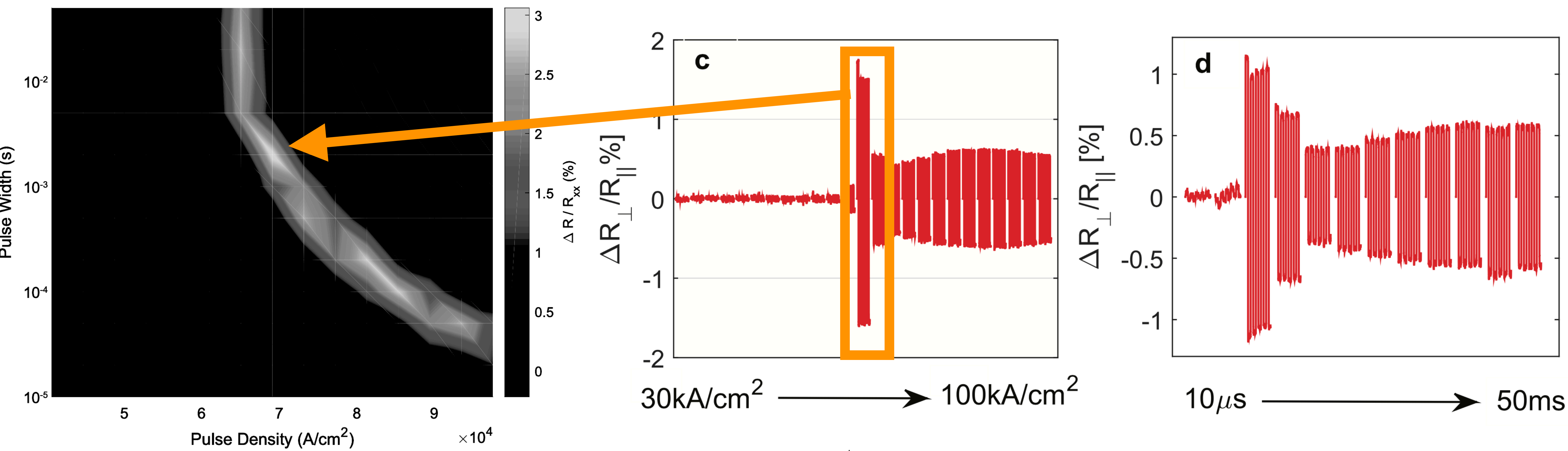
Zig-Zag order

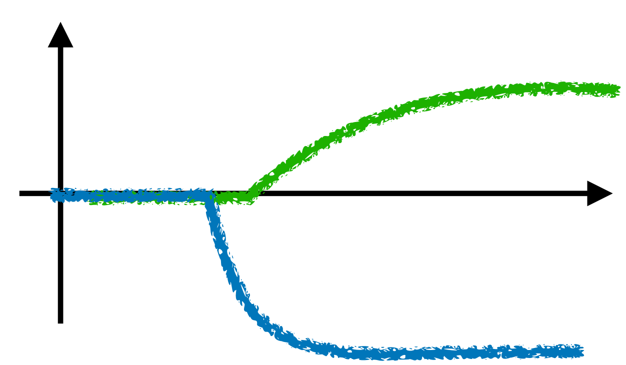
Evolution of the magnetic structure



Shan Wu, Bob Birgeneau, JGA *in preparation*

Anomalous current dependence

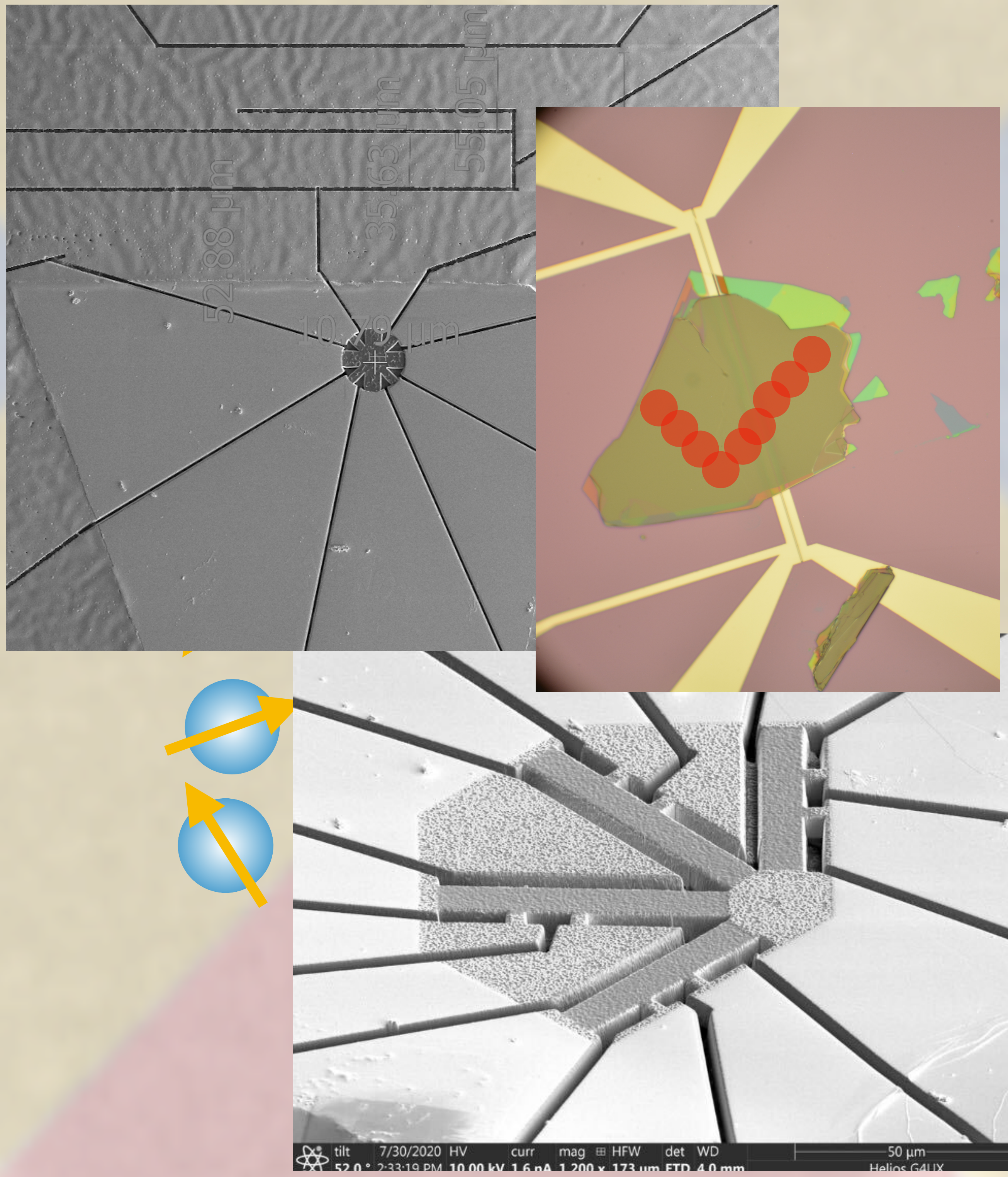


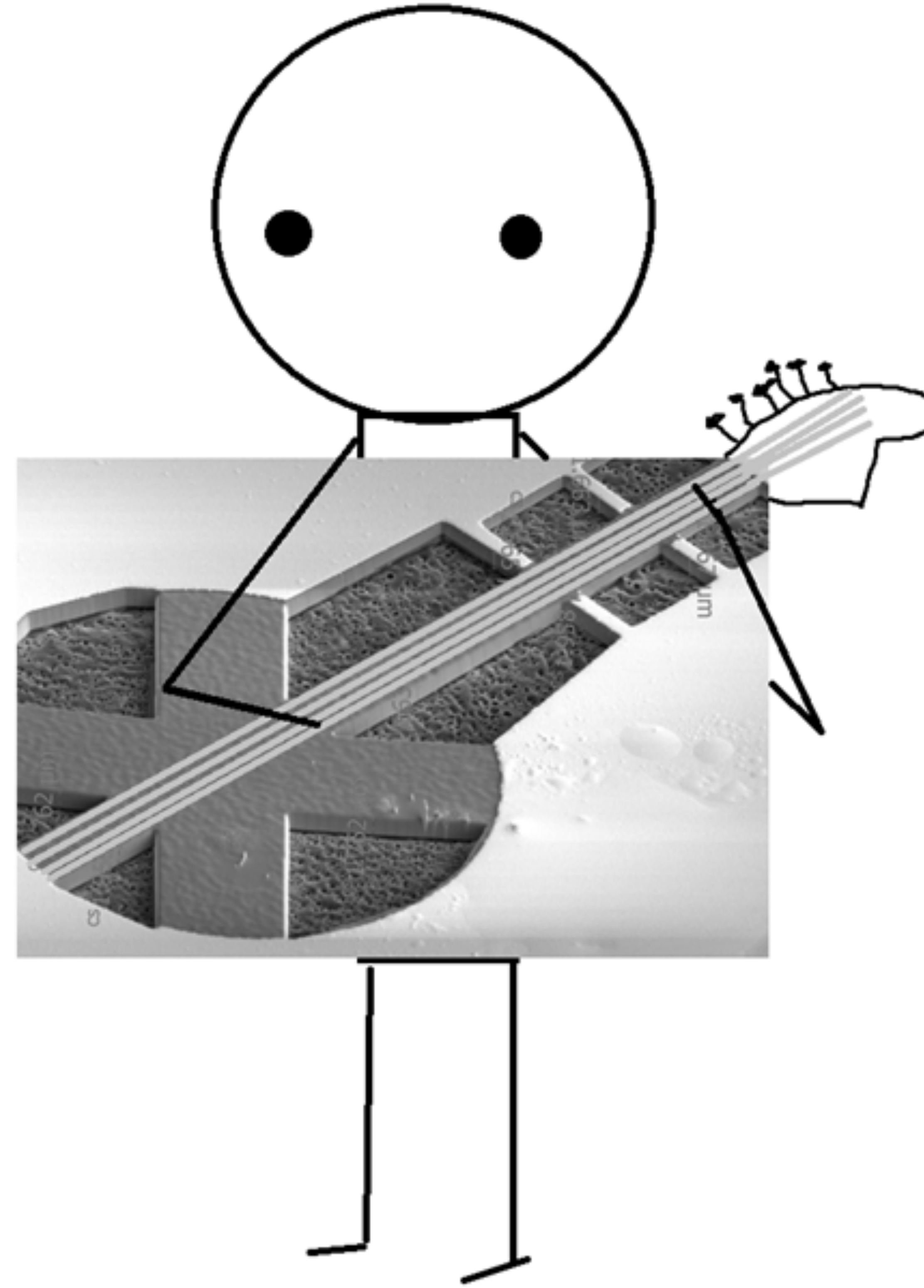


Can be naturally explained by the presence of two order parameters

Summary

- Collective spin-glass dynamic appears to facilitate the better spin transport into the AFM.
- Nearly order degenerate order parameters lead to highly tunable switching with unusual current/pulse width dependence.
- Lots of open questions remain. For example, the magnetic order is entirely in-plane, why is there single pulse saturation?





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