Imaging antiferromagnetic textures with NV-center microscopy

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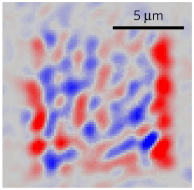
QUOROM 4, June 24th 2021

slides available at https://magimag.eu

Techniques to image antiferromagnets

SHG



J.-Y. Chauleau *et al.* *Nat. Mat.* 16 (2017), 803

Techniques to image antiferromagnets

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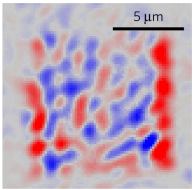
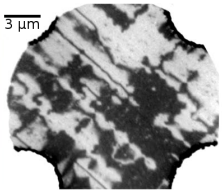


XMLD-PEEM



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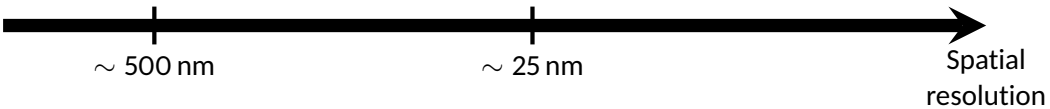
P. Wadley *et al.* *Nat. Nano.* 13 (2018), 362



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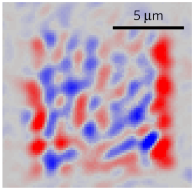

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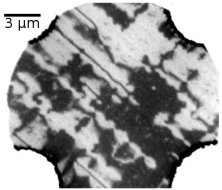
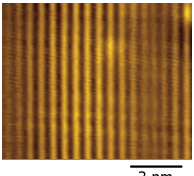
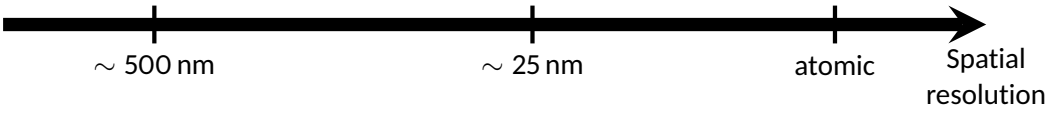


P. Wadley *et al.* *Nat. Nano.* 13 (2018), 362

SP-STM



M. Bode *et al.* *Nature* 447 (2007), 190



Techniques to image antiferromagnets

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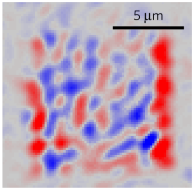

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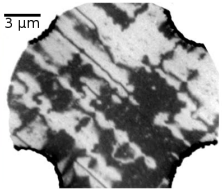

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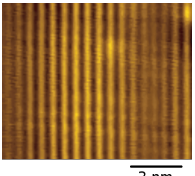
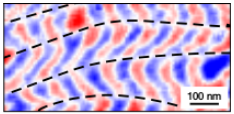


M. Bode *et al.* *Nature* 447 (2007), 190

~ 50 nm

~ 500 nm



~ 25 nm

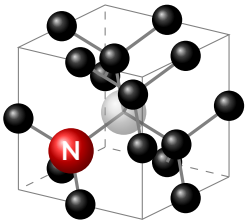
atomic

Spatial resolution

NV magnetometry

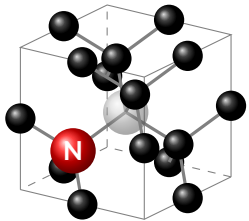
I. Gross *et al.* *Nature* 549 (2017), 252

NV centers to measure magnetic fields



Defect in diamond

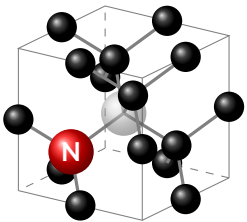
NV centers to measure magnetic fields



Defect in diamond

- Optical manipulation and reading
- Ambient conditions

NV centers to measure magnetic fields



Defect in diamond

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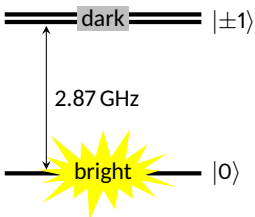
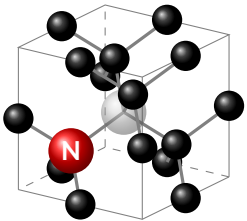
Spin-dependent fluorescence



NV ground state
spin $S = 1$

NV centers to measure magnetic fields



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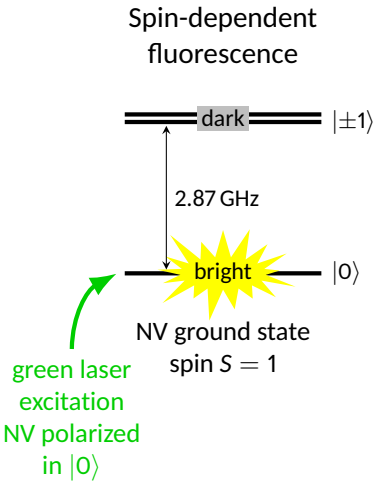
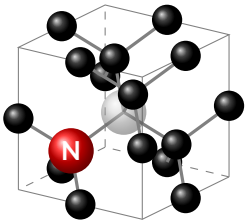


NV centers to measure magnetic fields



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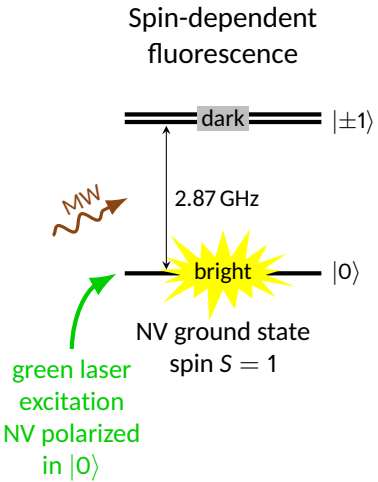
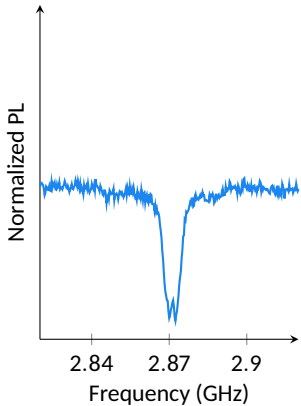
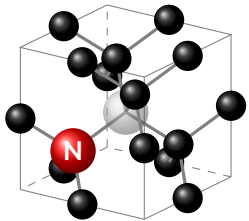




NV centers to measure magnetic fields



Defect in diamond

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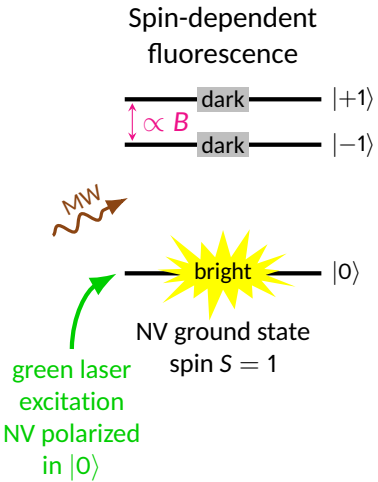

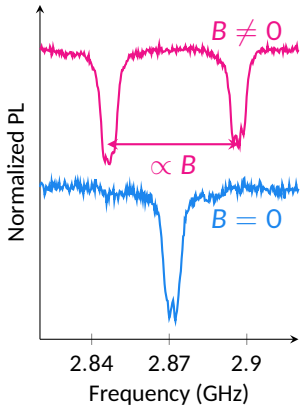

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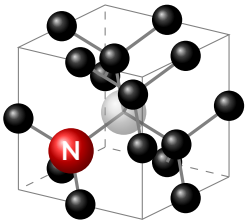

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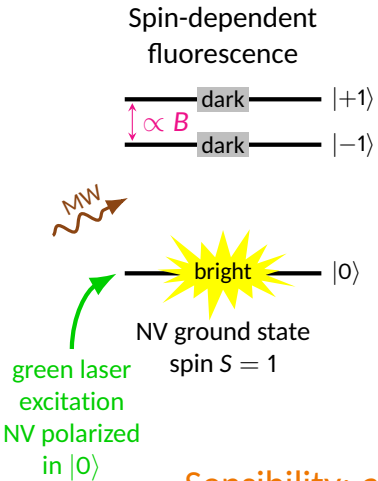
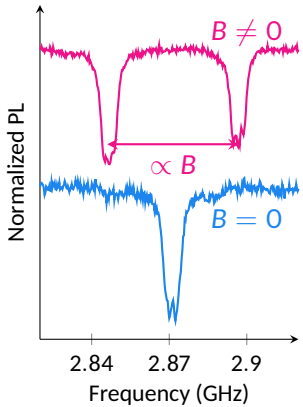
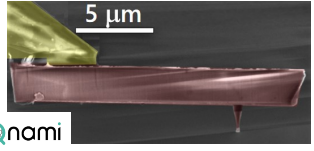




Sensibility: a few $\mu T/\sqrt{Hz}$

Quantitative scanning NV magnetometry on antiferromagnets

Diamond
AFM tip



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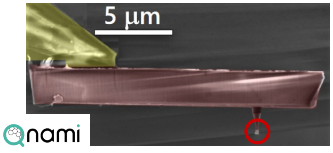
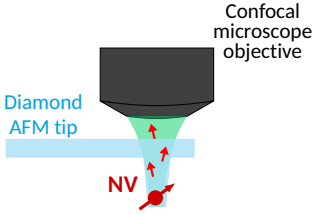
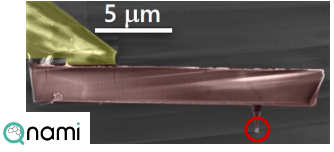


Implanted single
NV center

Quantitative scanning NV magnetometry on antiferromagnets





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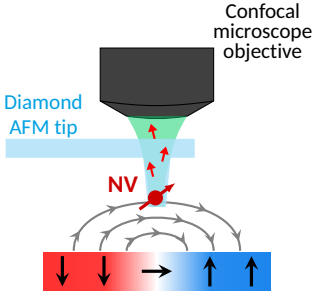

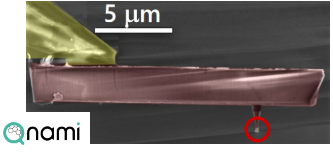

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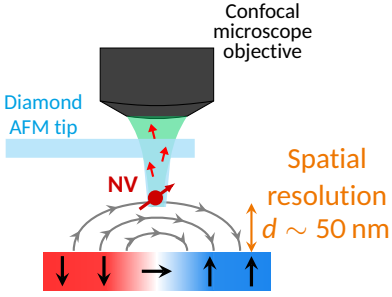
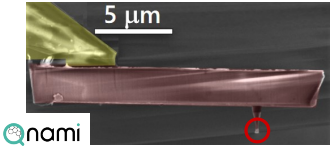
Quantitative scanning NV magnetometry on antiferromagnets





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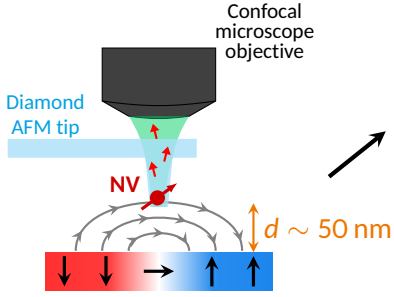
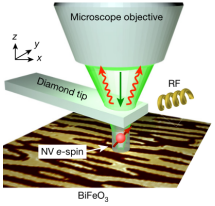
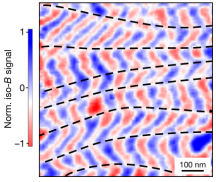


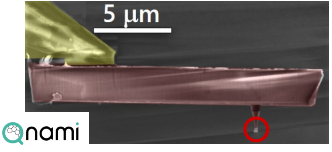
$BiFeO_3$: a room-temperature multiferroic





I. Gross *et al.* *Nature* 549 (2017), 252

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



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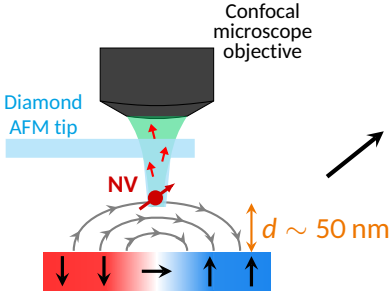

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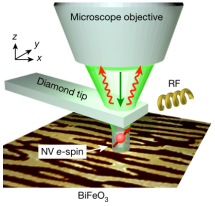

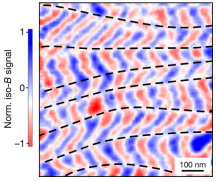

← ferroelectric DW

I. Gross *et al.* *Nature* 549 (2017), 252

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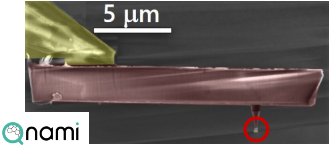

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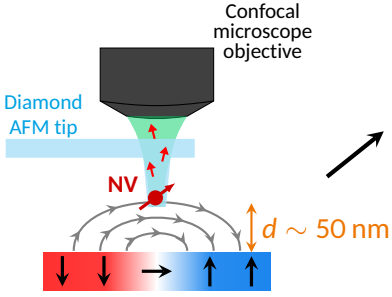
Quantitative scanning NV magnetometry on antiferromagnets



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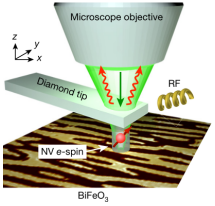
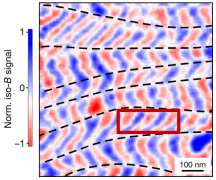


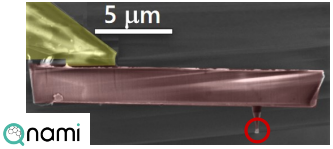


← ferroelectric DW

Cycloidal modulation of the AFM order

I. Gross *et al.* *Nature* 549 (2017), 252

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



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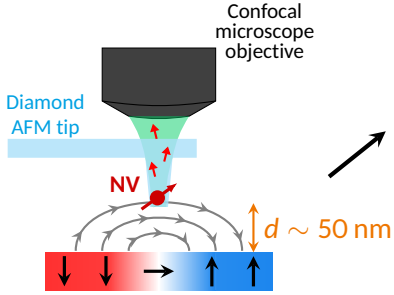

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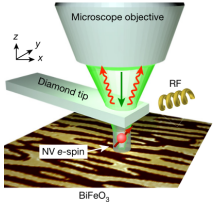

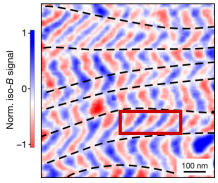

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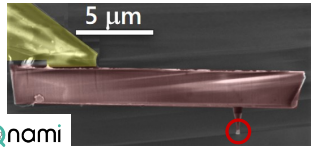
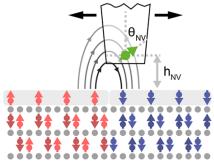
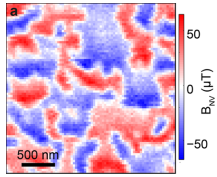


Implanted single NV center

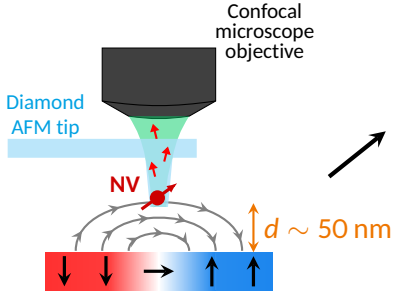
Cr_2O_3: a layered antiferromagnet



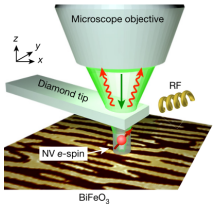


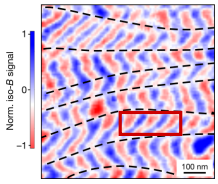
P. Appel *et al.* *Nano Lett.* 19 (2019), 1682

Quantitative scanning NV magnetometry on antiferromagnets



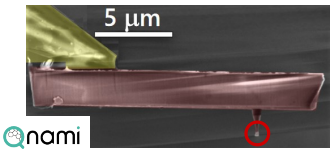
$BiFeO_3$: a room-temperature multiferroic





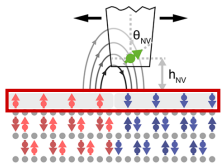
I. Gross *et al.* *Nature* 549 (2017), 252

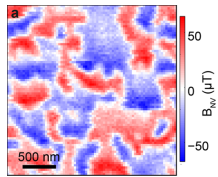
A. Haykal *et al.* *Nat. Comm.* 11 (2020), 1704



Implanted single NV center

Cr_2O_3: a layered antiferromagnet





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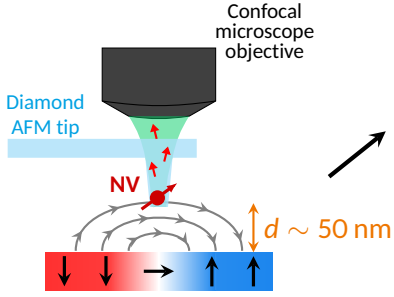

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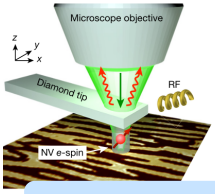
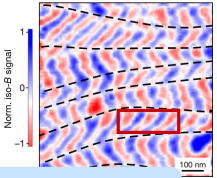




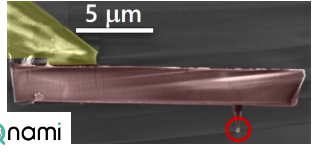
← ferroelectric DW

Cycloidal modulation of the AFM order

ature 549 (2017), 252
omm. 11 (2020), 1704

Antiferromagnets with small uncompensated moments

What if this is not the case?



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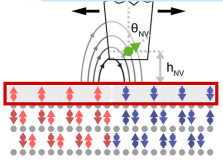

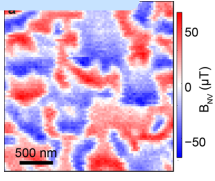

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Use magnetic noise instead of stray field!

- Completely compensated antiferromagnets = **no static stray field** to probe

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B. Flebus *et al.* *Phys. Rev. B* 98 (2018), 180409

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Thermal agitation
Spin waves

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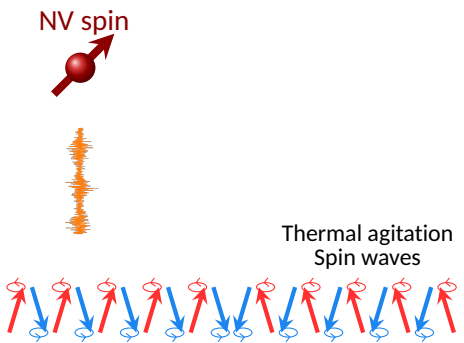

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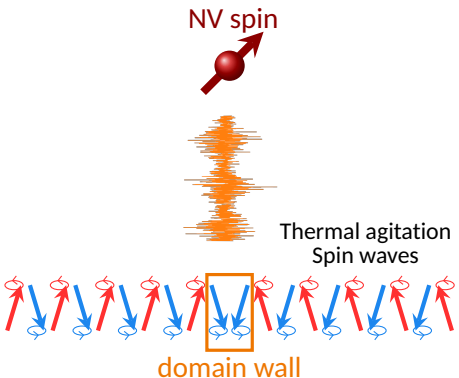
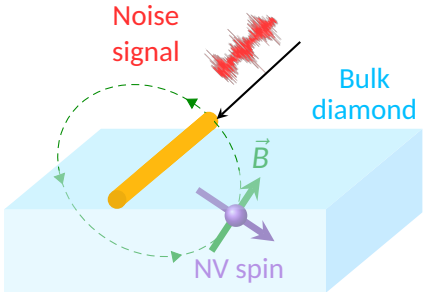


Acceleration of the NV spin relaxation with noise



M. Rollo *et al*. *PRB* 103 (2021), 235418

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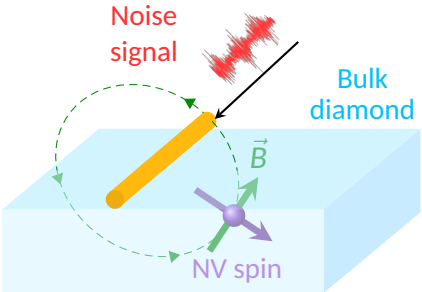

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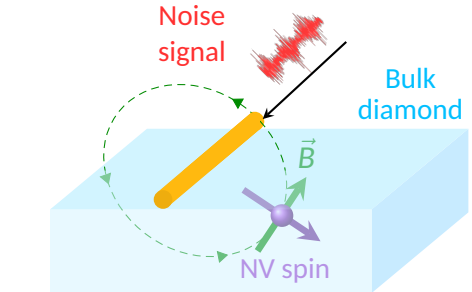

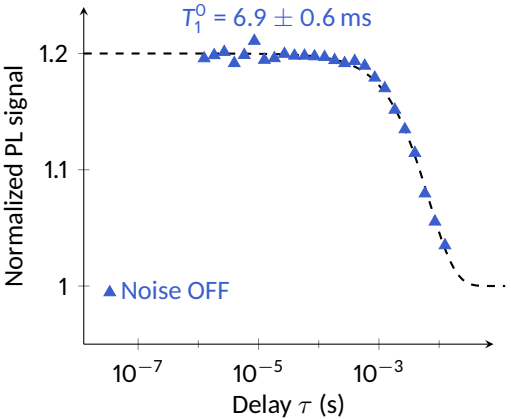

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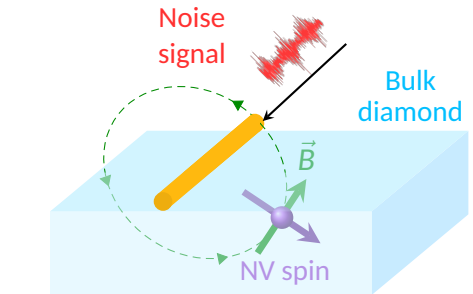

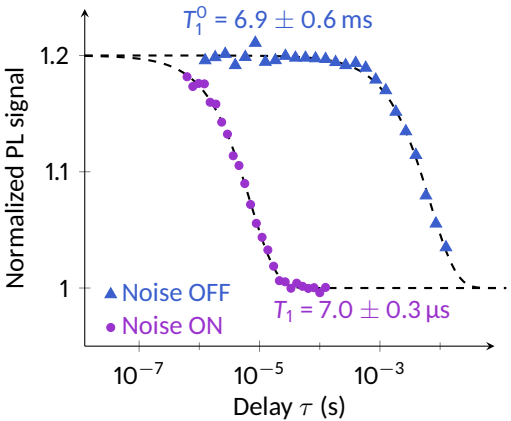

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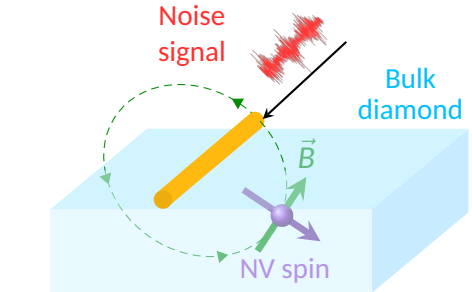

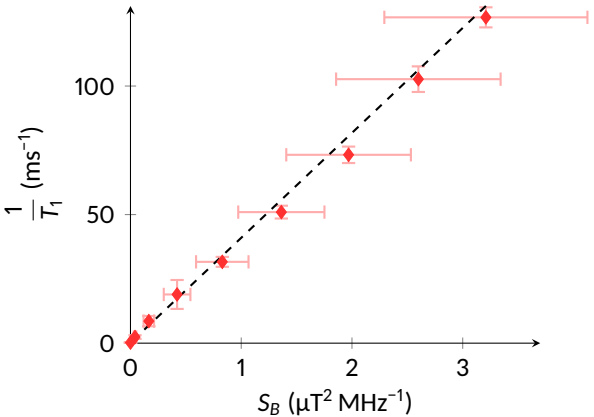

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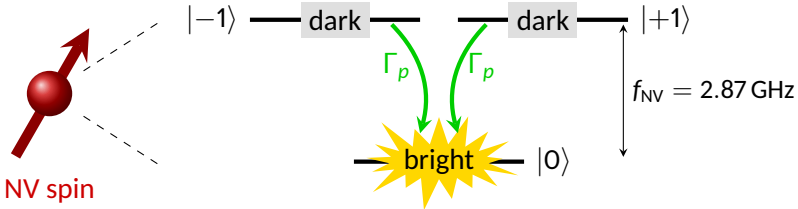
Effect on the emitted photoluminescence



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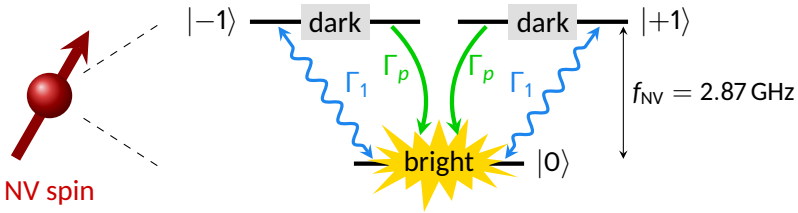

Relaxation rate $\Gamma_1 \propto S_{B_\perp}(f_{NV})$ magnetic field spectral density at the resonance frequency f_{NV}

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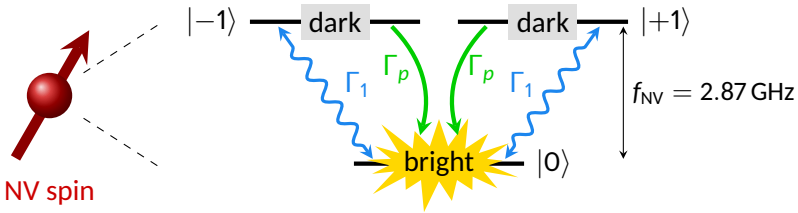

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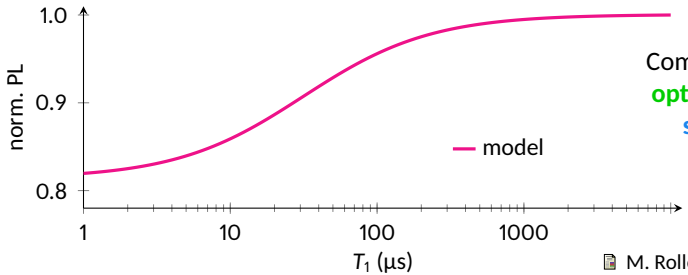

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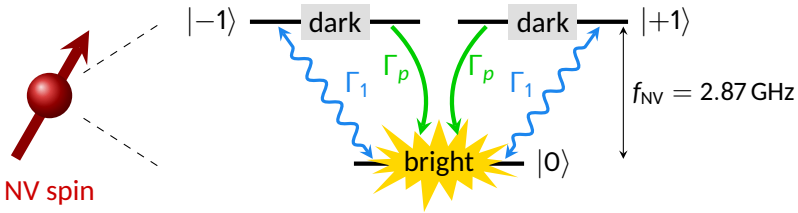

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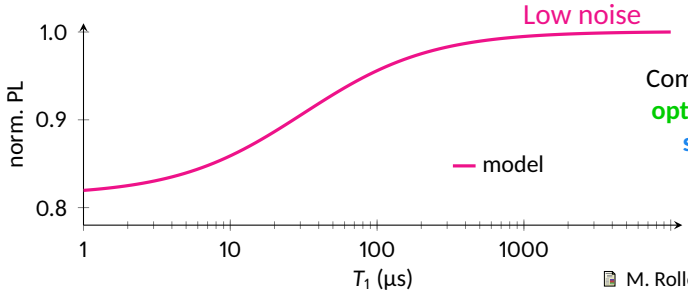

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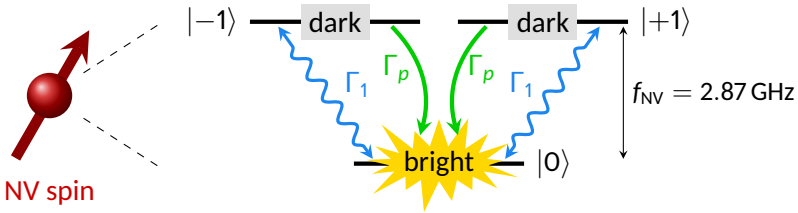

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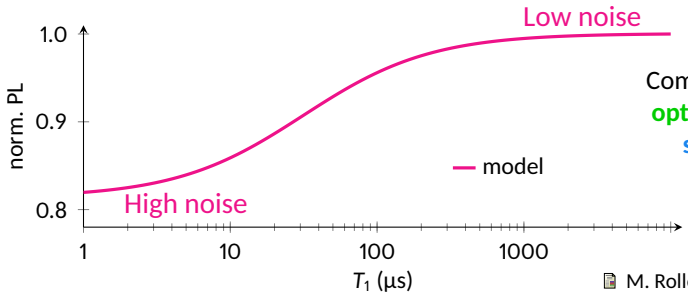

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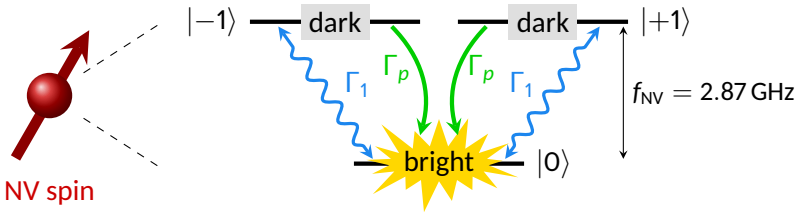

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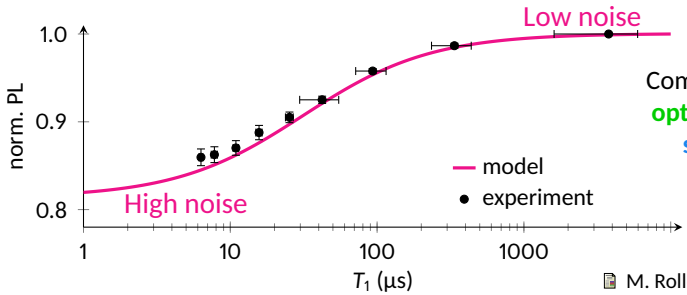

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Application to imaging of synthetic antiferromagnets

Collaboration UMR CNRS/Thales: William Legrand, Fernando Ajejas, Karim Bouzehouane, Nicolas Reyren, Vincent Cros

A. Finco *et al.* *Nat. Commun.* 12 (2021), 767

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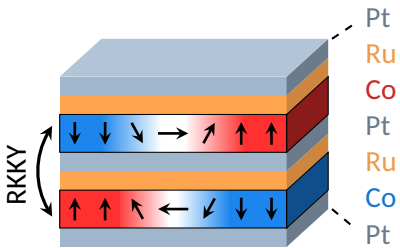

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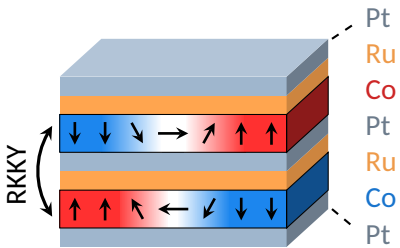

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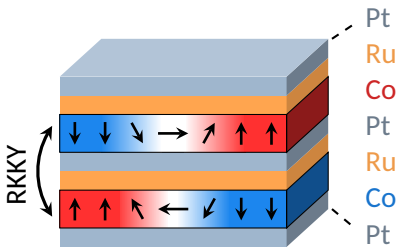

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Perfect test system for noise imaging!

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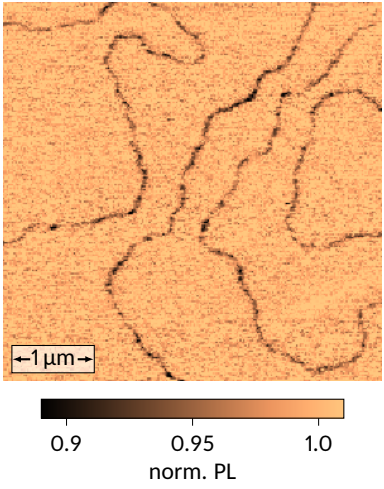
Detection of domain walls by relaxometry



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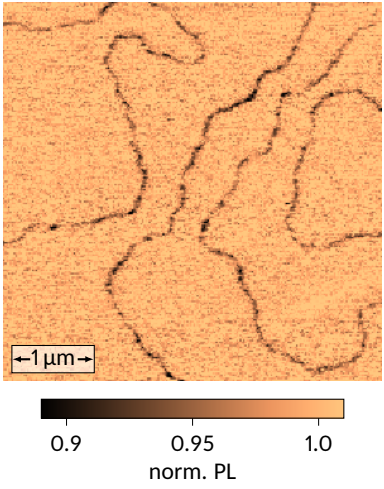

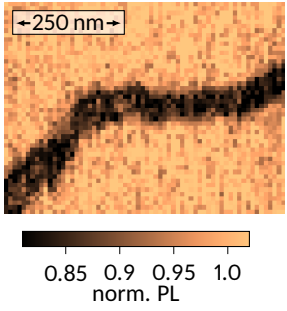

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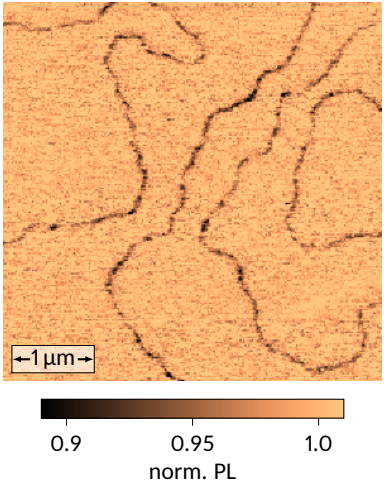
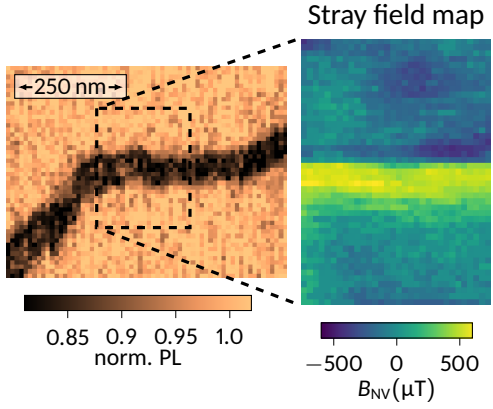
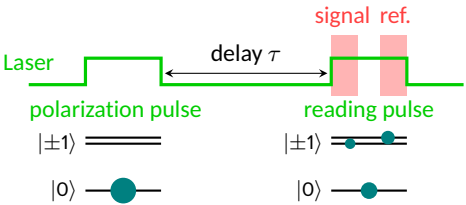




Local variation of the relaxation time



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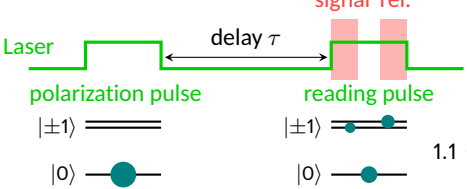

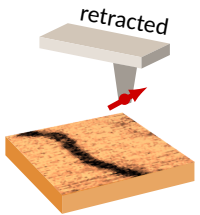

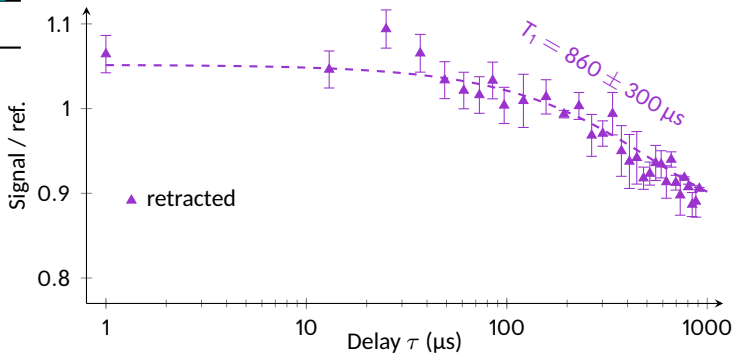

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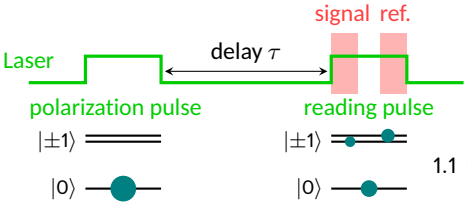

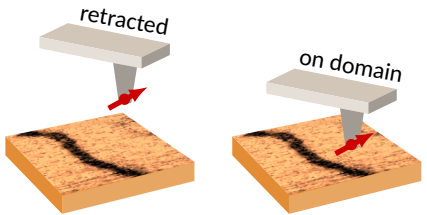

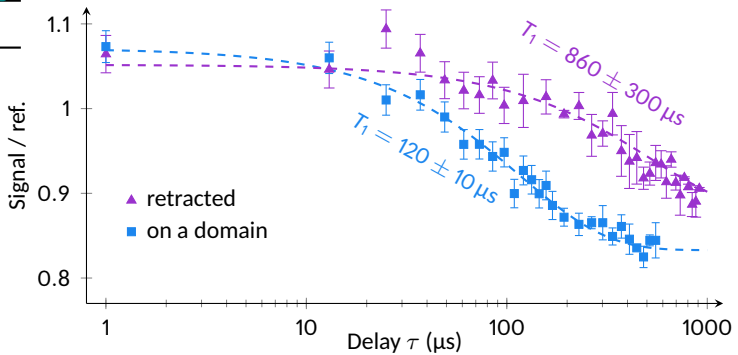

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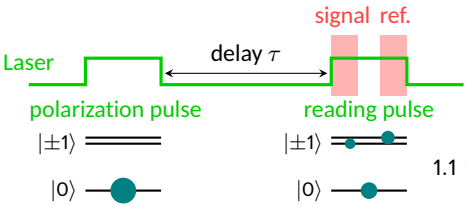
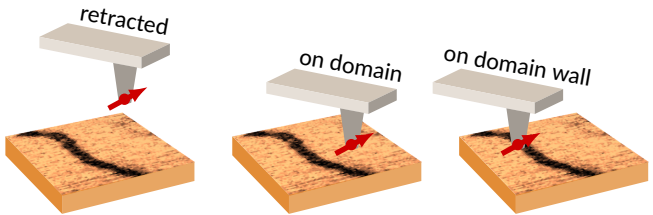
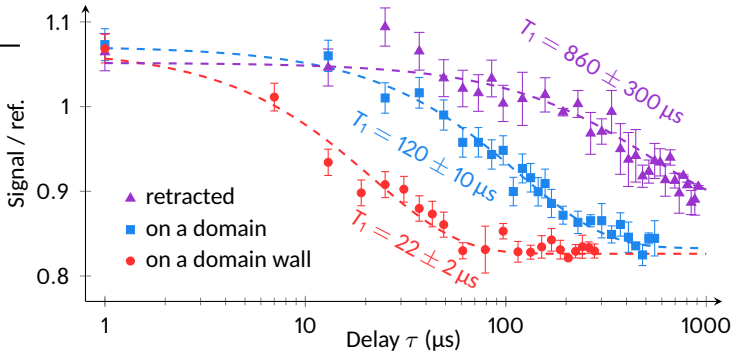
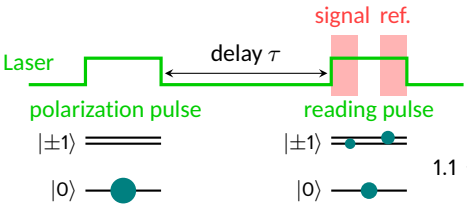
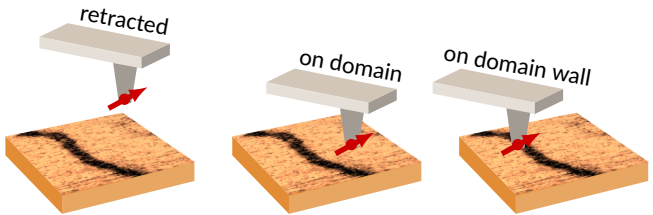






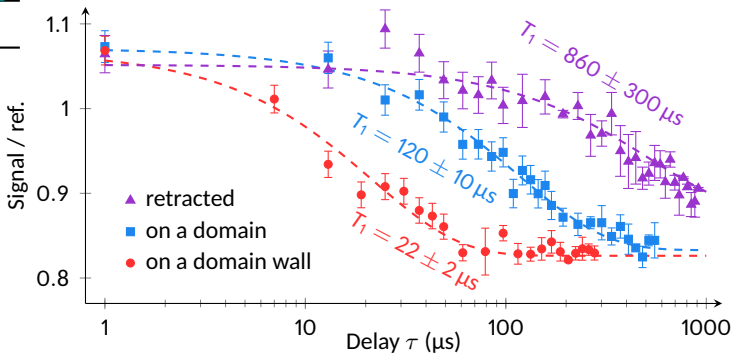
Local variation of the relaxation time





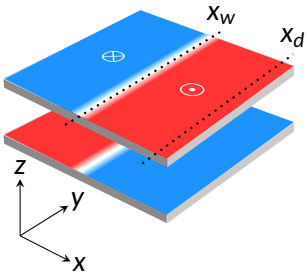
Clear diminution of T_1

→ **Enhancement of the spin relaxation**



Origin of the noise: spin waves

Collaboration C2N: Jean-Paul Adam, Joo-Von Kim



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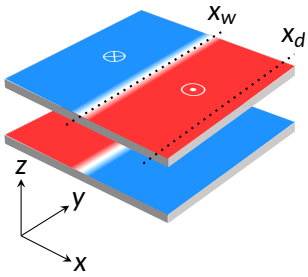

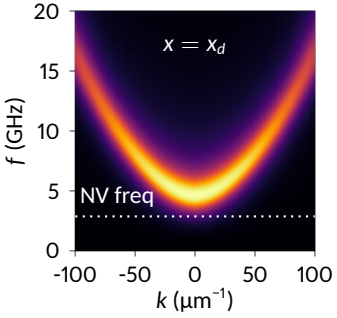

- NV frequency slightly below the gap, in the tail of power spectral density, which is the reason why we detect some noise when approaching the tip.

Origin of the noise: spin waves

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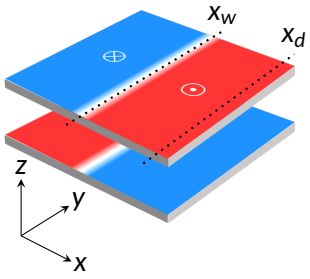
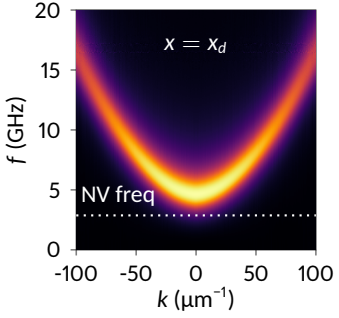
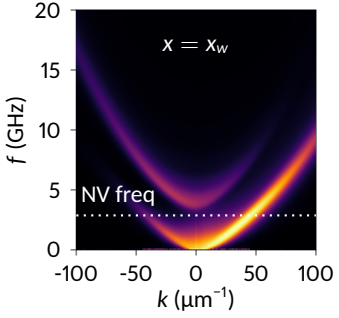


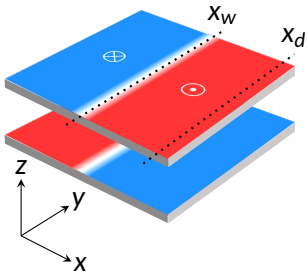


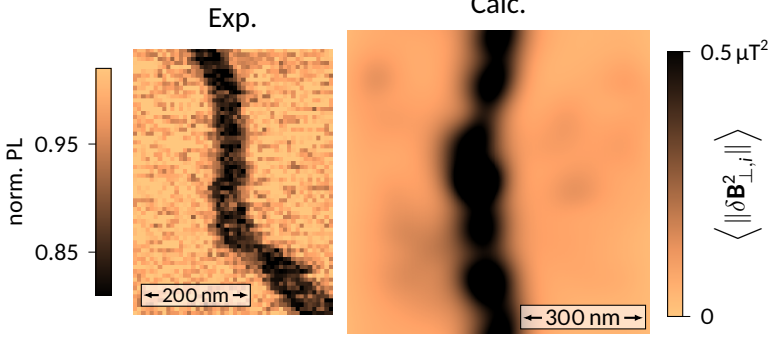


- NV frequency slightly below the gap, in the tail of power spectral density, which is the reason why we detect some noise when approaching the tip.
- No gap in the domain walls, presence of modes at the NV frequency: **the NV center is more sensitive to the noise from the walls!**

Origin of the noise: spin waves

Collaboration C2N: Jean-Paul Adam, Joo-Von Kim





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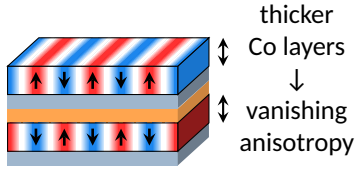
Imaging a spin spiral



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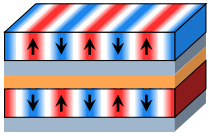
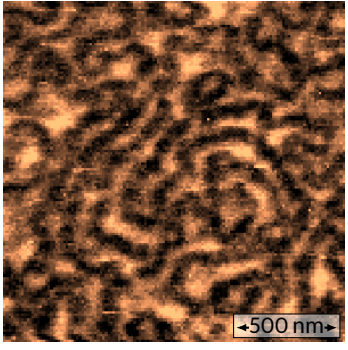
Imaging a spin spiral



thicker
Co layers
↓
vanishing
anisotropy

W. Legrand *et al*. *Nat. Mat.* 19 (2020), 34



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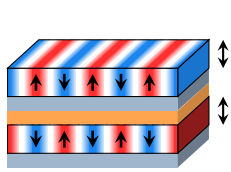

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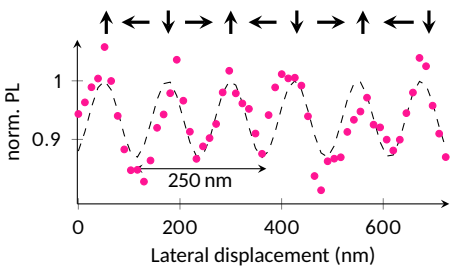
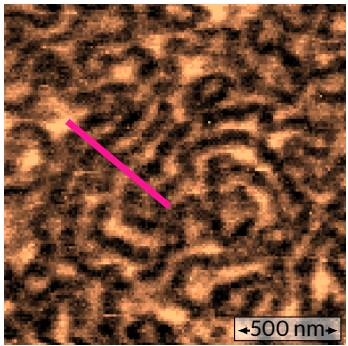
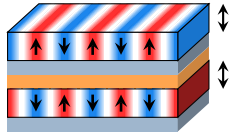




Imaging a spin spiral



thicker Co layers ↓ vanishing anisotropy

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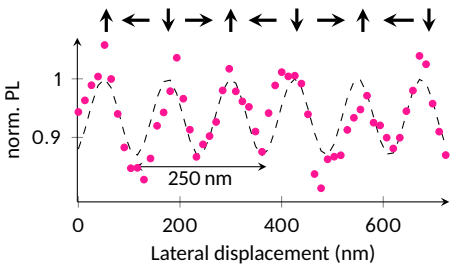
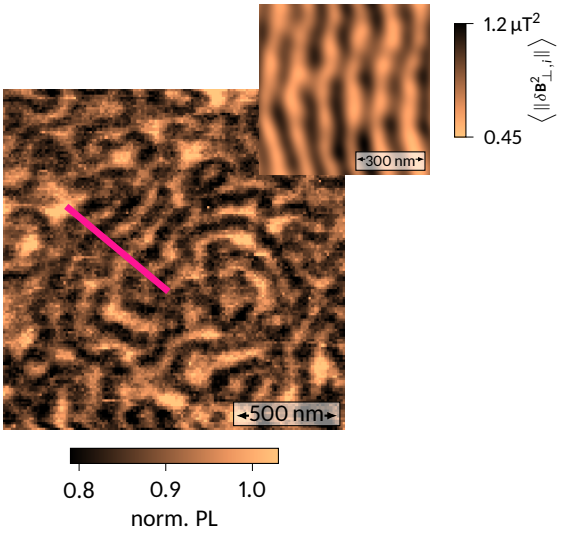
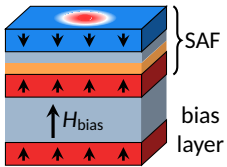


Calculated noise map



and antiferromagnetic skyrmions!



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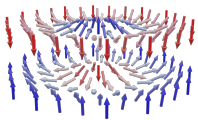

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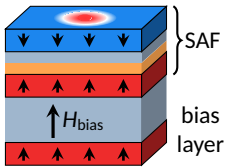

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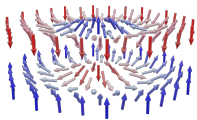

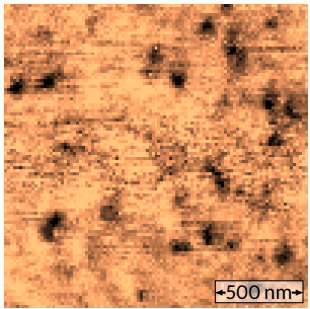

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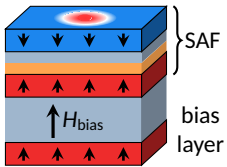

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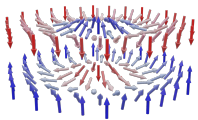

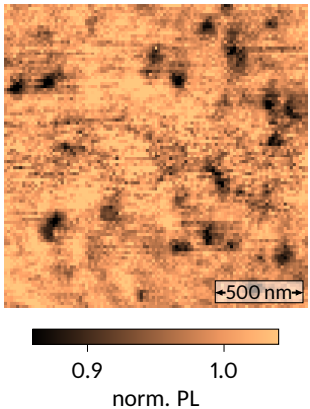

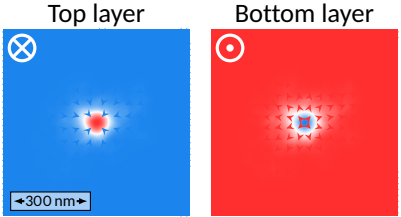

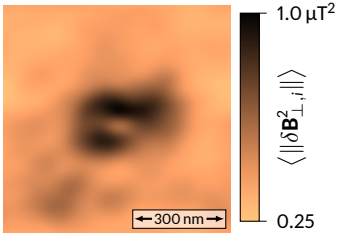

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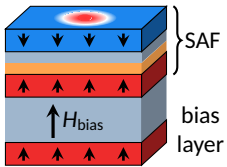

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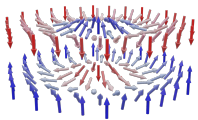
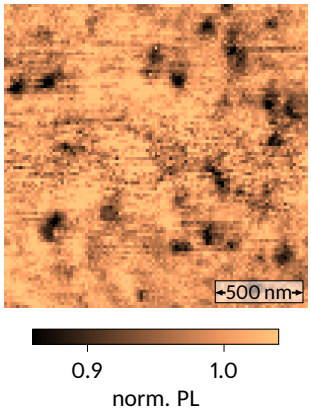
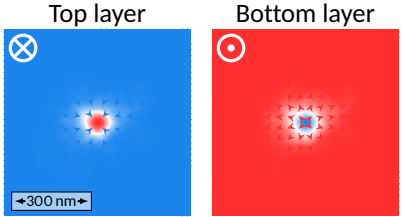
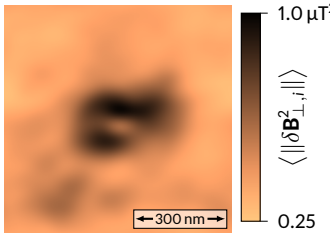




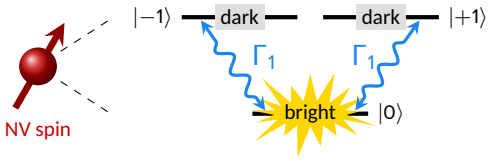


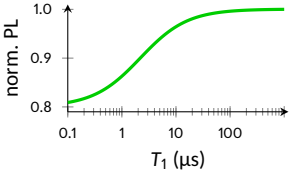


We are not probing the internal modes but the scattering of spin waves on the skyrmions

Summary

→ All optical detection of magnetic noise with NV centers





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Summary

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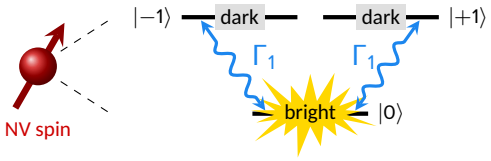

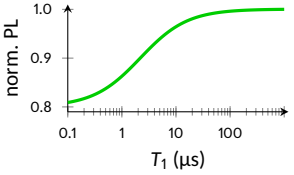

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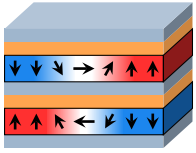
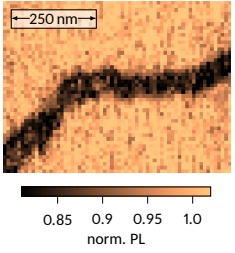
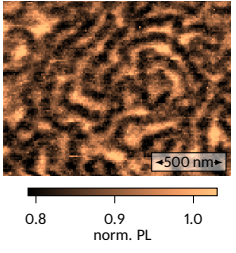
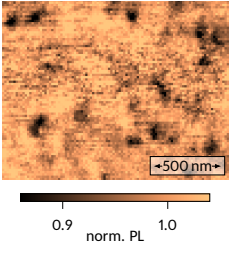
→ Application to the imaging of magnetic textures in synthetic antiferromagnets









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Acknowledgments

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Jean-Paul Adam
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Joo-Von Kim

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