

Depth resolved vector magnetometry on D17 with Endurance upgrades

Thanks to everyone directly and indirectly involved in the D17 project
from its beginning until today and in the future.

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D17 Polarised Neutron Reflectometer
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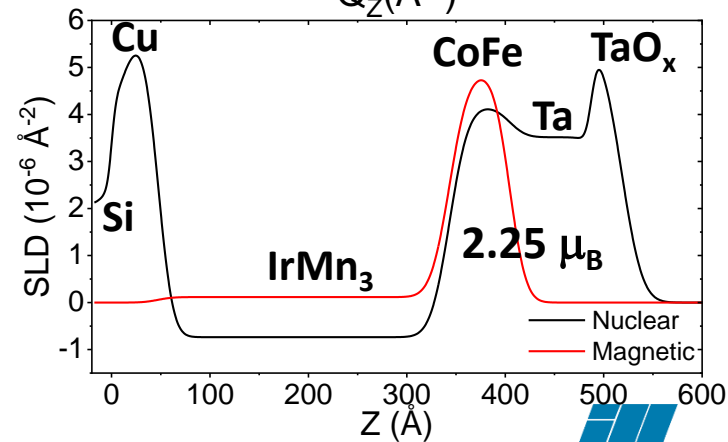
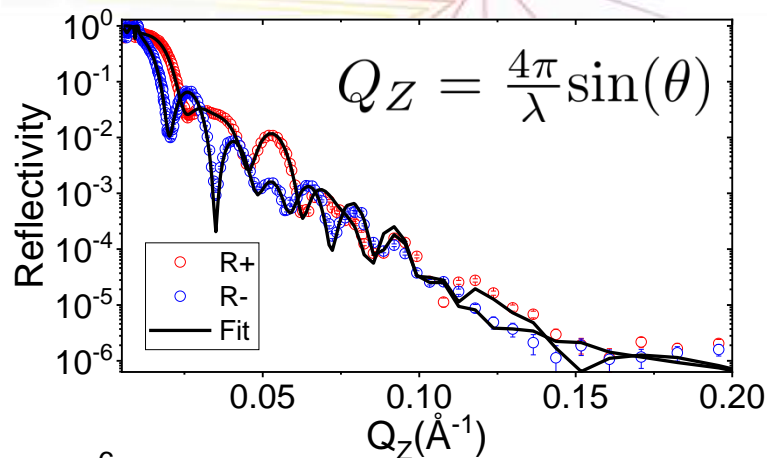
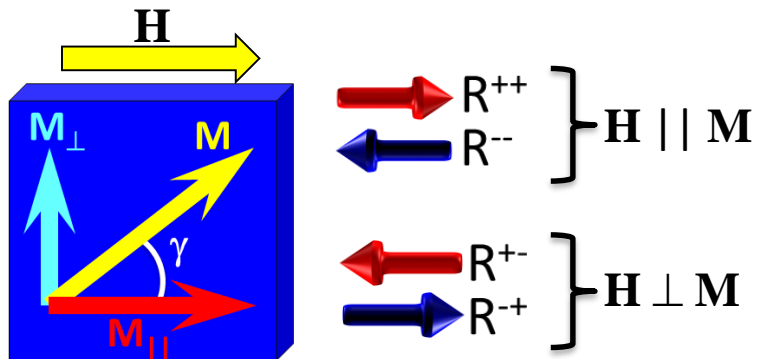
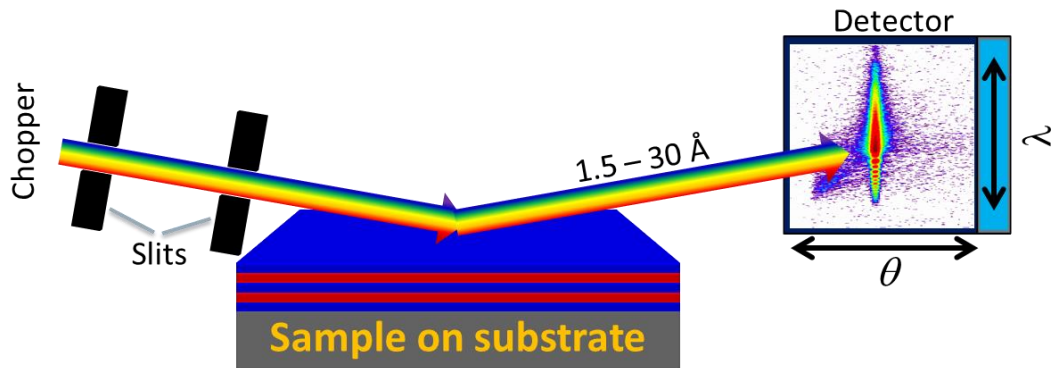
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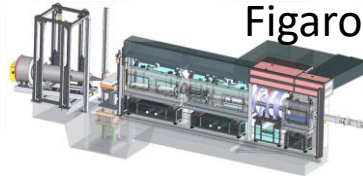
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Polarized neutron reflectometry in a nutshell

➤ Depth resolved vector magnetometry



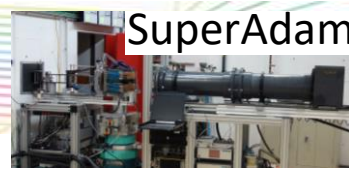
Science covered



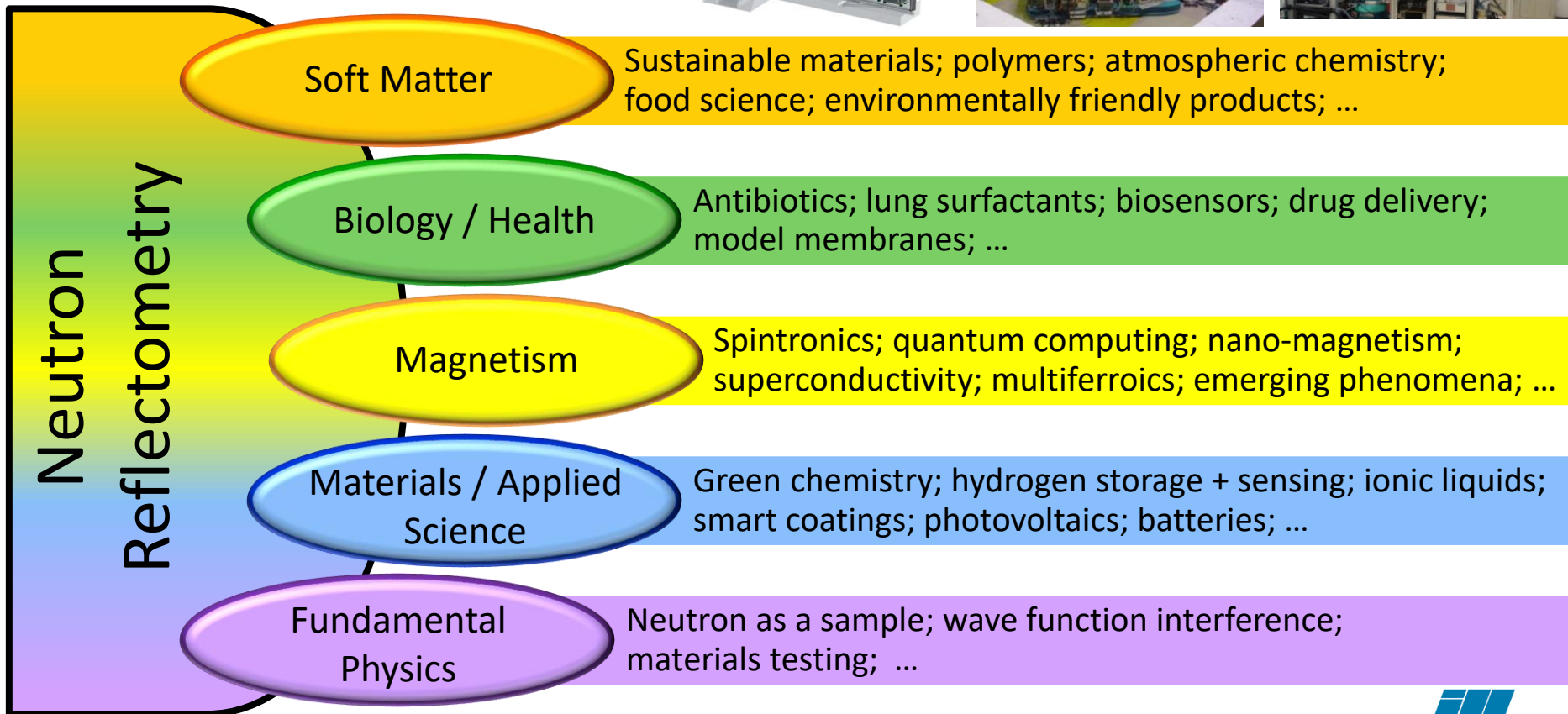
Figaro



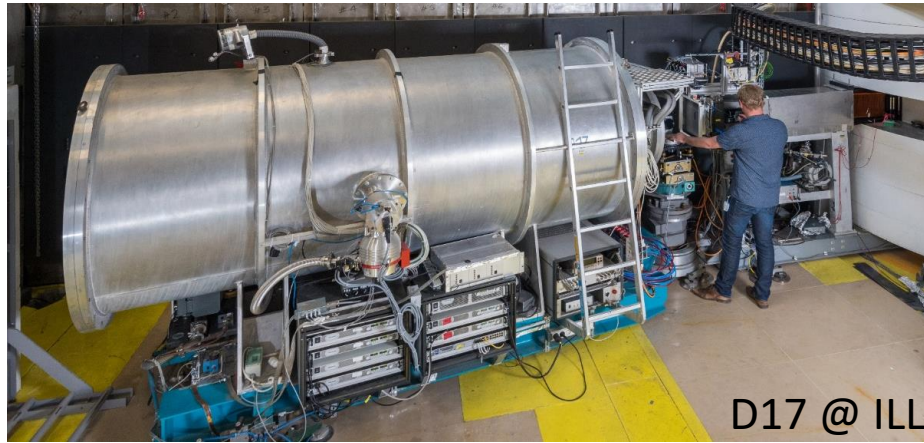
D17



SuperAdam



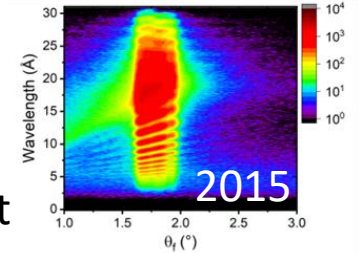
The D17 polarized neutron reflectometer



ToF polarization



Coherent Summation



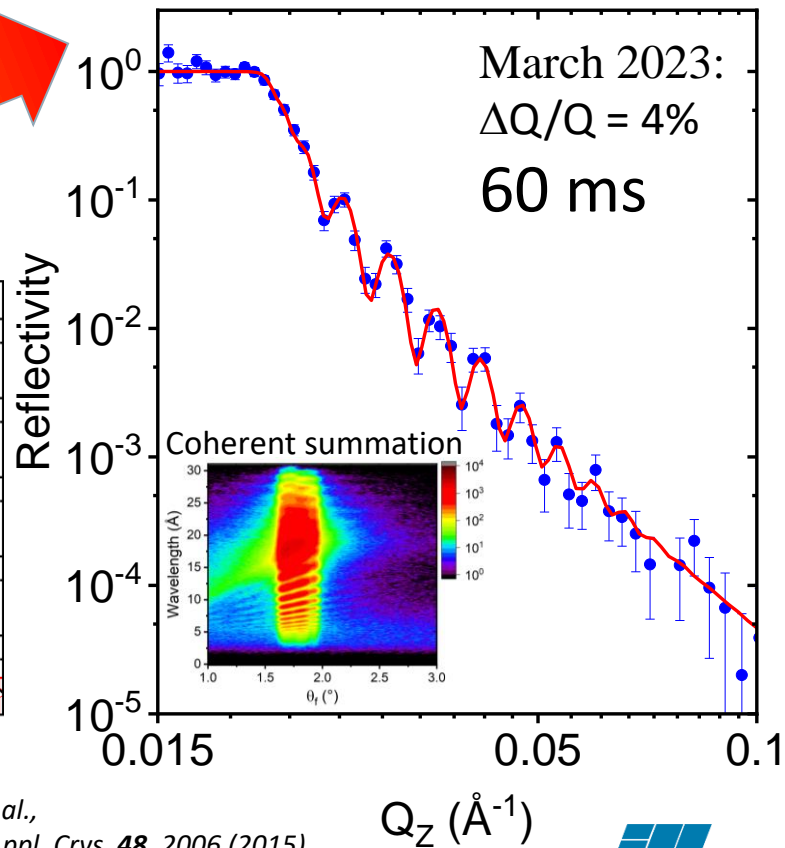
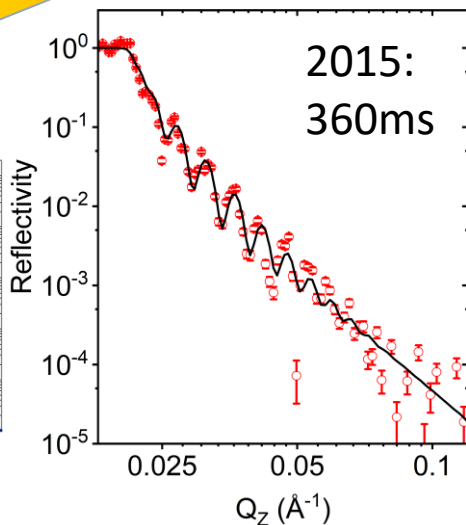
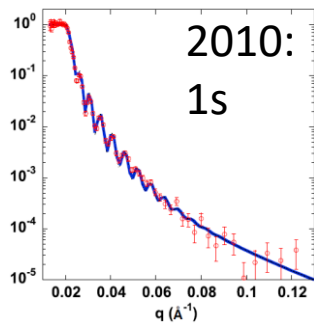
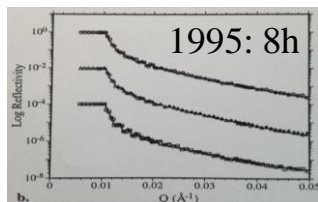
Requirements:

- Diverse topics = versatile sample environment
- Adapted to scientific question = flexible resolution
- Kinetics + fast measurements = high flux
- Few data corrections = high polarization efficiency
- High sensitivity = large Q-range
- High signal-to-noise ratio = low background

Kinetic acquisitions of non-cyclic processes

Same sample: 100 nm Ni/Glass

Continuous instrument and data treatment development
equivalent to a factor of ~500 000 improvement



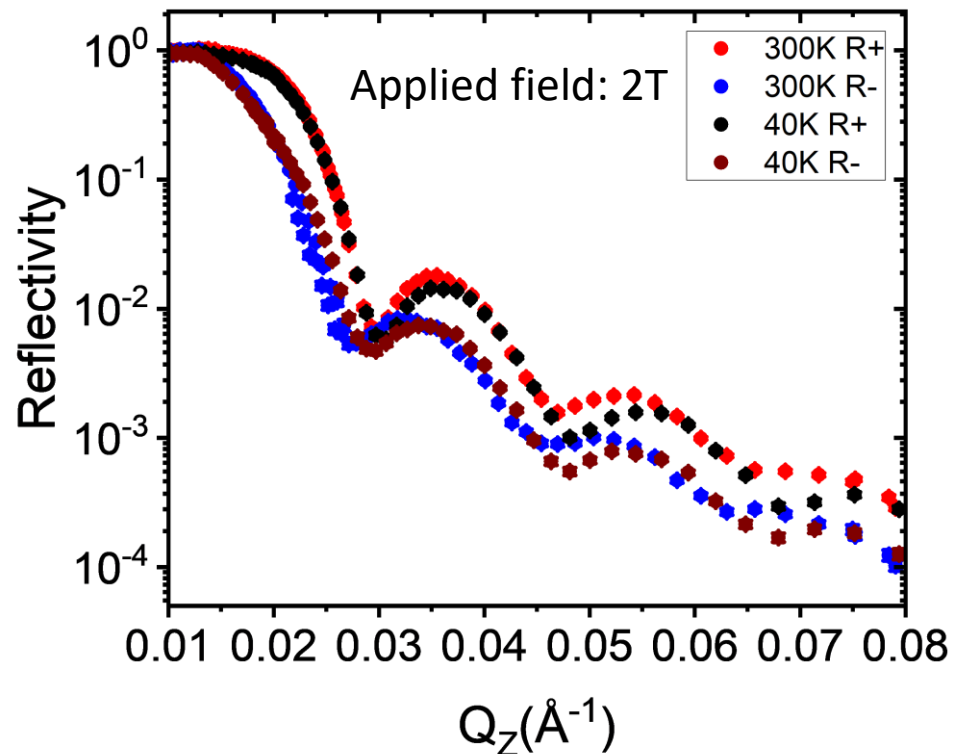
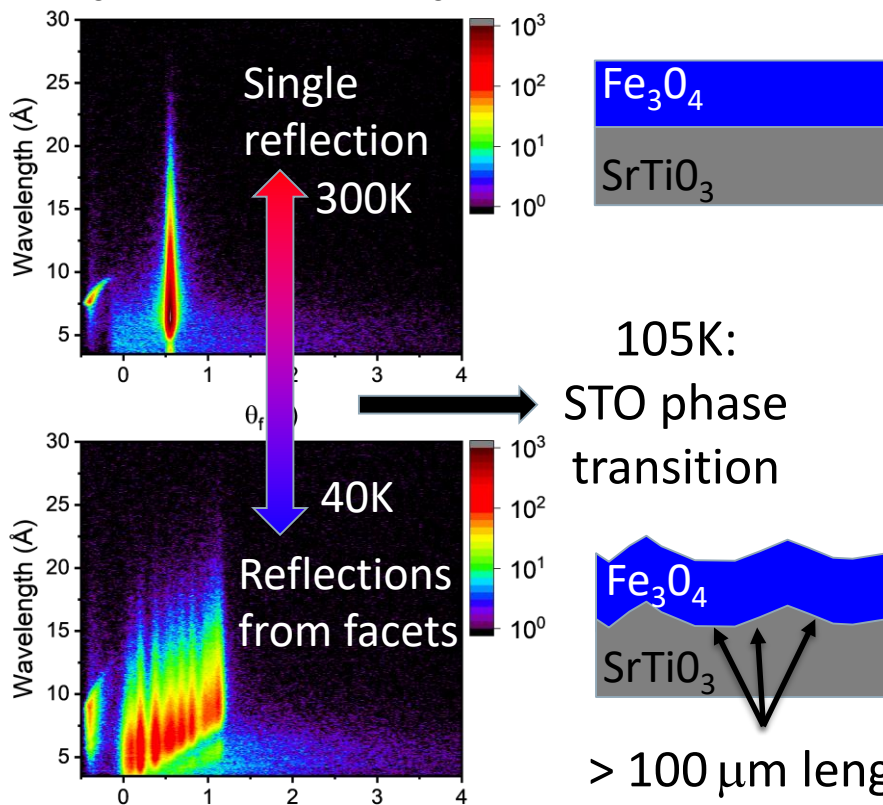
R. Cubitt et al.,
Journal of Appl. Crys. **48**, 2006 (2015).

Q_z (Å⁻¹)

Flattening bent or faceted surfaces

Data: March 2024

Fe₃O₄(40 nm)/SrTiO₃-substrate



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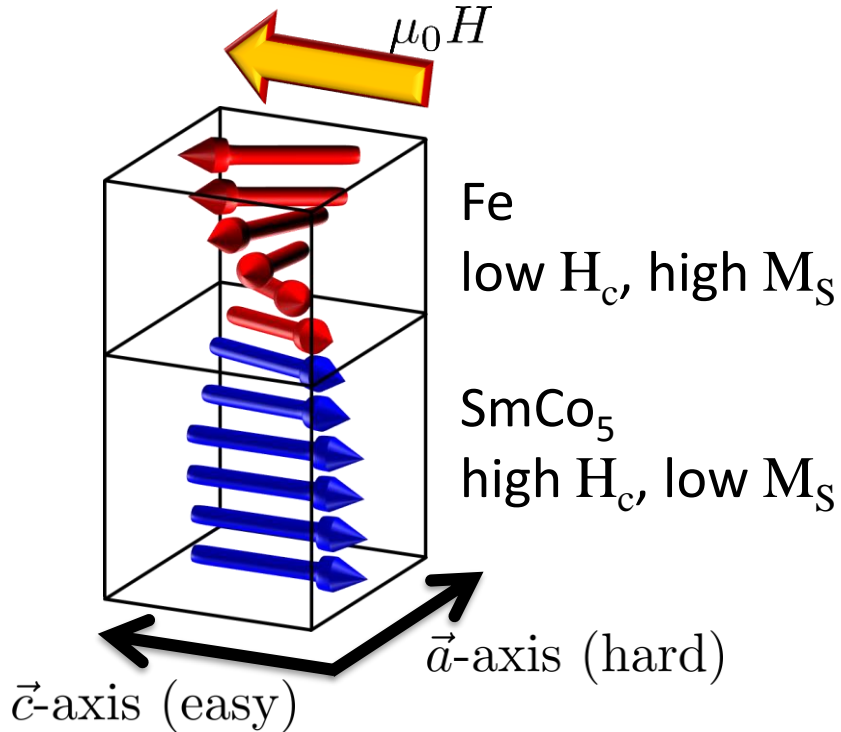
θ_f (°)


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R. Cubitt et al.,
Journal of Appl. Cryst. **48**, 2006 (2015).

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Magnetization vector depth profiling of hard/soft magnetic exchange springs



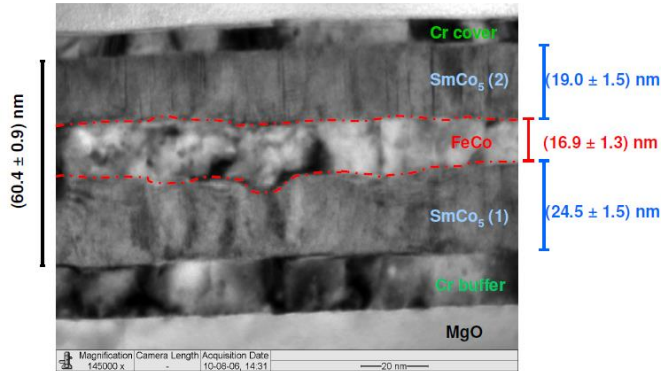
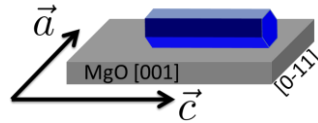
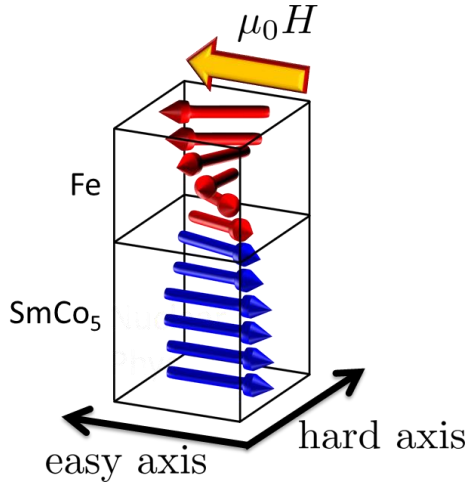
 Leibniz Institute
for Solid State and
Materials Research
Dresden

Volker Neu

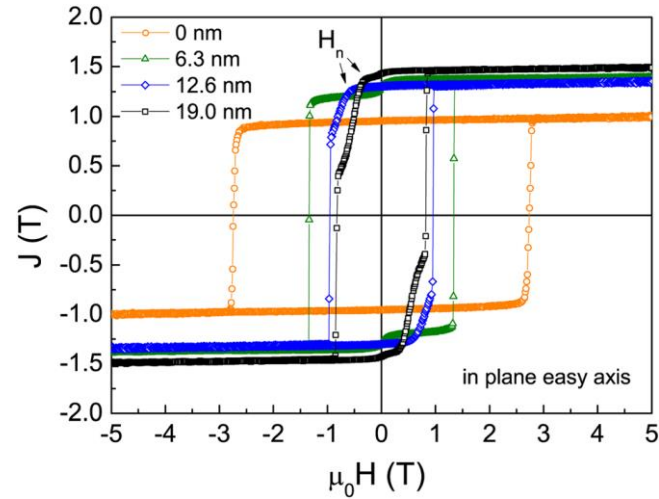
Finding application in:

- ✓ Exchange coupled composite recording media
- ✓ Read head structures and sensors
- ✓ Improved permanent magnets for motors and magneto-mechanics
- ✓ Logic circuits

SmCo₅/Fe exchange springs



- Combine hard and soft magnetic materials
- Fe: low H_c , high M_S ; SmCo₅: high H_c , low M_S

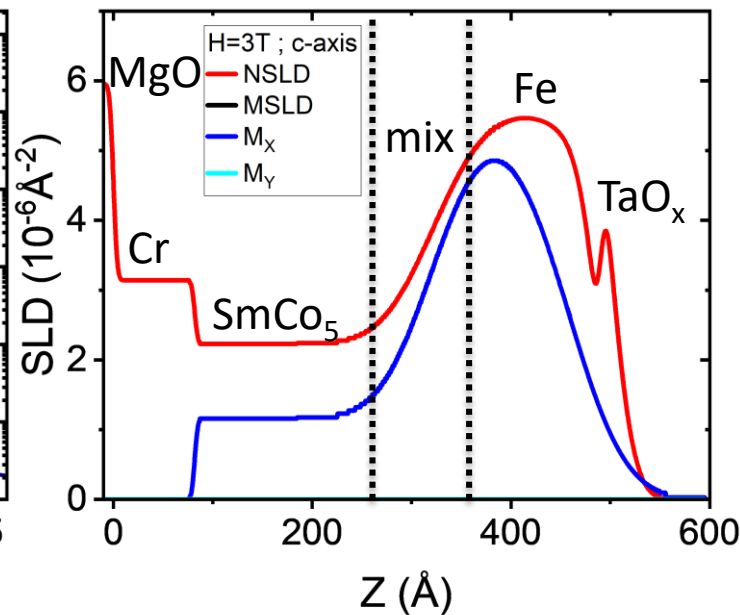
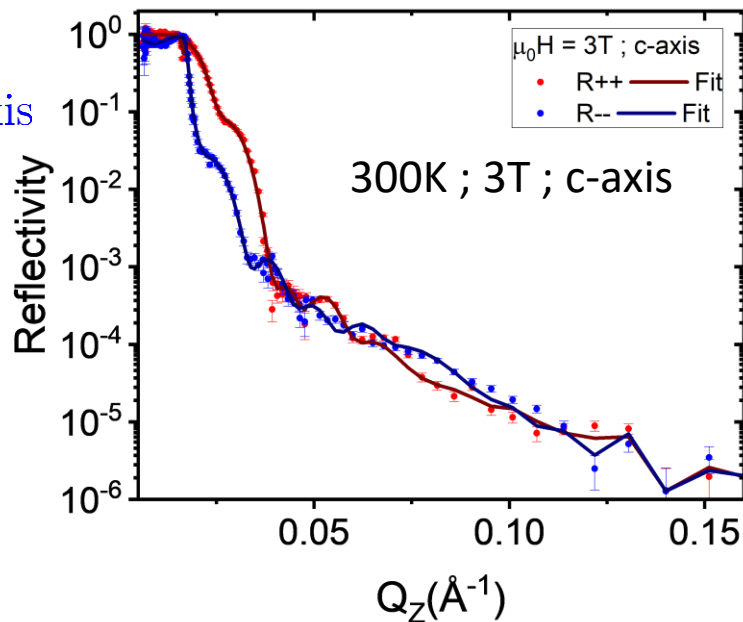
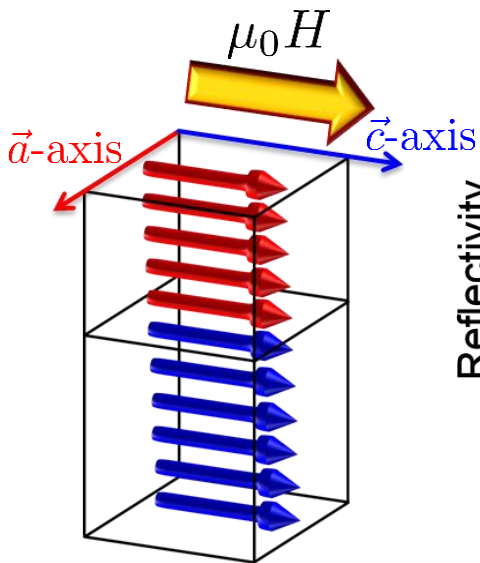


- Extract: Depth dependent magnetization
⇒ Spring nucleation, extension, vector rotation

S. Sawatzki et al. *Journal of Applied Physics* **109**, 123922 (2011).

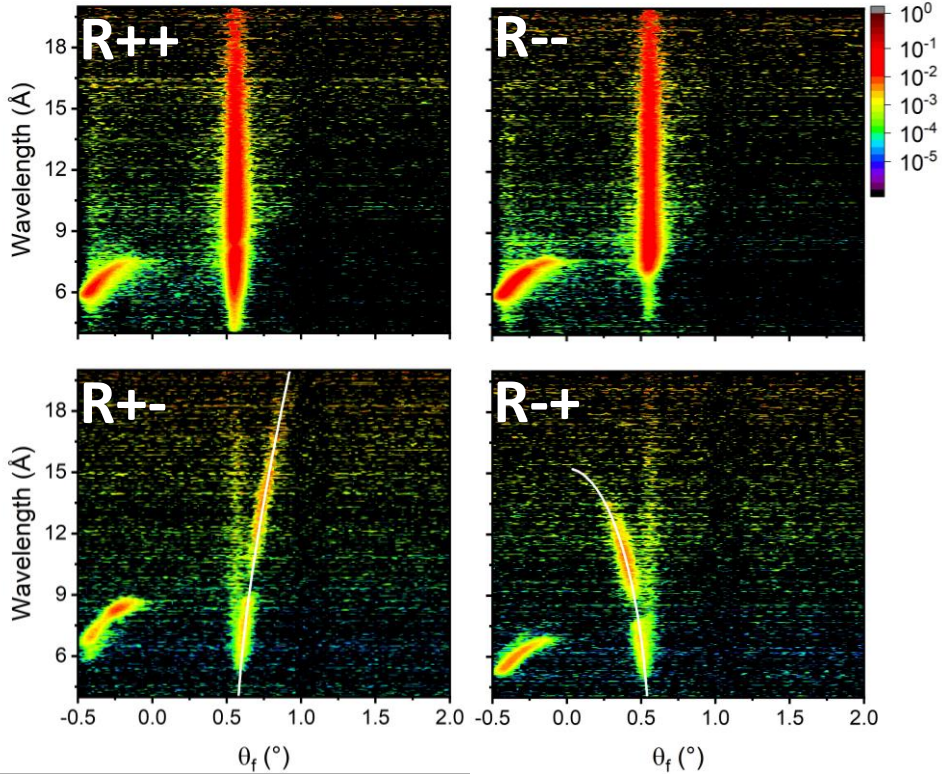
SmCo₅/Fe: Depth profile at saturation

Sample 7x7 mm²: MgO(001) / Cr (70 Å) / SmCo₅ (200 Å) / Fe (100 Å) / Ta (20 Å)

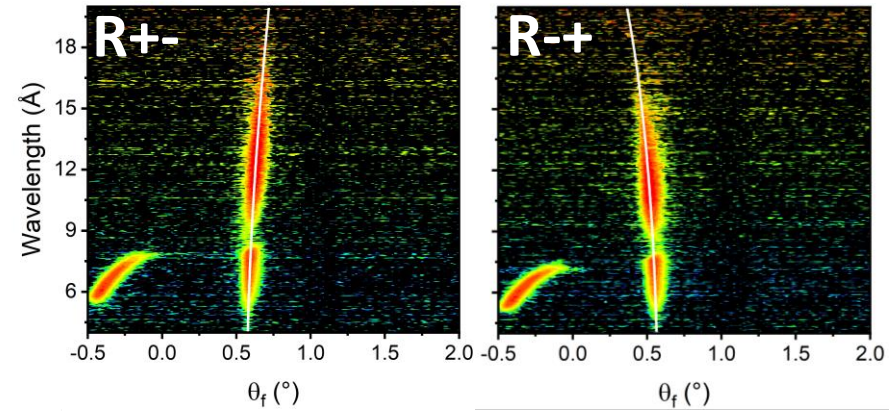


Birefringent spin-flip scattering

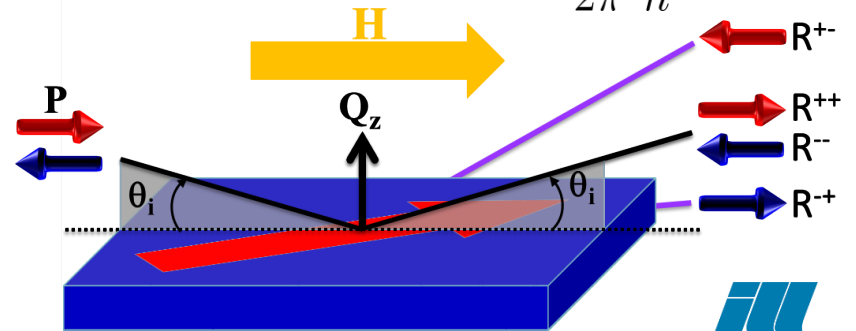
External field: 0.3 T



External field: 0.1 T



$$\text{Spin flip: } \sin^2 \theta_f = \sin^2 \theta_i \pm \frac{2m_n \mu_n}{2\pi^2 \hbar^2} H \lambda^2$$

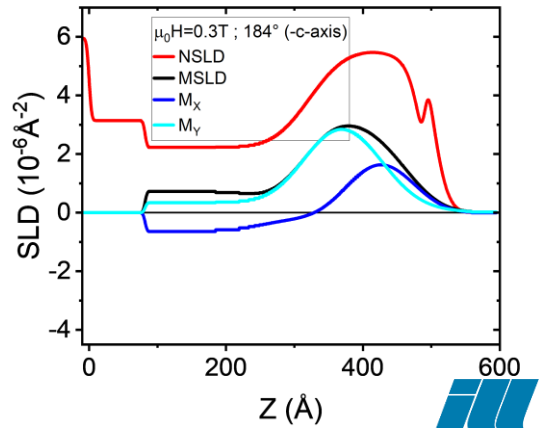
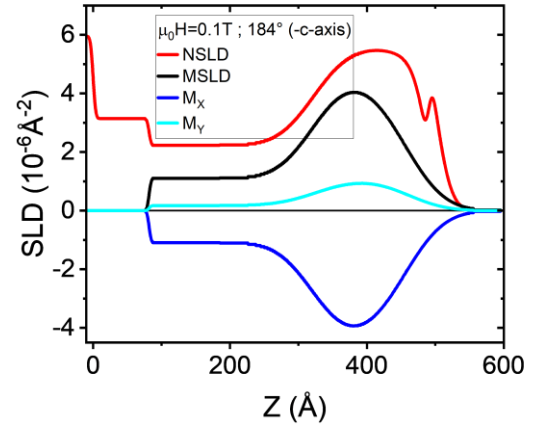
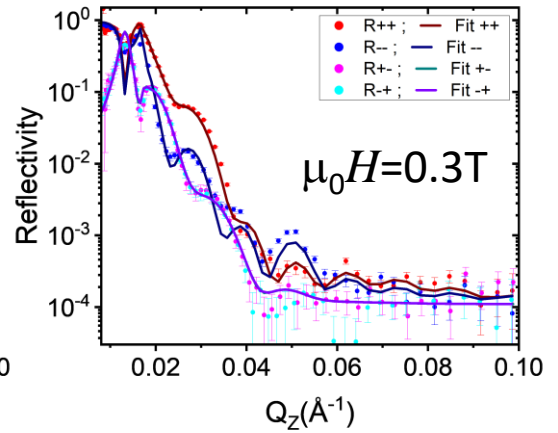
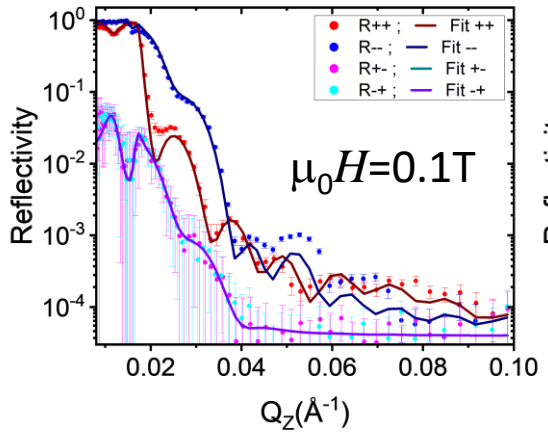
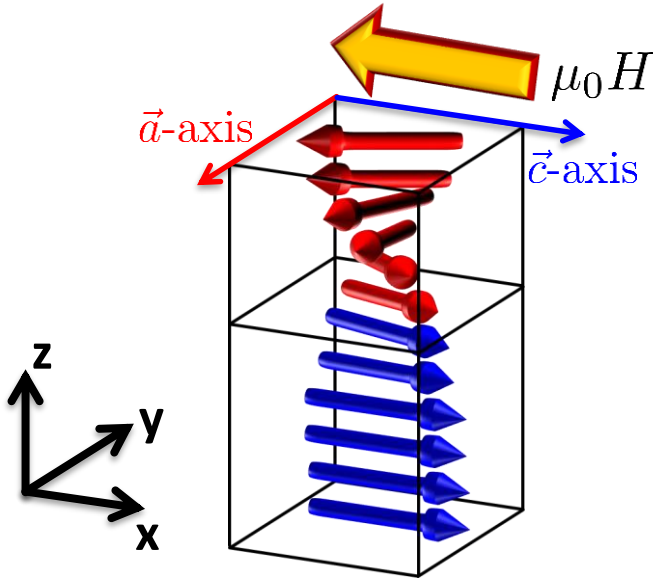


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SmCo₅/Fe: Springs in 0.1T & 0.3T @ 184°

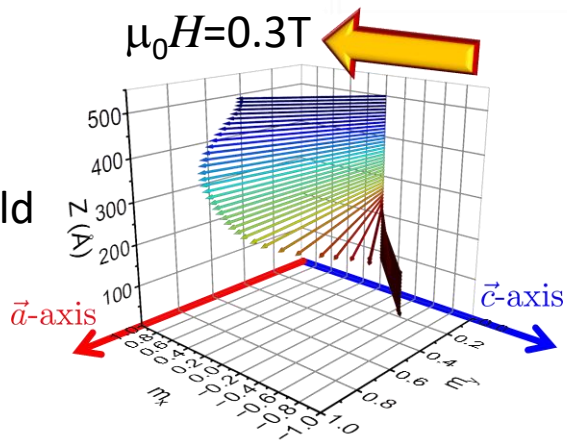
- Saturated in 3T
- Field reduced 0T
- Sample rotated 90° or 180°
- Field increased to 0.1T or 0.3T
- $M_x \parallel \text{Field}$; $M_y \perp \text{Field}$



SmCo₅/Fe: Exchange spring summary

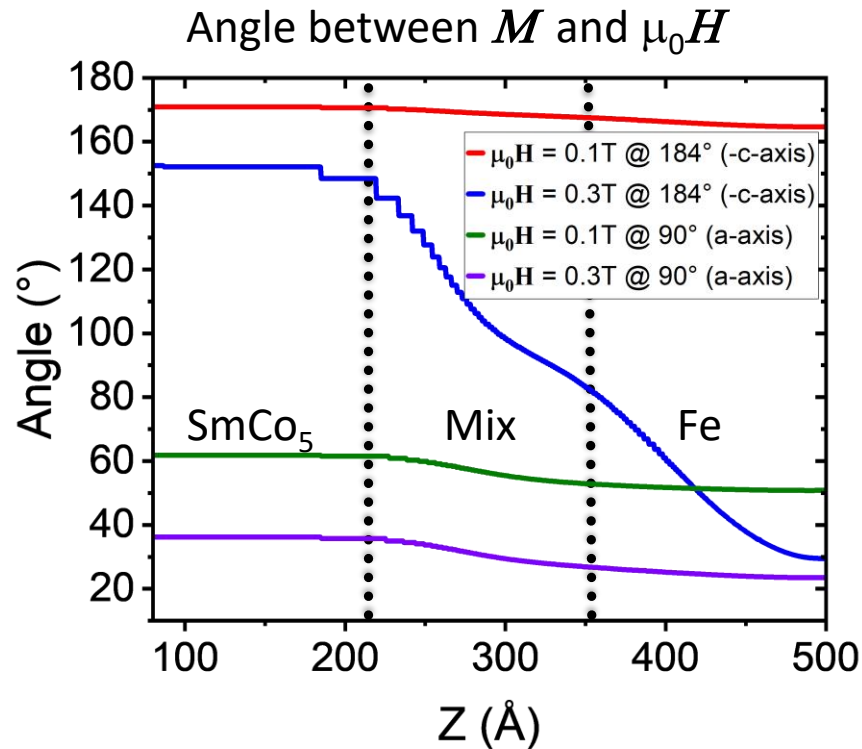
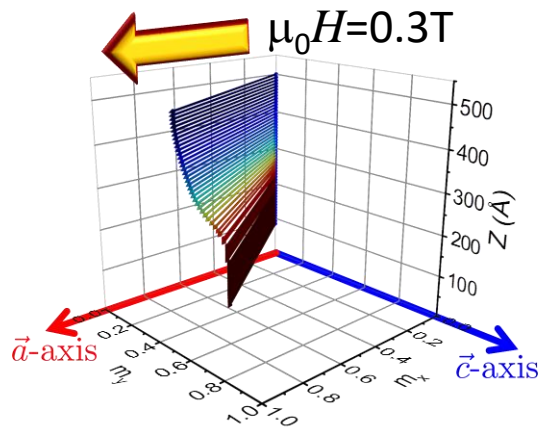
From initial saturation:

- Field antiparallel
- Constant 152° to field in SmCo₅
- Continuous spiral of 120° in Fe

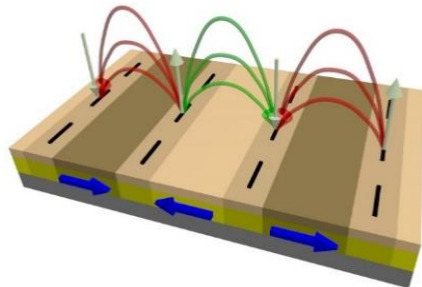
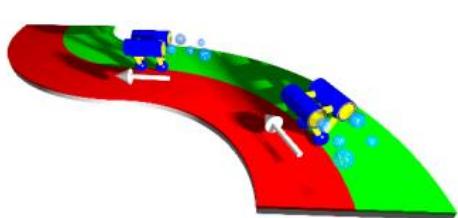


From initial saturation:

- Field perpendicular
- Constant 36° to field in SmCo₅
- Continuous spiral of 12° in Fe

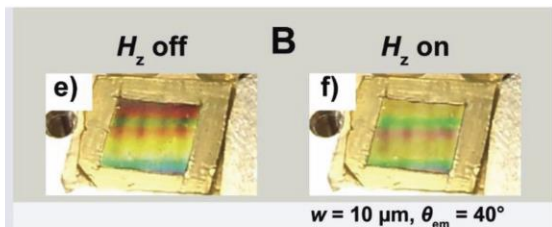
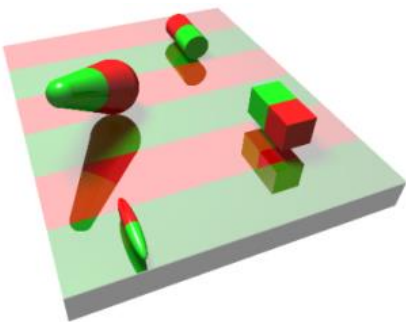


Quantifying magnetic domain textures



U N I K A S S E L
V E R S I T Ä T

Arno Ehresmann

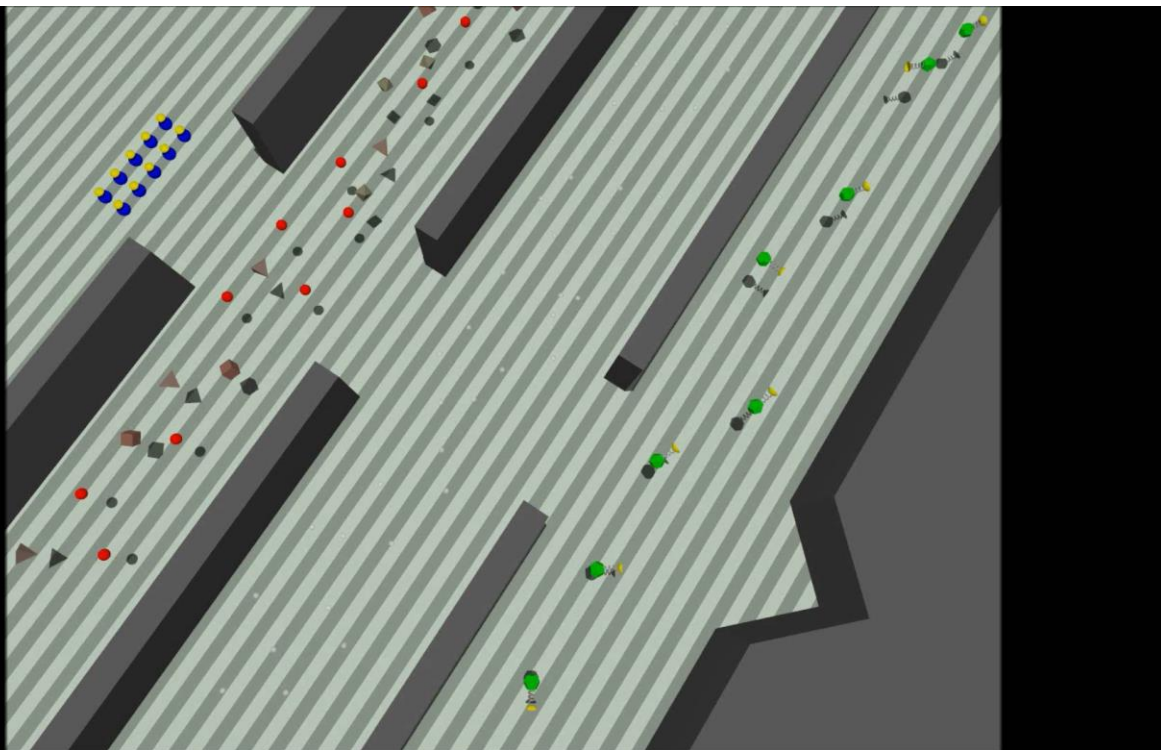


Applications in

- ✓ lab-on-a-chip applications
- ✓ optically active surfaces
- ✓ biosensor devices
- ✓ self-organization of molecules
- ✓ template for magnetically active polymers

I. Koch et al., Adv. Opt. Mater. 6, 8, 1800133 (2018).

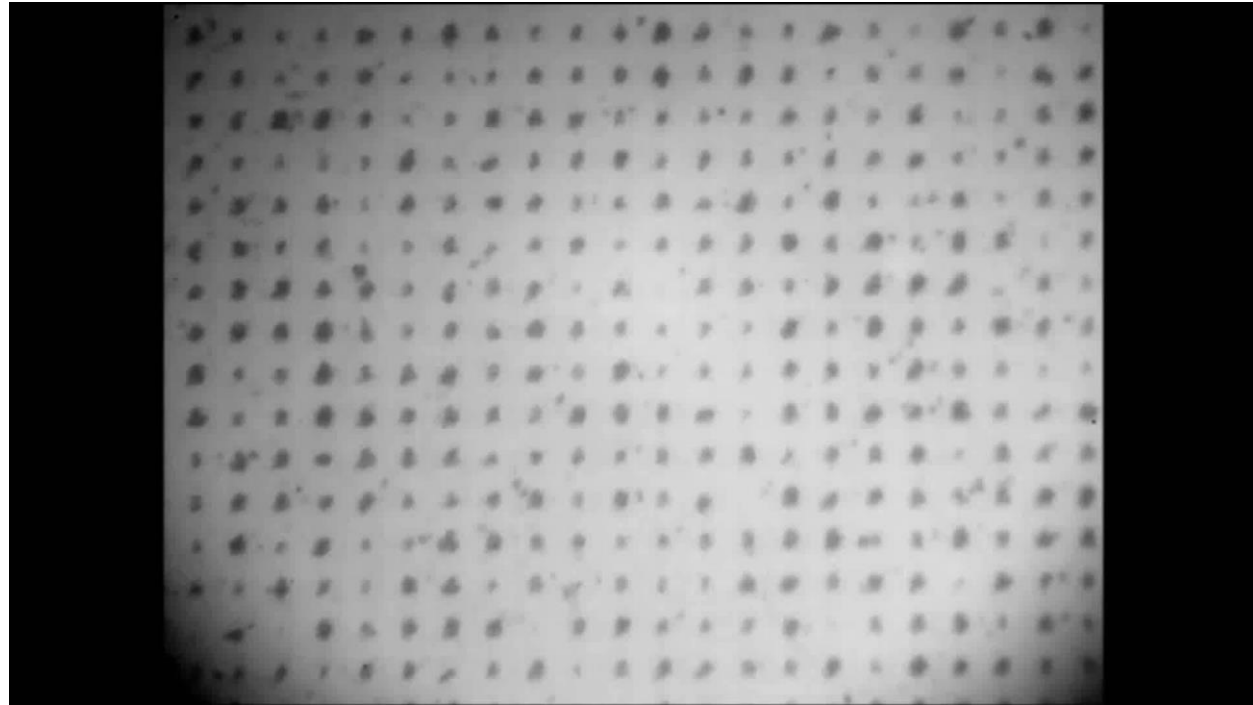
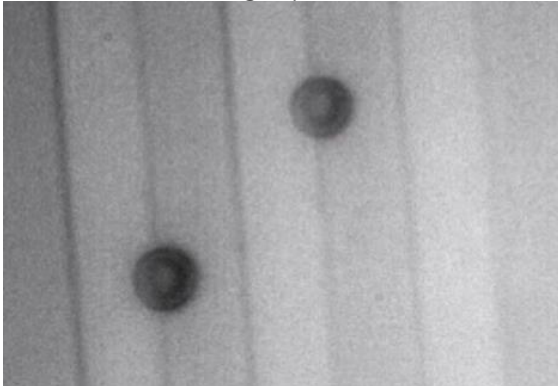
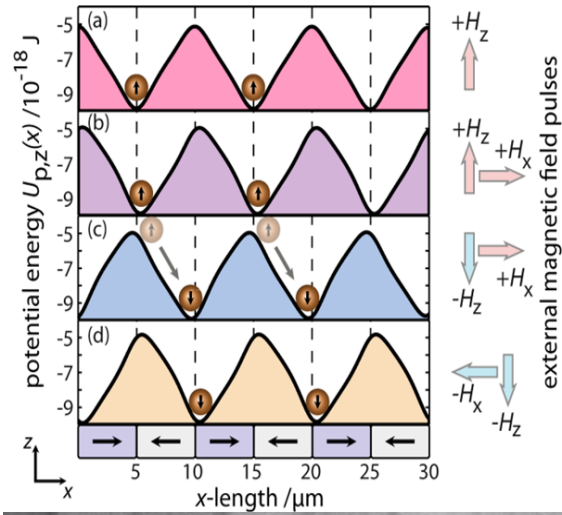
Lab-on-a-chip



Enhanced efficiency of Particle

- Transport
- Interaction
- Washing
- Label binding
- Concentration
- Detection

Full motion control



D. Holzinger *et al.* *ACS Nano* **9**, 7323 (2015).

R. Huhnstock *et al.* *Scientific Reports* **11**, 21794 (2021).

Magnetic domain patterning

1. CoFe/IrMn₃ **exchange bias** bilayer

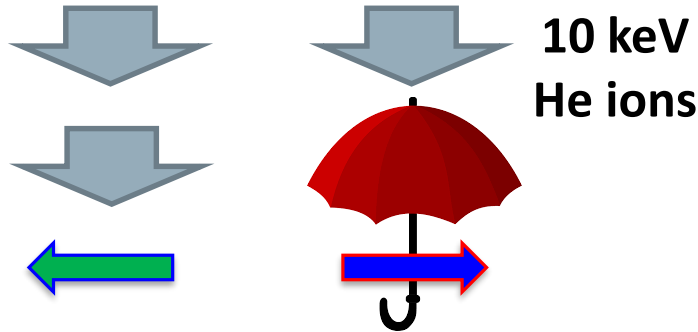
field cooling: 

2. Deposit **photolithography** mask

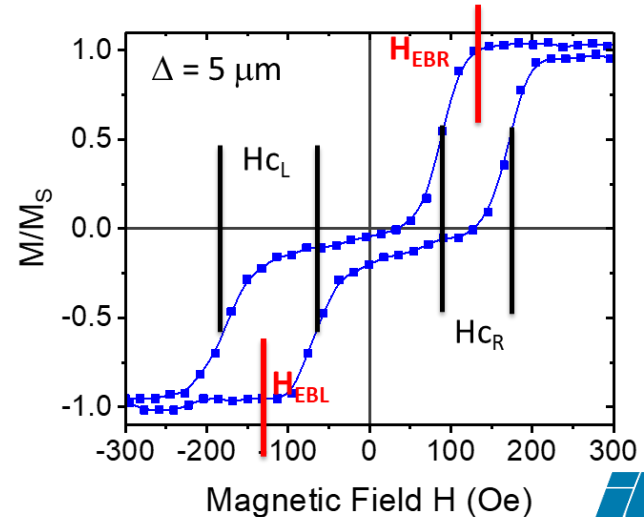
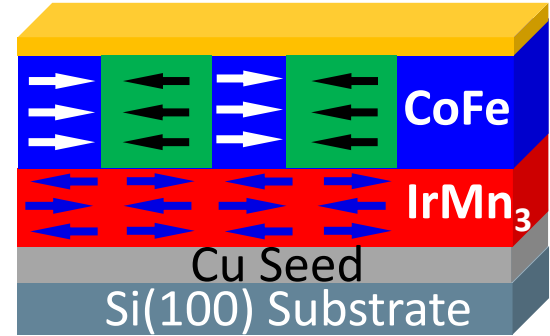
3. Change external field direction



4. **Light-ion bombardment** in field

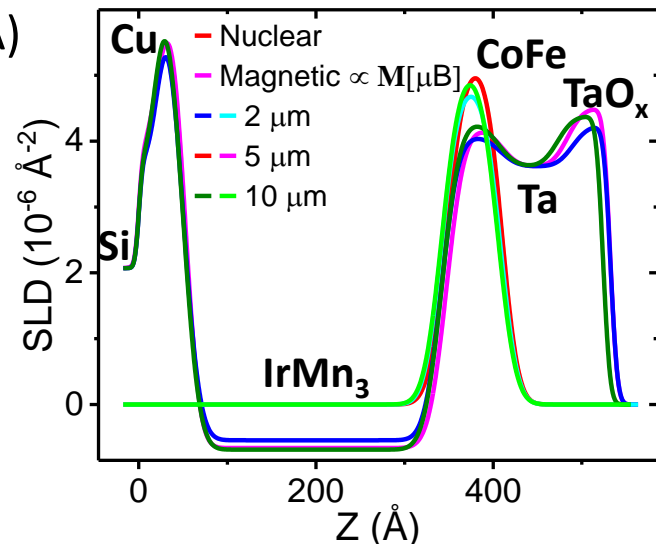
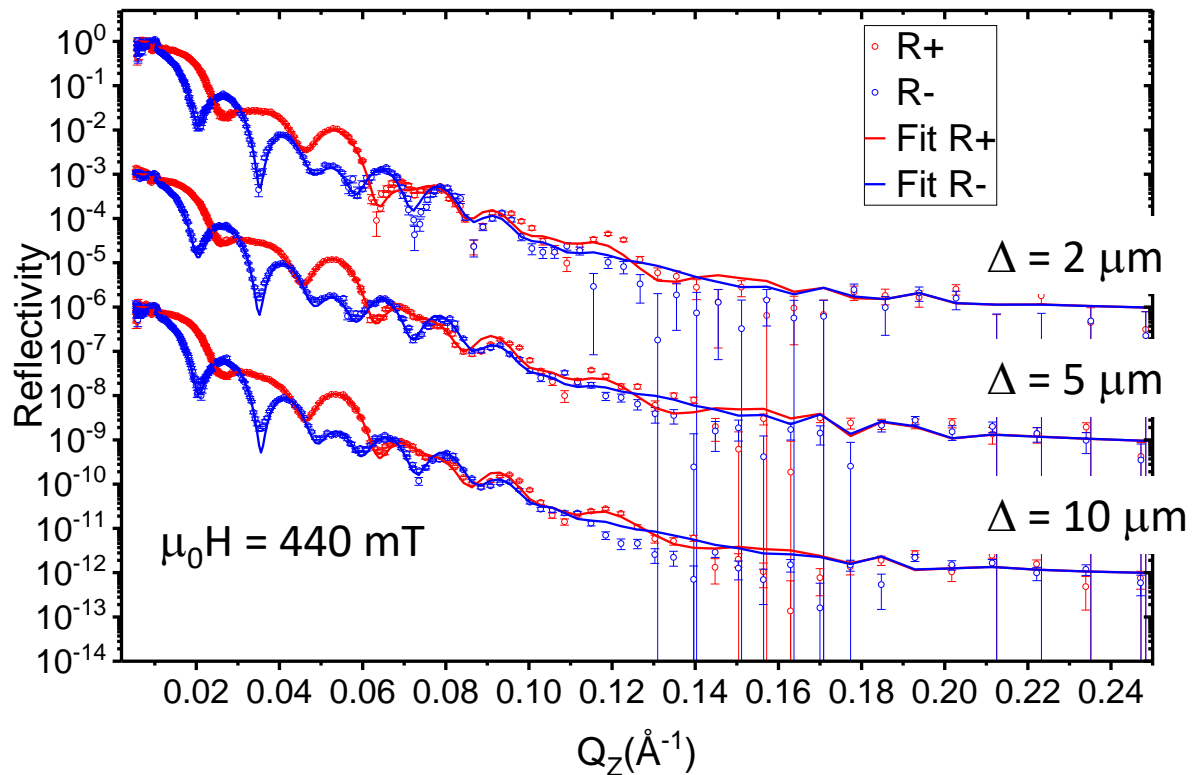


5. Remove lithography mask



Structural integrity from specular fits

Si(001) / Cu (50 Å) / IrMn₃ (300 Å) / CoFe (100 Å) / Ta (100 Å)



M_s/CoFe :

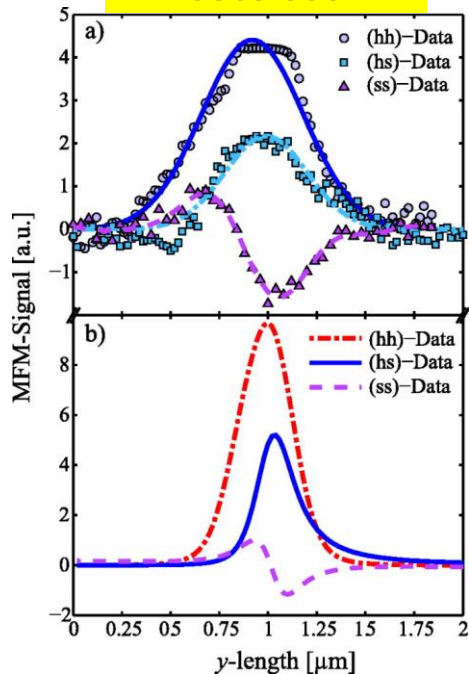
$\Delta = 2 \mu\text{B}$: $2.1 \mu\text{B}$

$\Delta = 5 \mu\text{B}$: $2.25 \mu\text{B}$

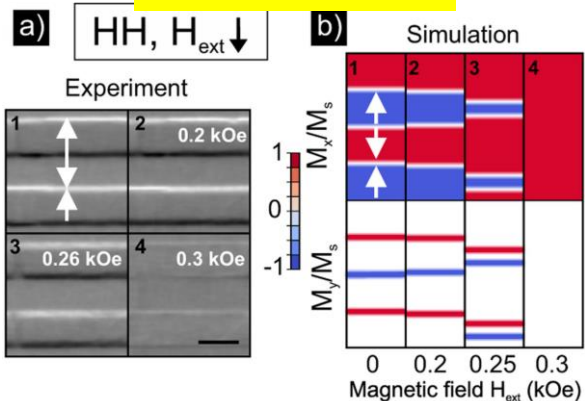
$\Delta = 10 \mu\text{B}$: $2.35 \mu\text{B}$

Quantifying lateral domain textures

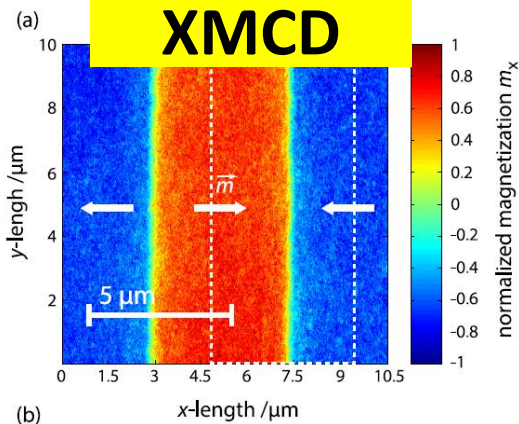
MFM



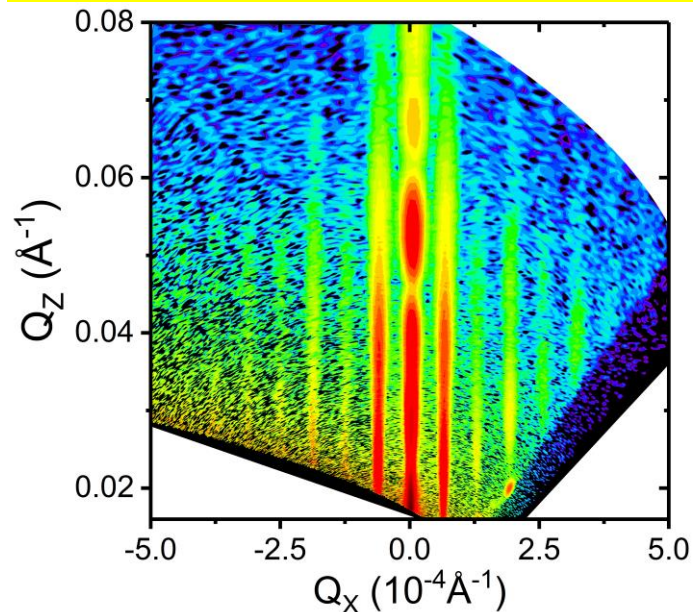
SMRM



XMCD



Polarized off-specular scattering



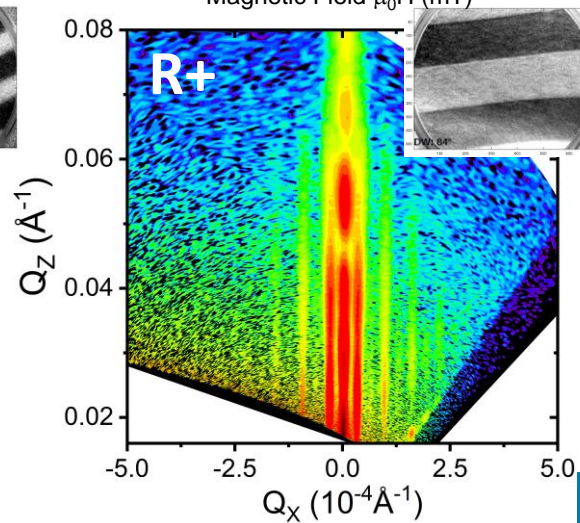
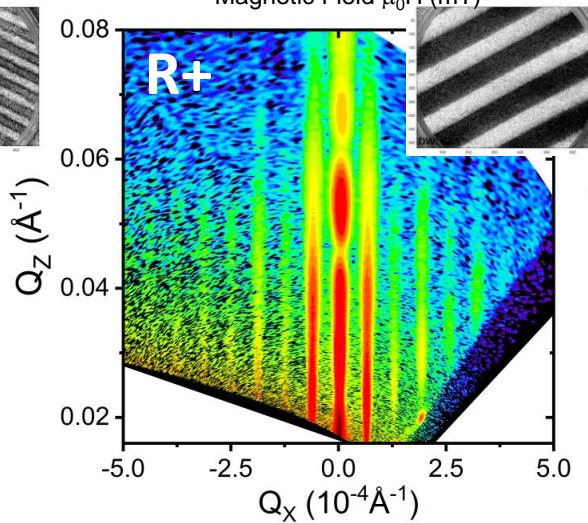
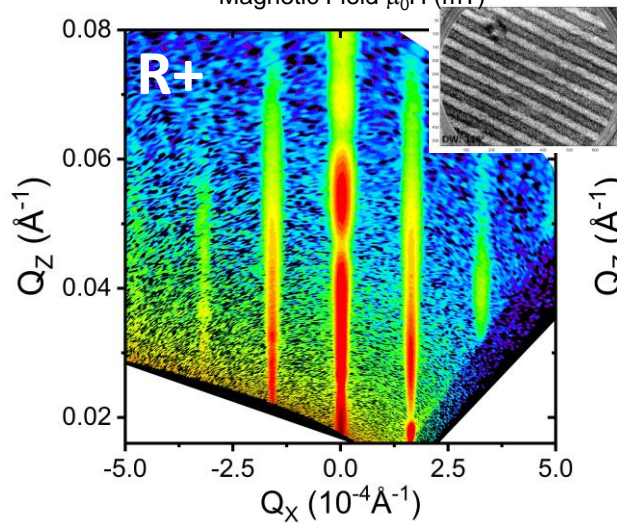
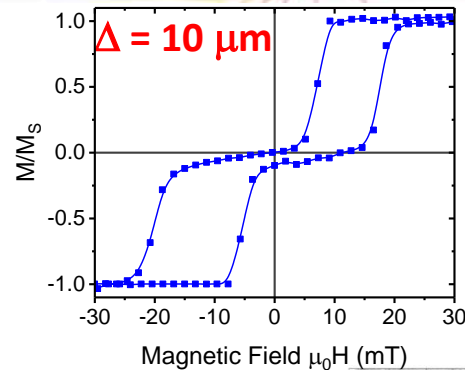
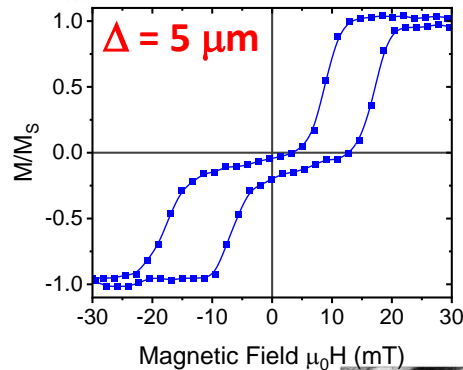
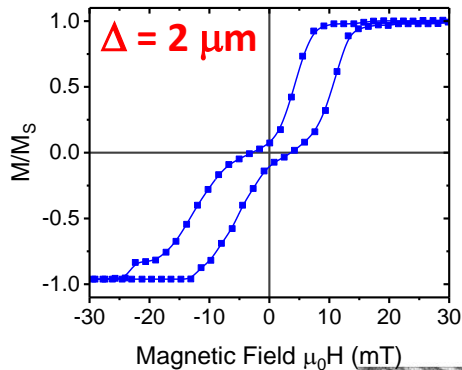
- D. Holzinger *et al.* *JAP* **114**, 013908 (2013).
- N. Zingsem *et al.* *J. Phys. D* **50**, 9 (2017).
- D. Mitin *et al.* *Nanotechnology* **29**, 7 (2018).
- T. Saerbeck *et al.* *Nanomaterials* **10**, 752 (2020).

28/03/2024

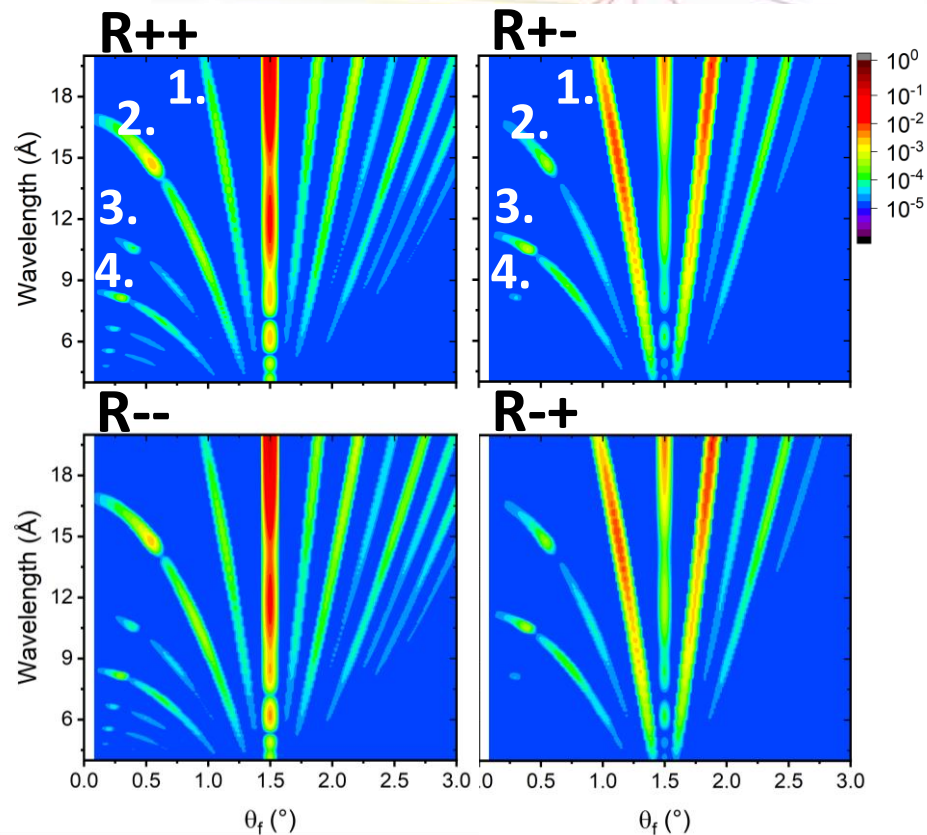
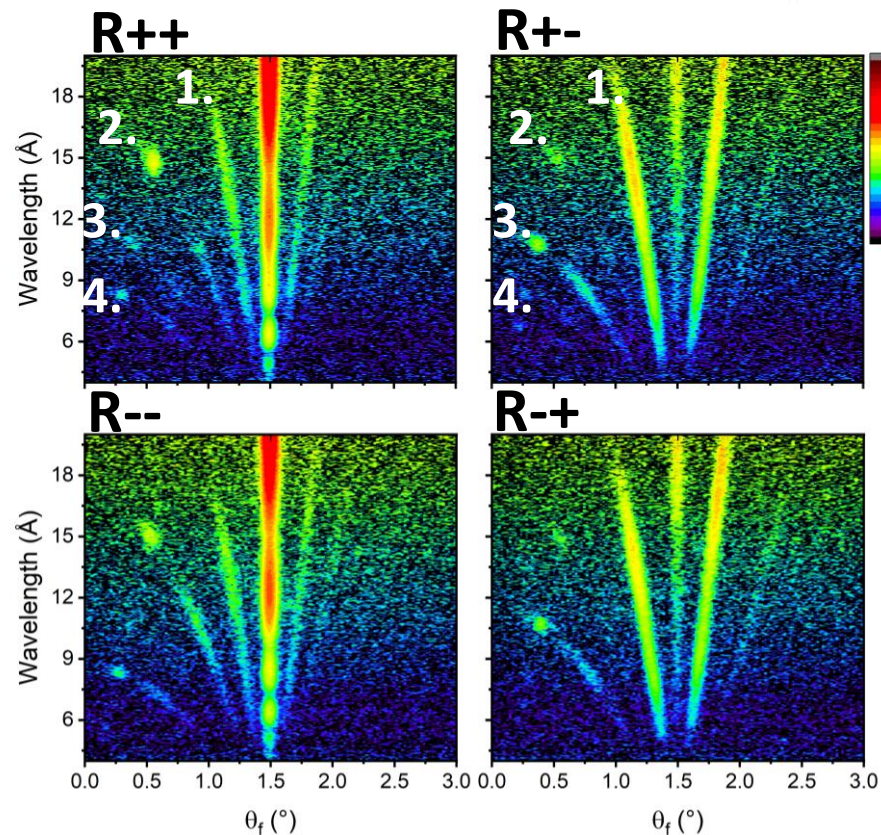
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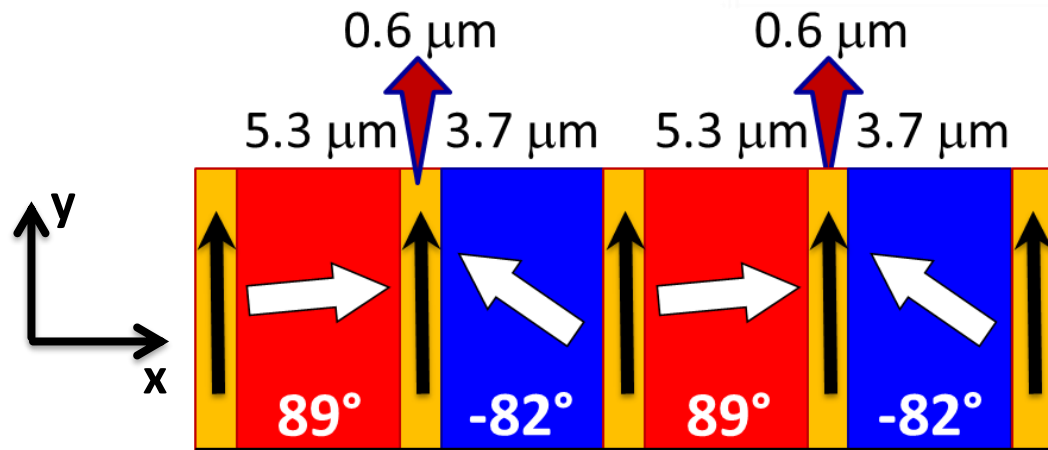
Size dependent off-specular scattering



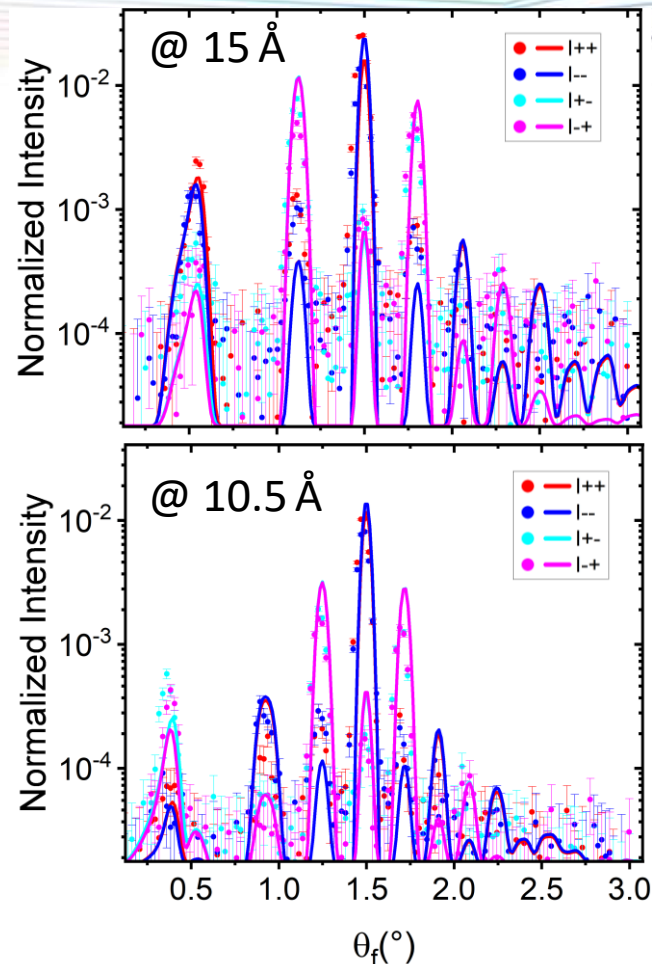
Full spin-resolved scattering simulation



Domain wall sensitivity

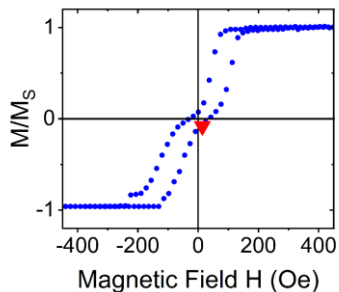
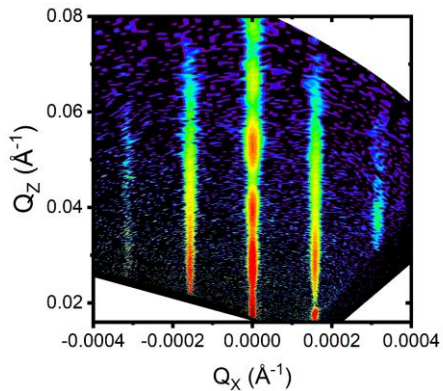


- Odd order: spin-flip dominated
- Even order: non-spin-flip dominated
- Spin-asymmetry in non-spin-flip and spin-flip
- Only reproduced with domain wall of
- ✓ precise width ($\pm 0.1 \mu\text{m}$)
- ✓ magnetization directions ($\pm 2^\circ$)

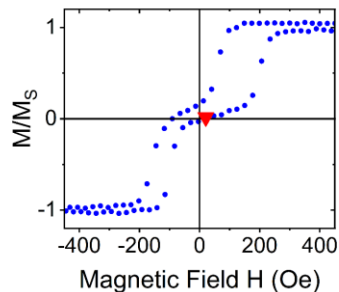
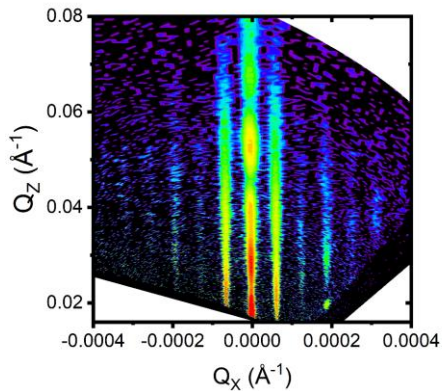


Hysteresis measurements

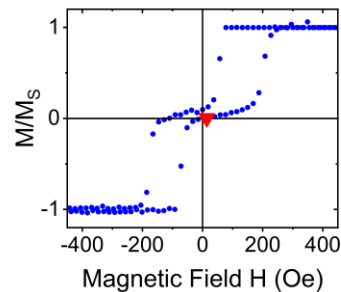
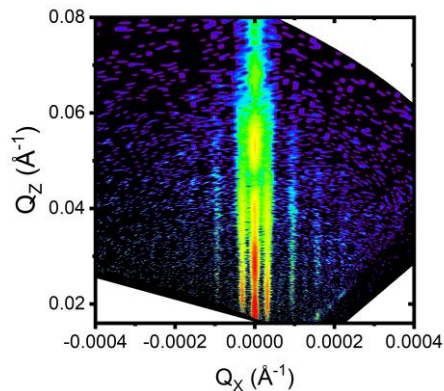
2 μm Domains



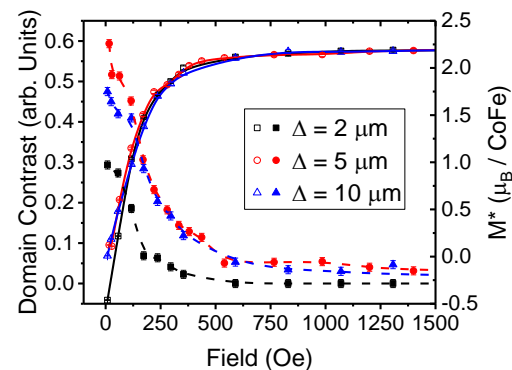
5 μm Domains



10 μm Domains

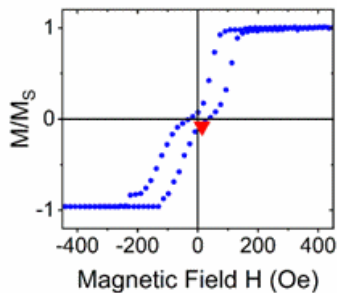
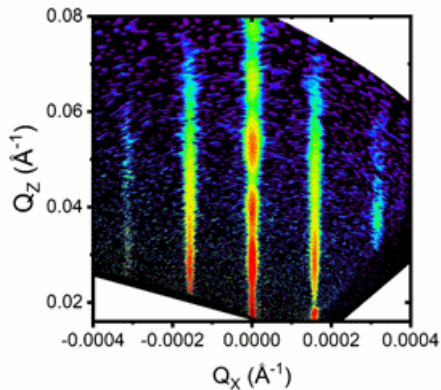


Field dependence

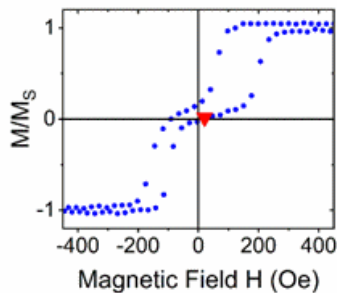
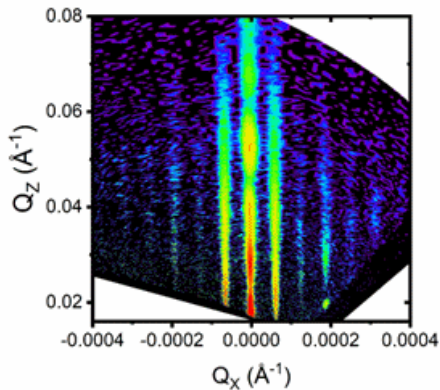


Hysteresis measurements

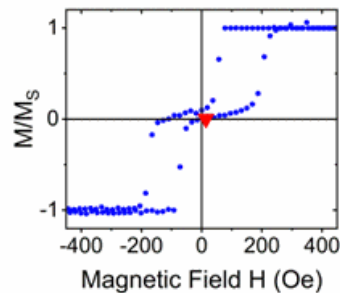
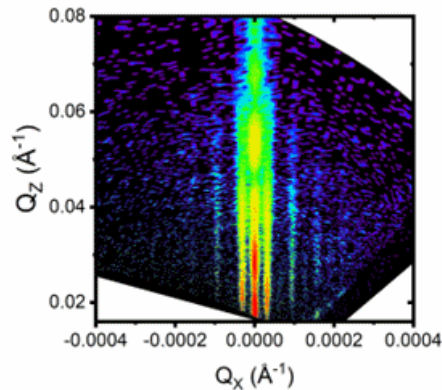
2 μm Domains



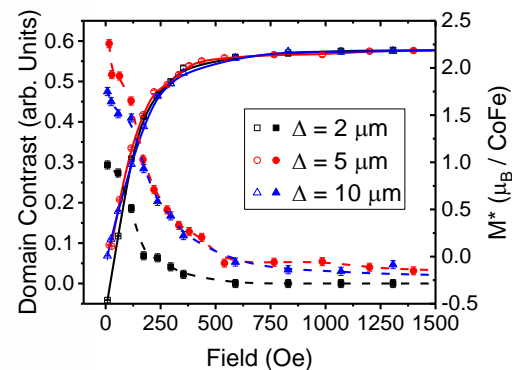
5 μm Domains



10 μm Domains



Field dependence



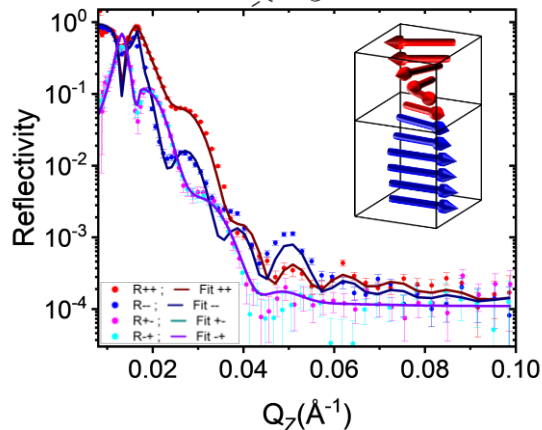
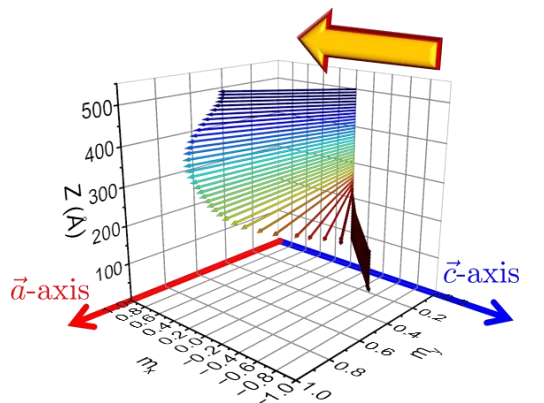
Summary

D17

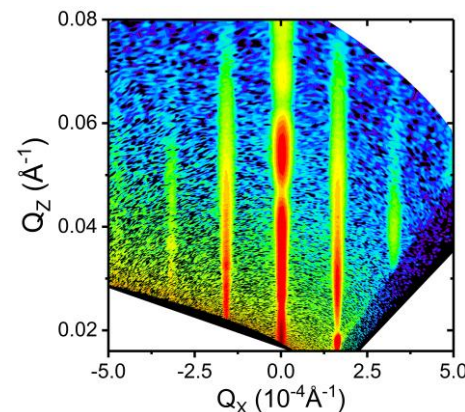
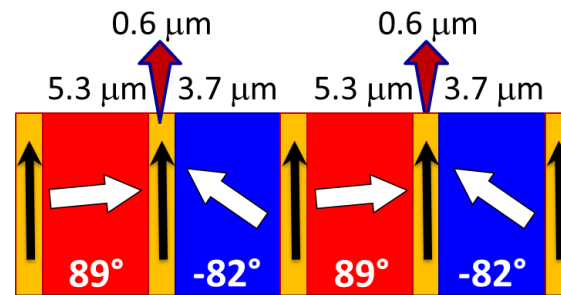
with upgrades:

- ✓ Diverse topics
- ✓ Fast measurements
- ✓ Adapted to experiment
- ✓ High sensitivity
- ... lower the background
- ... more to come ...

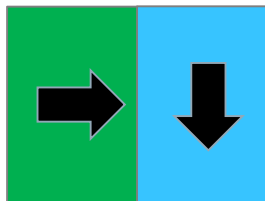
Magnetic depth profiles



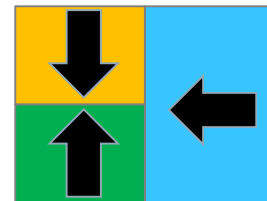
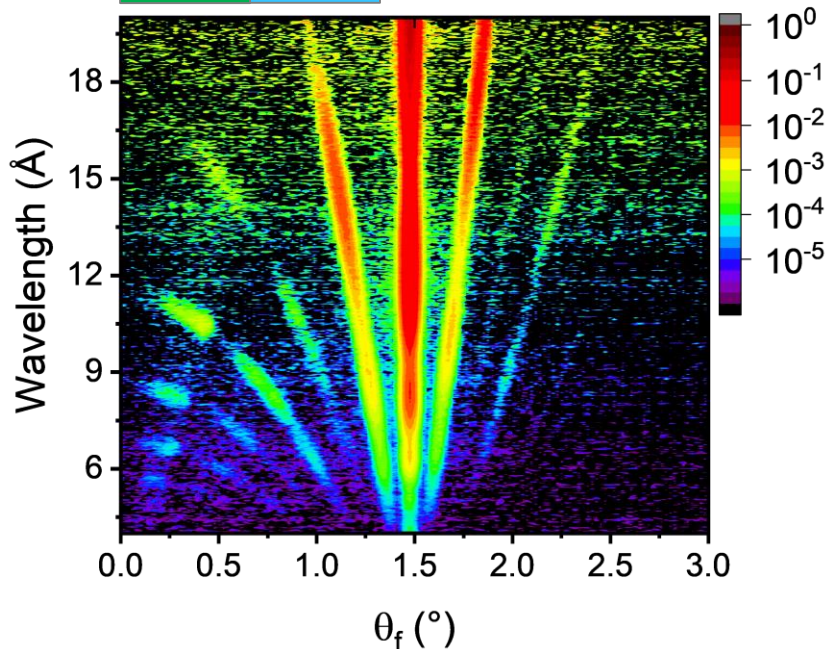
Magnetic domain textures



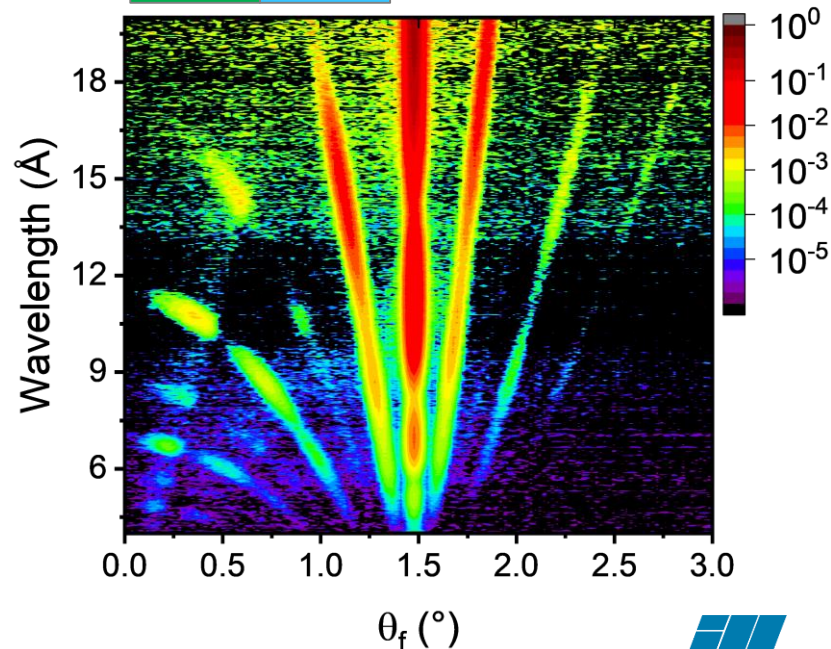
Mixing different domain orientations



90° walls



180° + 90° walls



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I N S T I T U T L A U E L A N G E V I N