TT 24.5 Statics and dynamics of complex magnetic states in microstructures

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Laboratoire Charles Coulomb
Team Solid-State Quantum Technologies (S2QT)

CNRS and Université de Montpellier, Montpellier, France

DPG Spring Meeting, March 10th 2026, Dresden

slides available at `https://magimag.eu`

Our team at L2C in Montpellier

https://solidstatequantumtech-l2c.fr/

SOLID STATE Quantum technologies

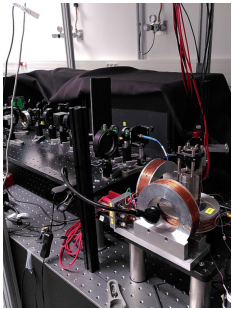
The scanning NV people

Roméo Beignon
Carolin Schrader
Elijah Wane
Priya Maurya

Vincent Jacques

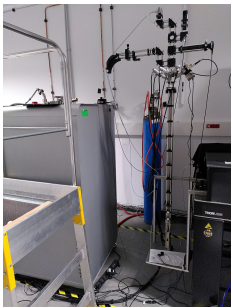
Our NV microscopes

Custom
Attocube based



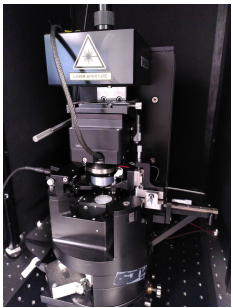
Room temperature
Easy to modify

Custom
Attocube based, 4 K



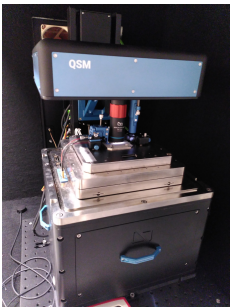
Low temperature
0.5 T vectorial $\vec{B}$ field

ProteusQ
Qnami



Room temperature
Easy to use, good AFM

QSM
Qzabre

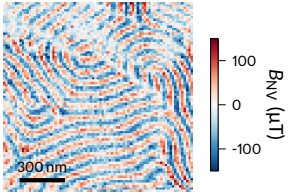


Room temperature
80 mT vectorial $\vec{B}$ field

We are always happy to collaborate!

Our research topics

Antiferromagnets



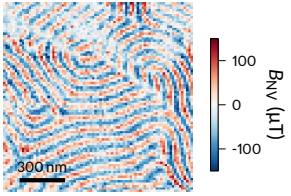
A. Finco and V. Jacques. *APL Mater.* 11 (2023), 100901

A. Finco *et al.* *PRL* 128 (2022), 187201

A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

Our research topics

Antiferromagnets



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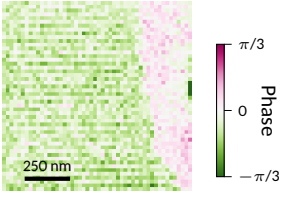
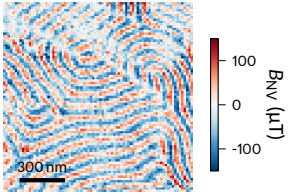
A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

Towards electrometry



Our research topics

Antiferromagnets



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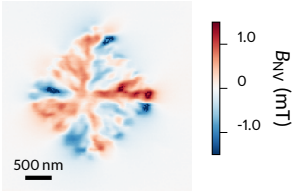
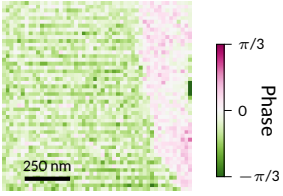
A. Finco *et al.* *PRL* 128 (2022), 187201
A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

2D magnets



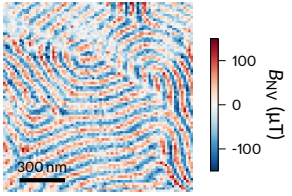
F. Fabre *et al.* *Phys. Rev. Mater.* 5 (2021), 034008
E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

Towards electrometry



Our research topics

Antiferromagnets



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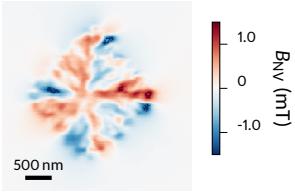

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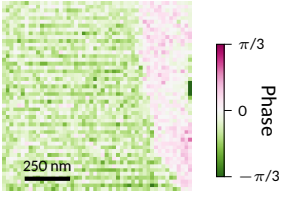
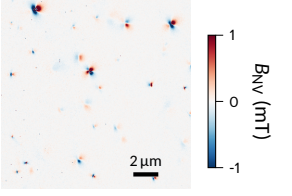


Paleomagnetism



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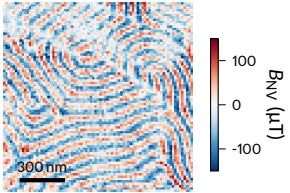

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A. Finco *et al.* *PRL* 128 (2022), 187201
A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

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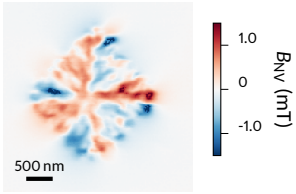
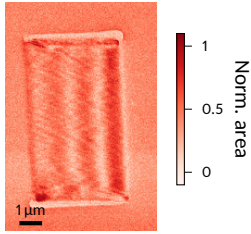


F. Fabre *et al.* *Phys. Rev. Mater.* 5 (2021), 034008
E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

Spin wave mapping



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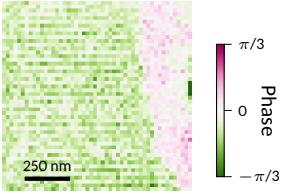

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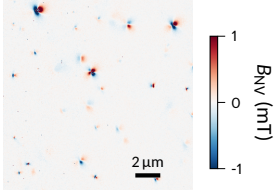

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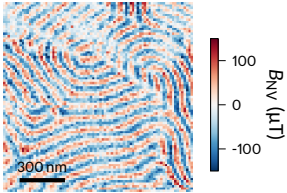
Antiferromagnets



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A. Finco *et al.* *PRL* 128 (2022), 187201
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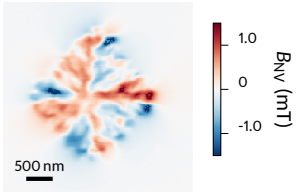

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E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

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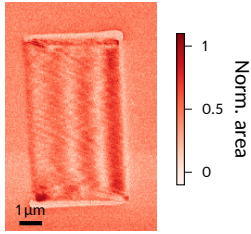
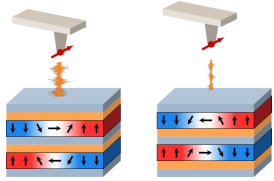
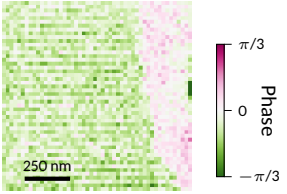


Relaxometry



M. Rollo *et al.* *Phys. Rev. B* 103 (2021), 235418
A. Finco *et al.* *Nat. Commun.* 12 (2021), 767
A. Finco *et al.* *PRL* 135 (2025), 136703

Towards electrometry



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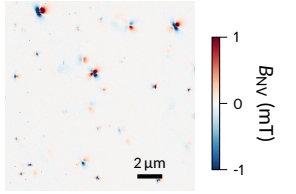
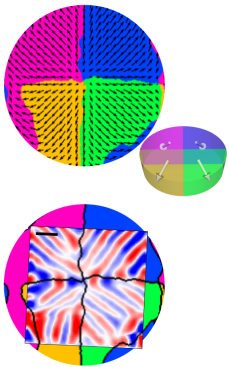


Outline

Multiferroic solitons in $BiFeO_3$



laboratoire
Albert Fert

A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

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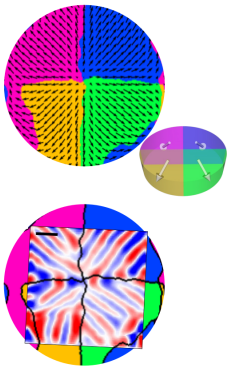

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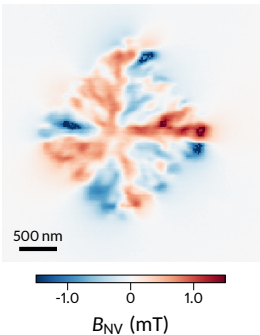
Room temperature vortices in a 2D ferromagnet



E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

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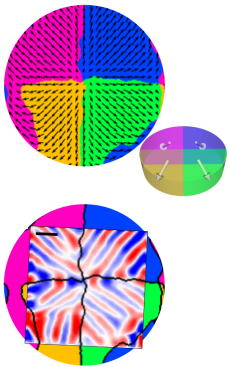

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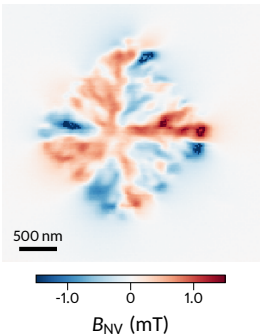
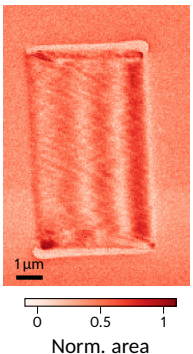


E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

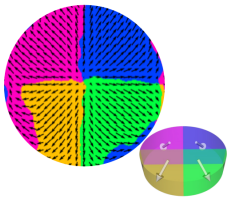
Imaging of spin waves

Roméo Beignon
MA 59.7, Fri 11:15



Outline

Multiferroic solitons in $BiFeO_3$



laboratoire Albert Fert

A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

Room temperature vortices in a 2D ferromagnet

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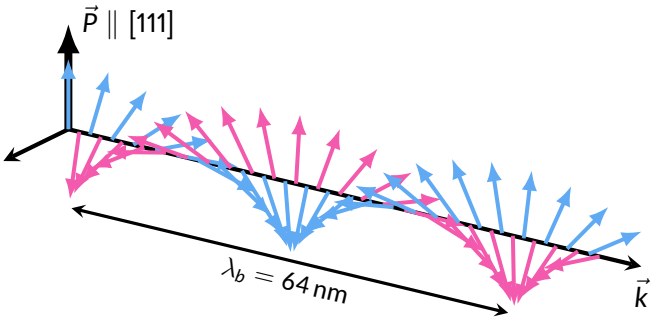
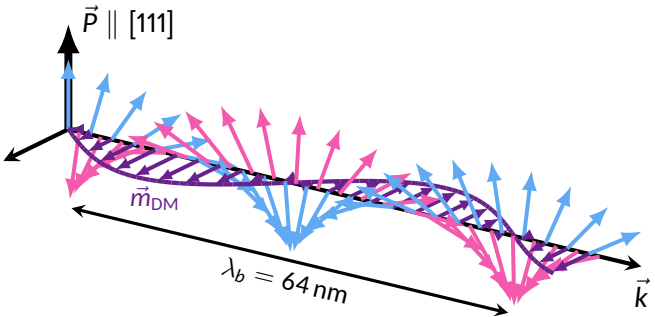
Magnetoelectric coupling in $BiFeO_3$

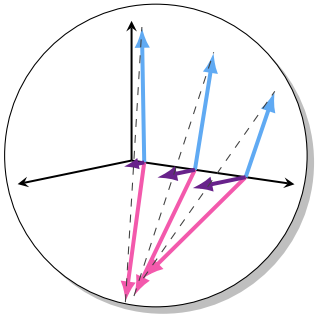


Fully compensated cycloid

→ **No stray field!**

Magnetoelectric coupling in $BiFeO_3$

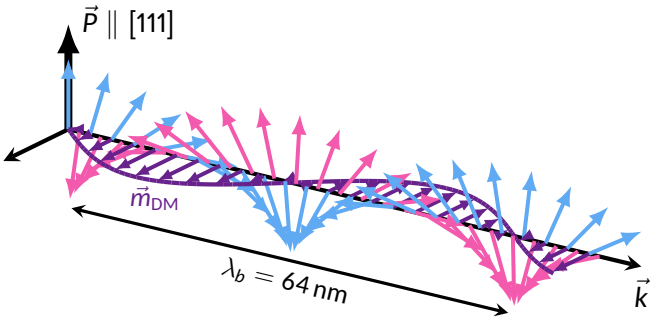




Spin density wave
Weak uncompensated moment
→ **Small stray field**

M. Ramazanoglu *et al.* *PRL* 107 (2011), 207206

Magnetoelectric coupling in $BiFeO_3$



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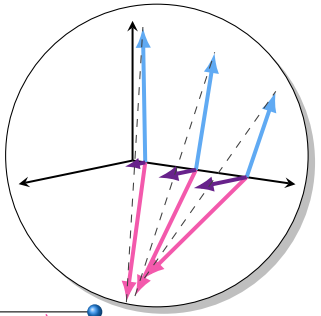


Cycloid wavevector $\vec{k}$ along one of the marked directions in the (111) plane.

M. Ramazanoglu *et al.* *PRL* 107 (2011), 207206

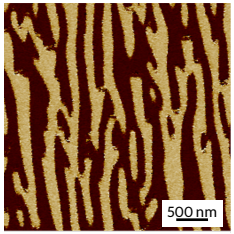
Strained $BiFeO_3$ films

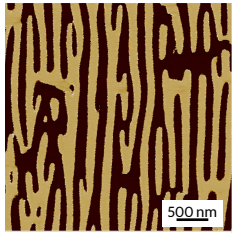
Substrate $DyScO_3$

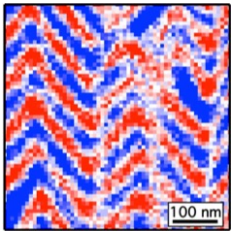
Substrate $SmScO_3$

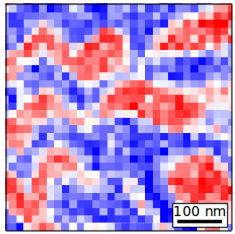
Ferroelectric state

Antiferromagnetic state









Strain -0.35%

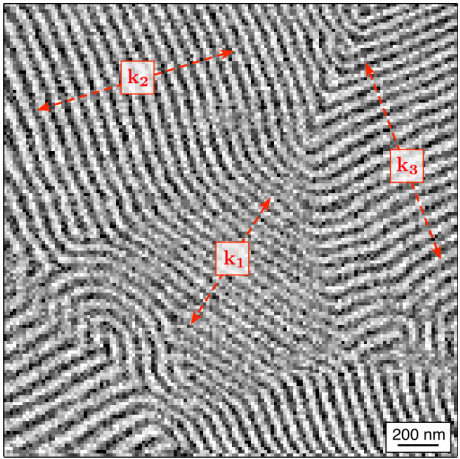
Strain +0.50%

The cycloid can be destabilized by strain. We can control this with the growth substrate in thin films.

Samples from laboratoire Albert Fert

A. Haykal *et al.* *Nat. Commun.* 11 (2020), 1704

$\vec{k}$ rotates freely at the surface of a bulk crystal



A. Finco *et al.* *PRL* 128 (2022), 187201

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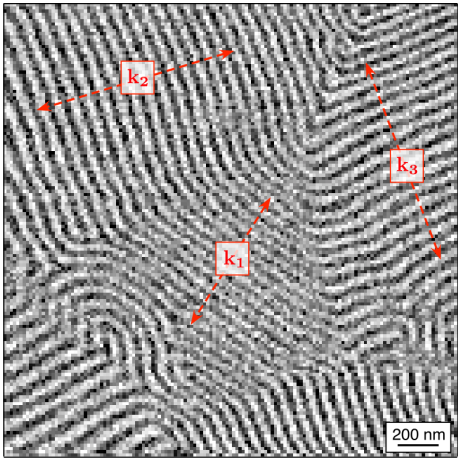
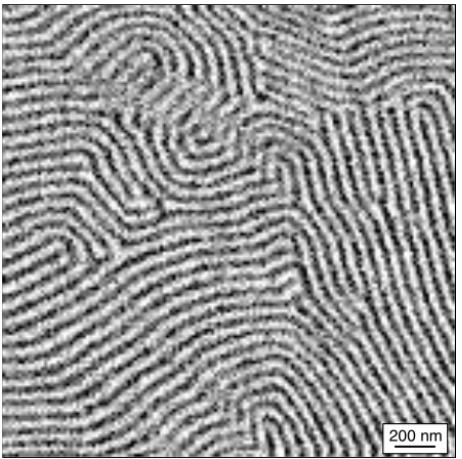




−1 0 1

iso-B signal

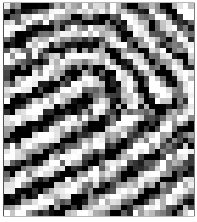
−1 0 1

iso-B signal

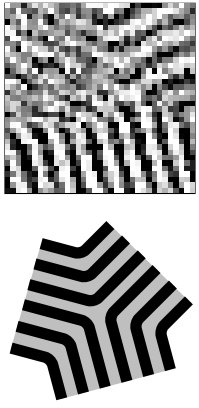
A. Finco *et al.* *PRL* 128 (2022), 187201

Topological defects in bulk $BiFeO_3$

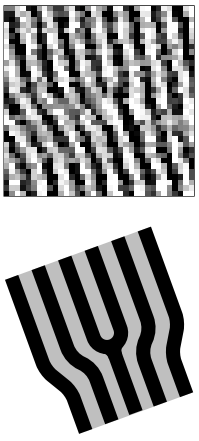
$+\pi$-disclination



$-\pi$-disclination



Edge dislocation



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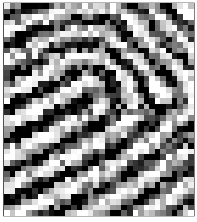
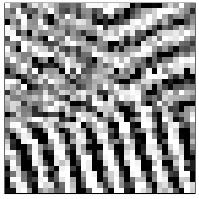
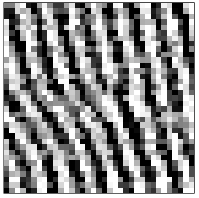
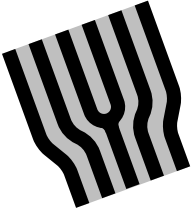


$-\pi$-disclination



Edge dislocation



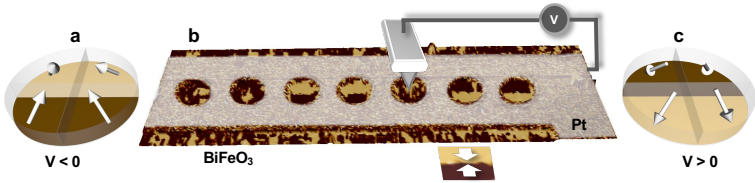


Perspective: electrical control?

A. Finco *et al.* *PRL* 128 (2022), 187201

Towards topological multiferroic textures

Use magnetoelectric coupling to stabilize an antiferromagnetic topological state



laboratoire Albert Fert

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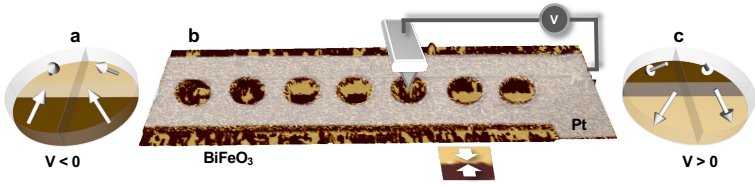

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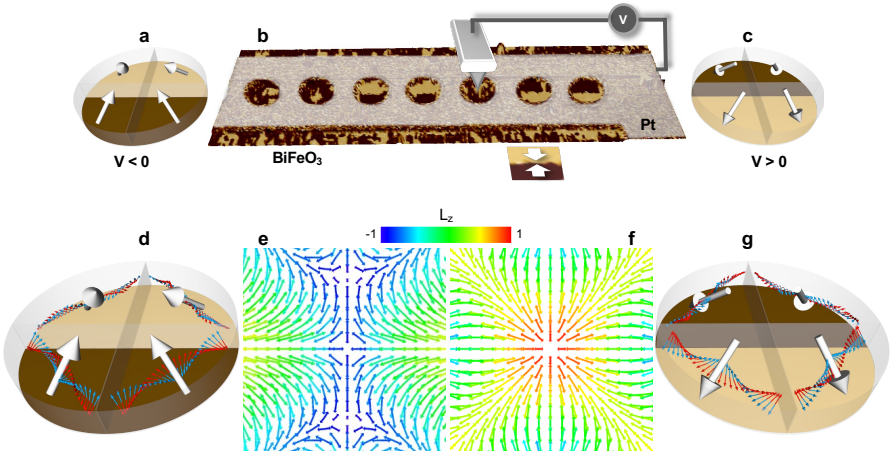

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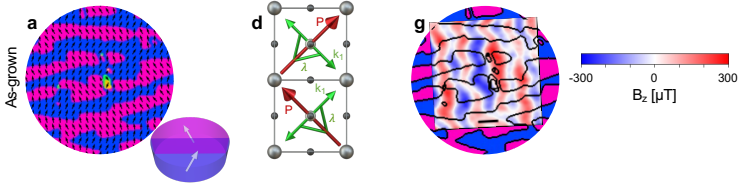
Cycloid flux closure



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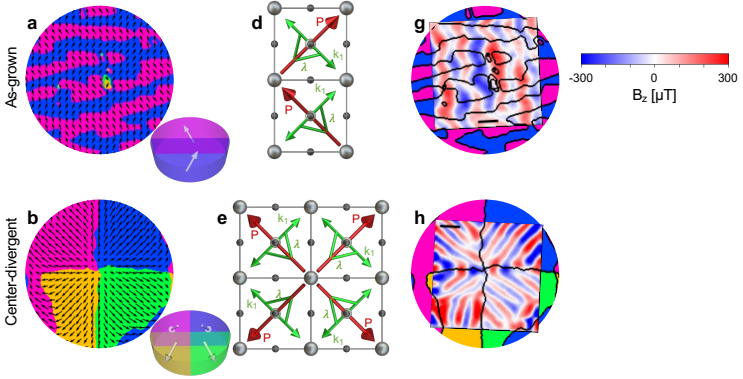

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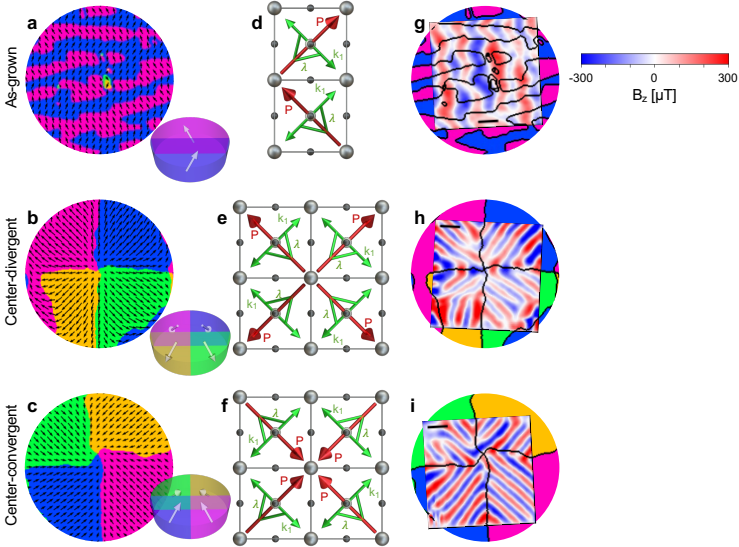

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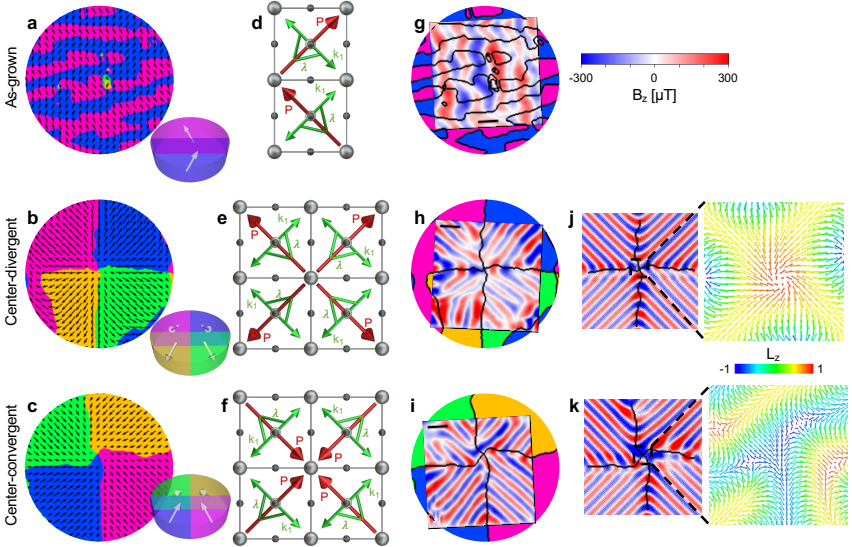

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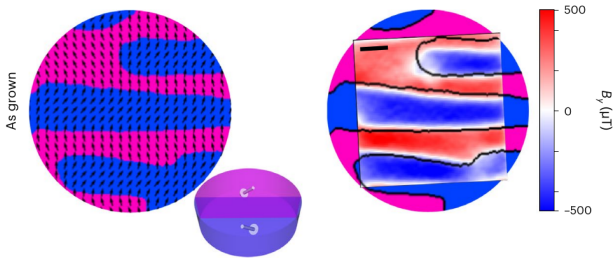
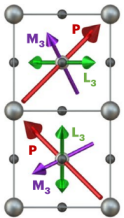
In a strained film

laboratoire
Albert Fert





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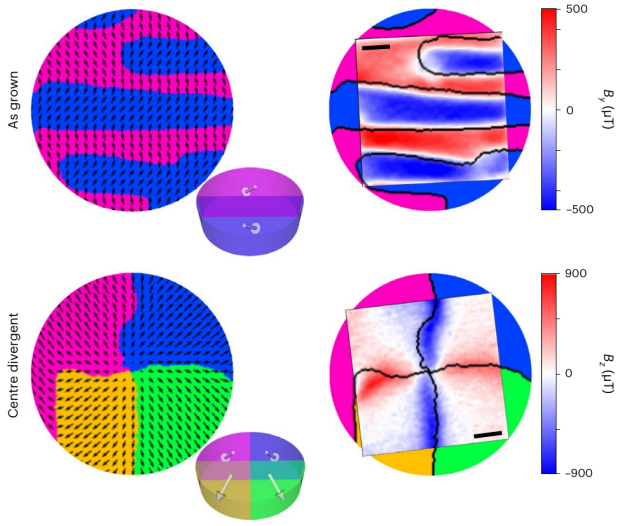
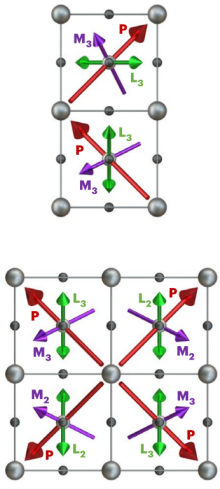
laboratoire Albert Fert





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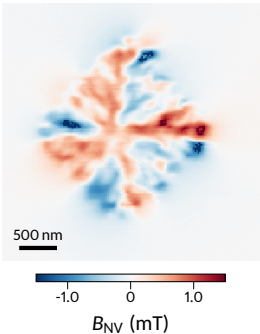

E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

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Roméo Beignon
MA 59.7, Fri 11:15

How to enhance T_C in van der Waals magnets?

Example: Fe_3GeTe_2, a ferromagnet with $T_C \simeq 230\,\mathrm{K}$ (bulk)

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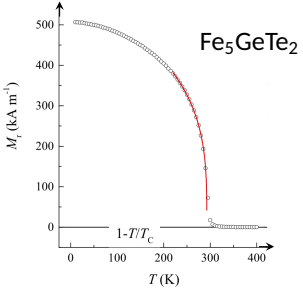

A. F. May *et al.* *ACS Nano* 13 (2019), 4436

M. Ribeiro *et al.* *npj 2D Mater. Appl.* 6 (2022), 10

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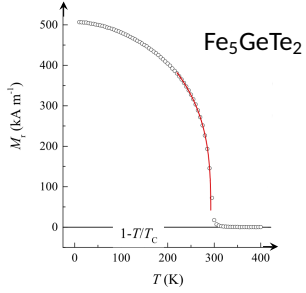

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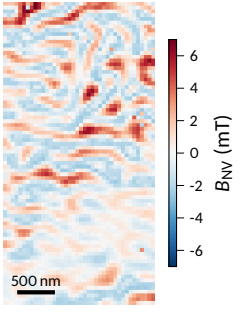
Ge → Ga



Y. Yuan *et al.* *APL Mater.* 11 (2023), 091101
C. Zhang *et al.* *Nat. Commun.* 15 (2024), 4472

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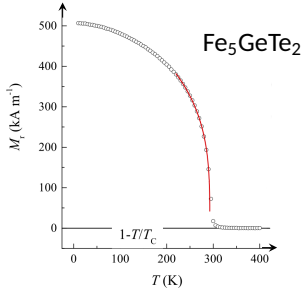

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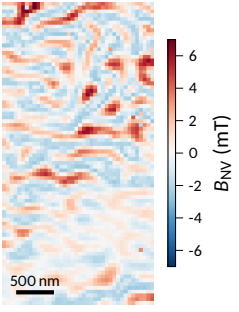
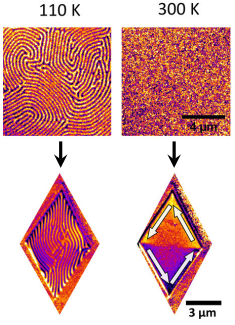


Y. Yuan *et al.* *APL Mater.* 11 (2023), 091101

C. Zhang *et al.* *Nat. Commun.* 15 (2024), 4472

Patterning?



Q. Li *et al.* *Nano Lett.* 18 (2018), 5974

Our Fe_5GeTe_2 sample

11.8 nm-thick film grown by MBE with 3 nm-thick Al capping

M. Ribeiro *et al.* *npj 2D Mater. Appl.* 6 (2022), 10

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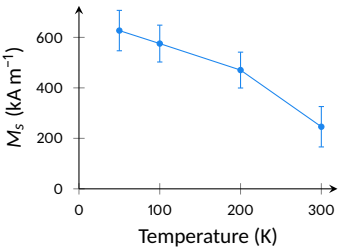
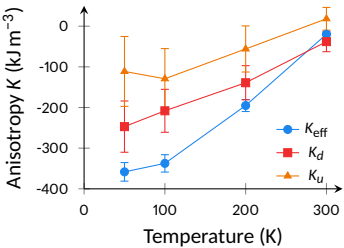
Macroscopic characterization





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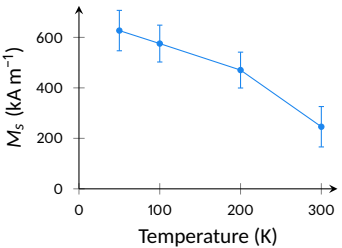
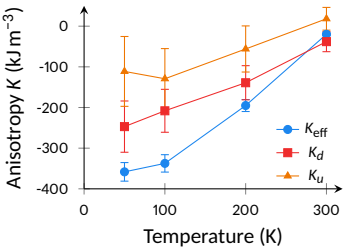
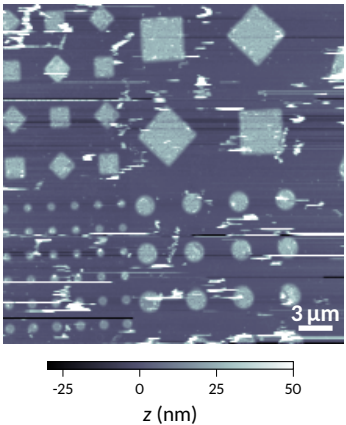
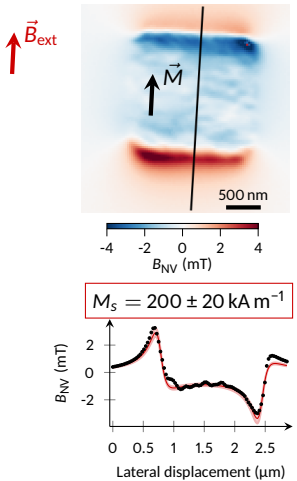




AFM scan



Saturation magnetization in various rectangles



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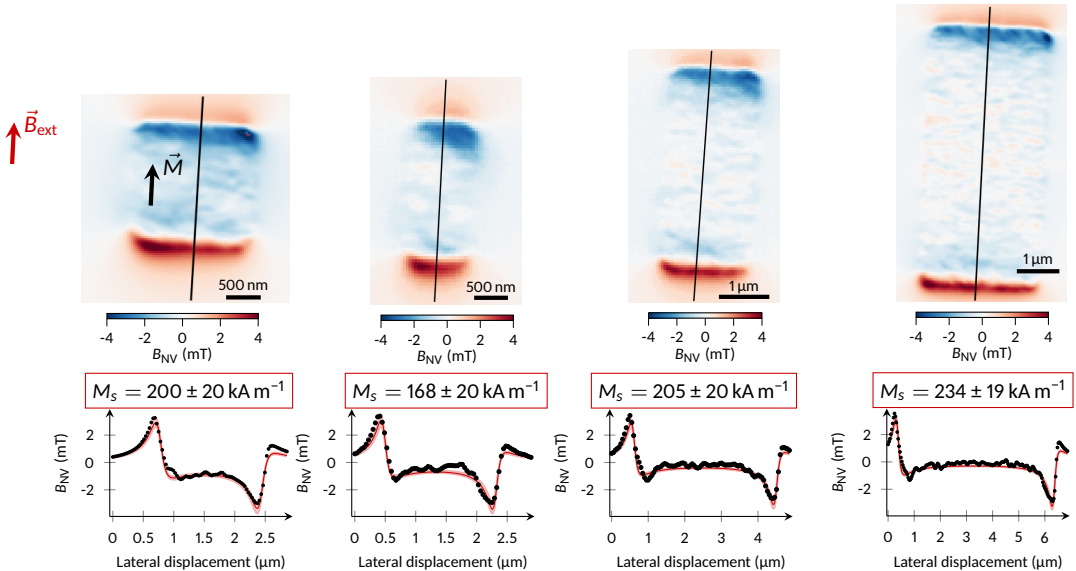

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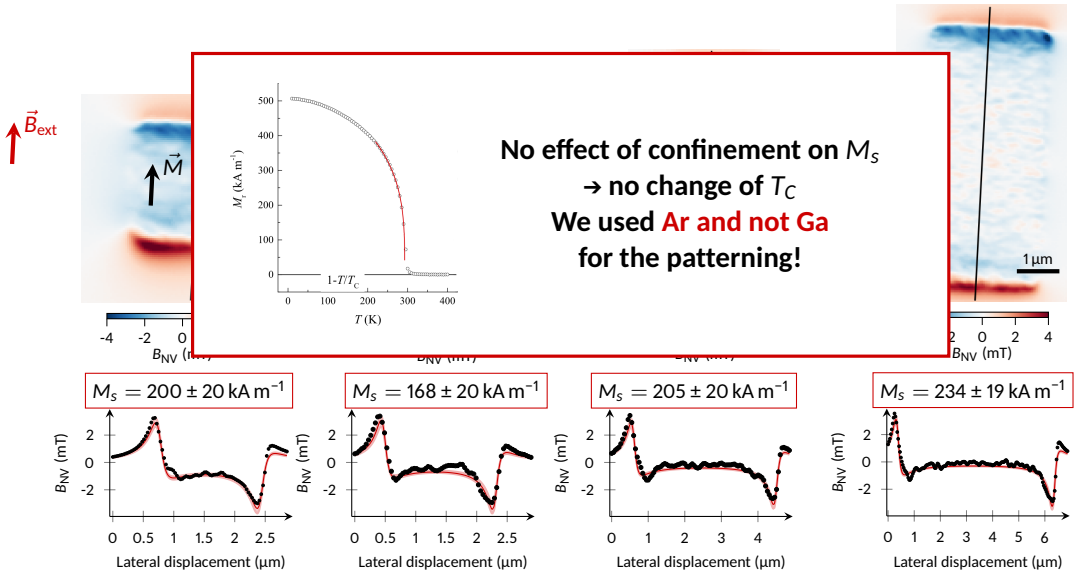
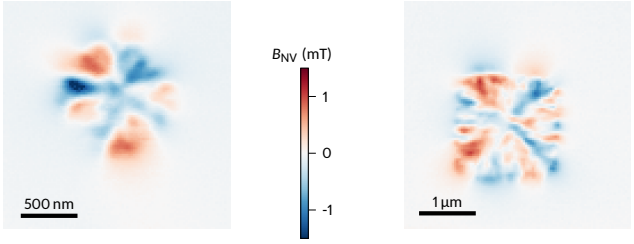


Vortices in micro-squares



’Flower’ stray field pattern typical of vortices in squares

E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

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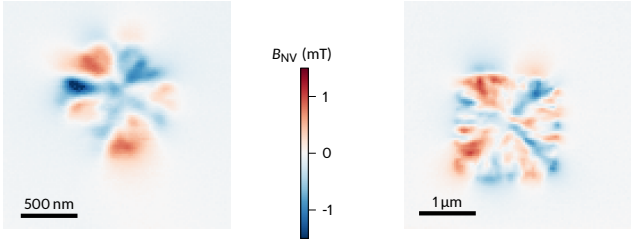

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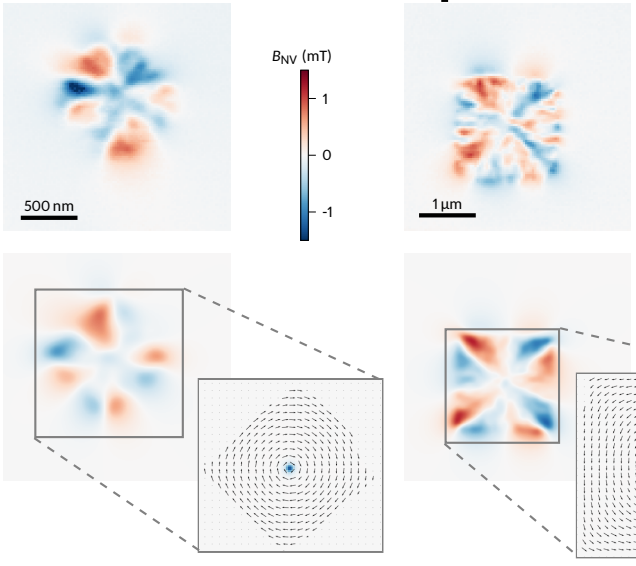

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Micromagnetic simulations including M_s disorder

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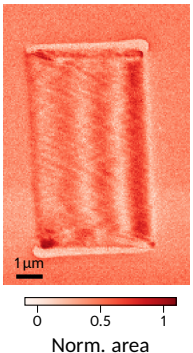
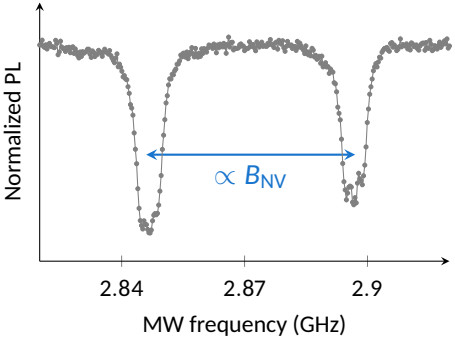


Imaging of spin waves with NV microscopy

The stray field from **resonant** spin waves can drive the NV spin transition



Shift ➔ Static stray field

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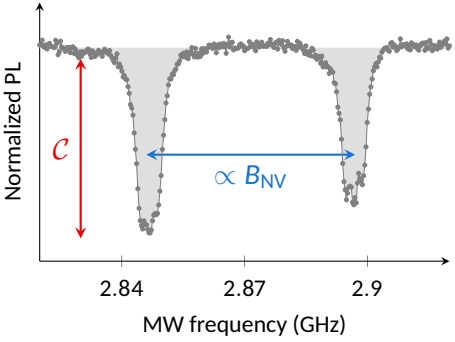

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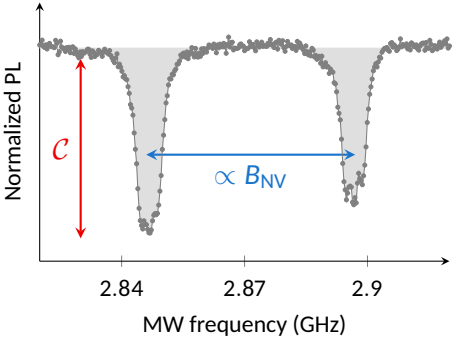

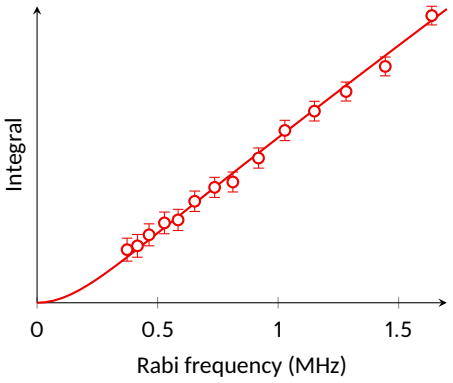

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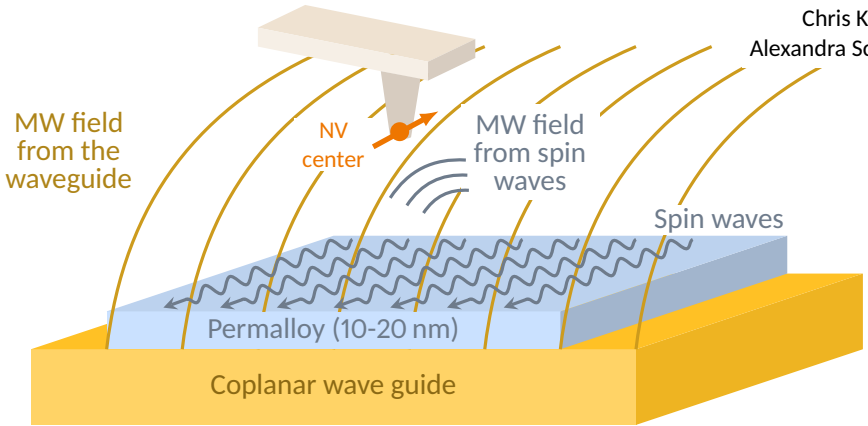
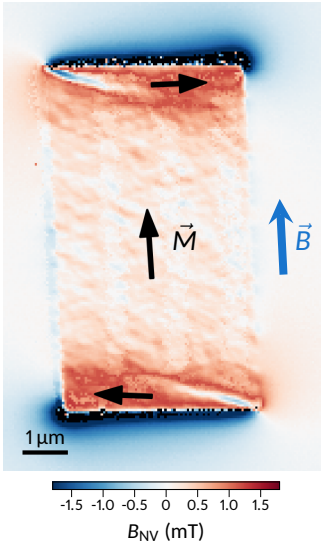
Experiments on Py microstructures

Interference between the microwave field from the antenna and the microwave field from the excited spin waves

Martin-Luther-Universität Halle-Wittenberg
Chris Körner, Rouven Dreyer
Alexandra Schrader, Georg Woltersdorf



Imaging propagating spin waves



Excitation at 2.87 GHz

$B = 1.4$ mT

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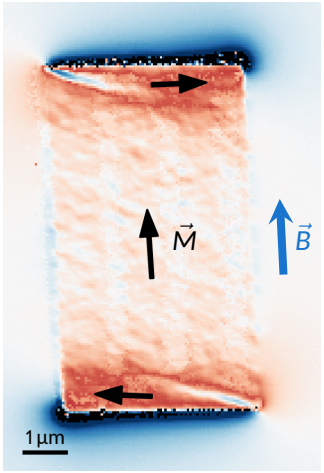

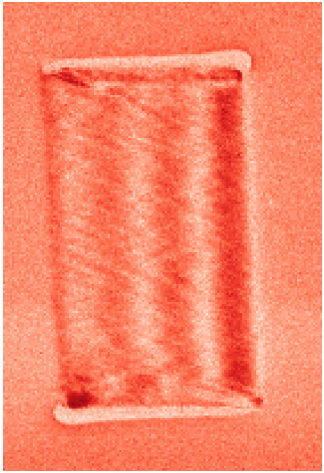

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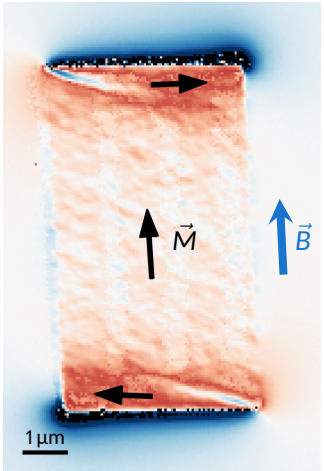

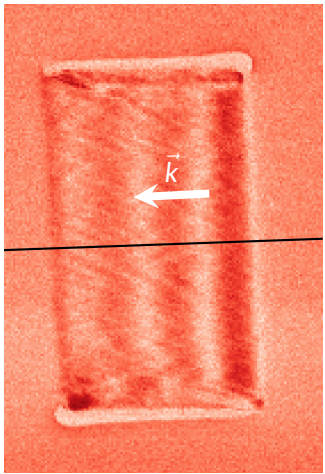

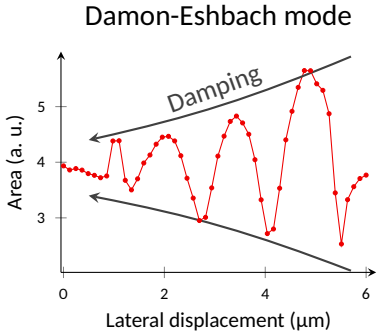

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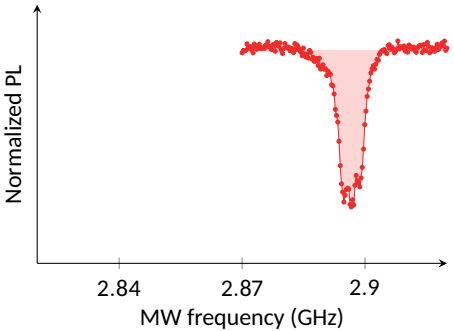

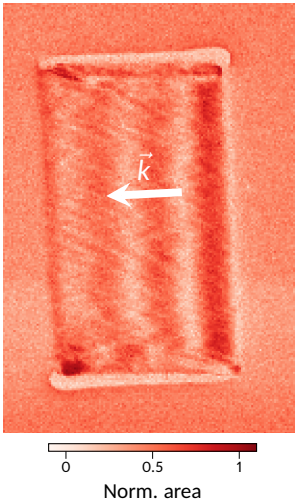

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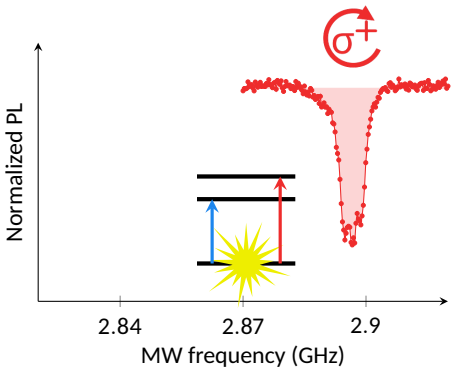
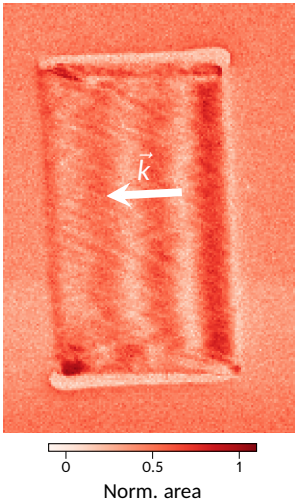
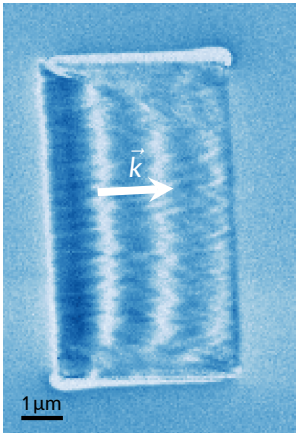
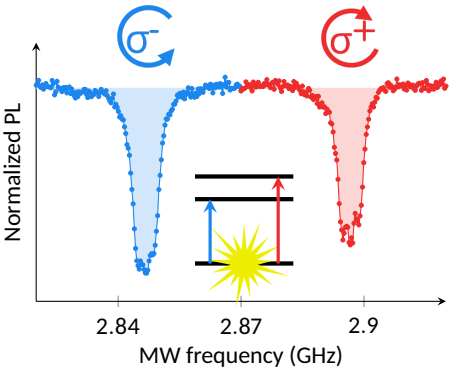
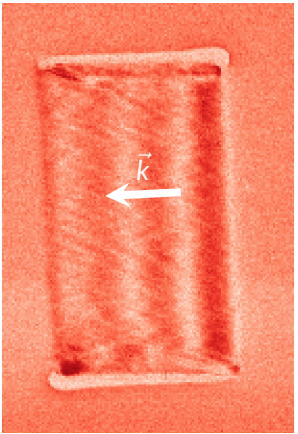




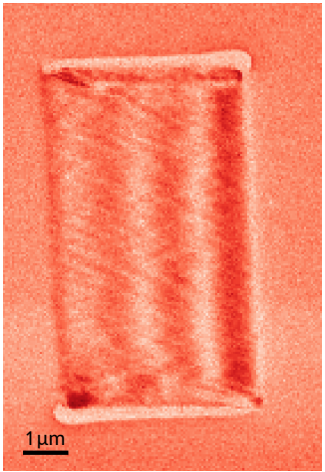
Where is the opposite $\vec{k}$?

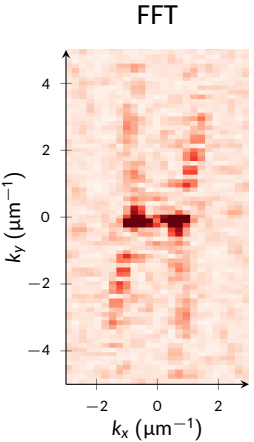




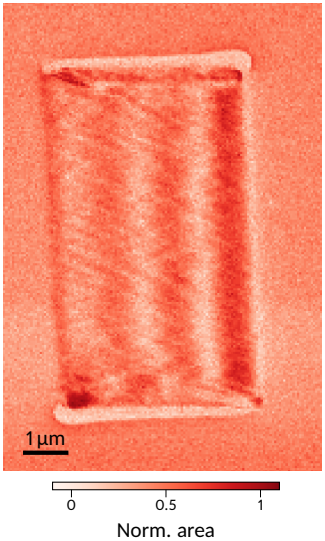


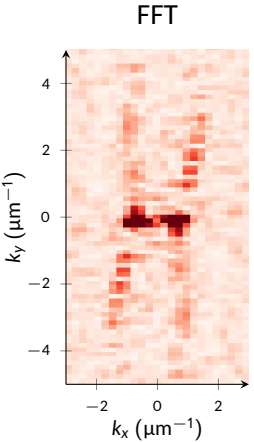
The “noise” pattern reveals the dispersion relation

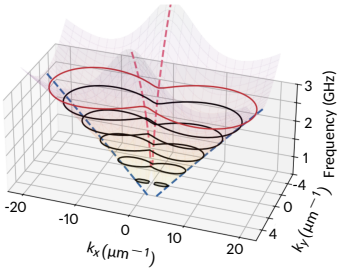




The “noise” pattern reveals the dispersion relation

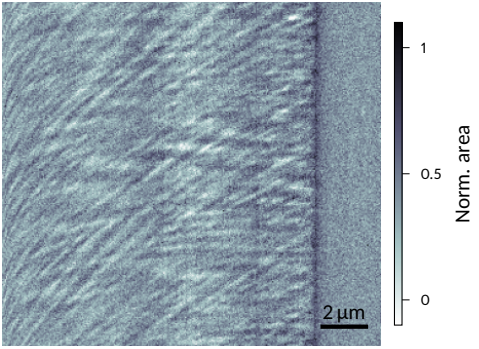


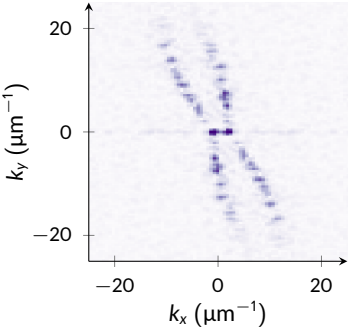




The dispersion does not fit!

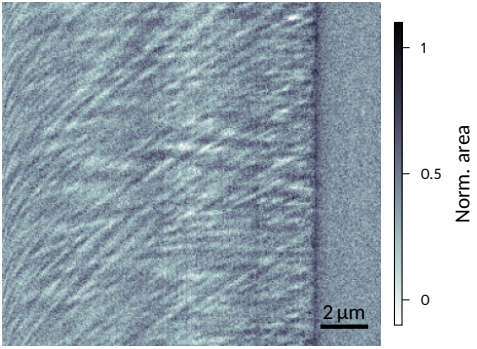
Permalloy film, 20 nm-thick, $B_{\text{ext}} = 1.4\,\text{mT}$

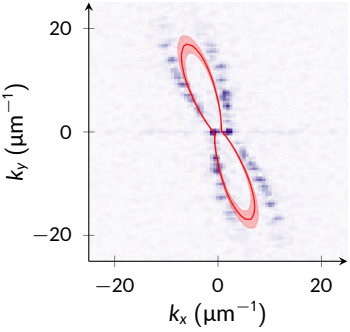




The dispersion does not fit!

Permalloy film, 20 nm-thick, $B_{ext} = 1.4$ mT



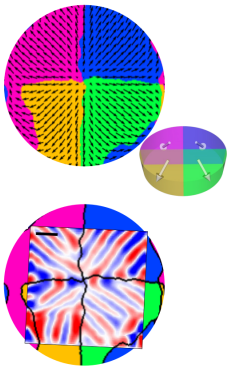


There is a non-linear phenomenon happening

➔ More insights: Roméo's talk MA 59.7, Friday 11:15

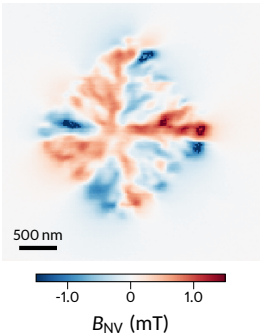
Summary

Multiferroic solitons in $BiFeO_3$



A. Chaudron *et al.* *Nat. Mater.* 23 (2024), 905

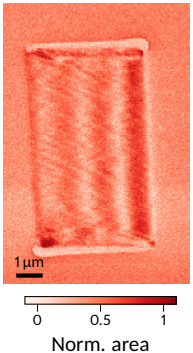
Room temperature vortices in a 2D ferromagnet



E. Sfeir *et al.* *PRMaterials* 9 (2025), 114003

Imaging of spin waves

Roméo Beignon
MA 59.7, Fri 11:15



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