Magnetic imaging via single spin relaxometry

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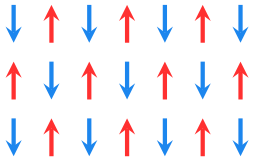
Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, Palaiseau, France

AIM 2021 virtual meeting, June 16th 2021

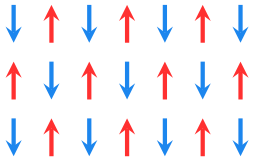
slides available at https://magimag.eu

Antiferromagnets for spintronics



Alternating magnetic moments

Antiferromagnets for spintronics

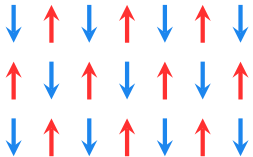


Alternating magnetic moments

- Antiferromagnetic textures are robust
- They do not produce stray field
- They have a fast dynamics in the THz range
- They can be switched in an energy-efficient way

T. Jungwirth *et al.* *Nat. Nano.* 11 (2016), 231
V. Baltz *et al.* *Rev. Mod. Phys.* 90 (2018)

Antiferromagnets for spintronics



Alternating magnetic moments

No net magnetization
Weak signals

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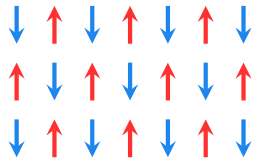
Antiferromagnets for spintronics



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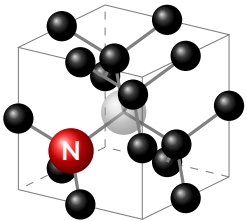
→ Antiferromagnetic structures are difficult to image!

S.-W. Cheong *et al.* *npj Quant. Mat.* 5 (2020), 1

The usual way to use NV centers for magnetic imaging



Defect in diamond

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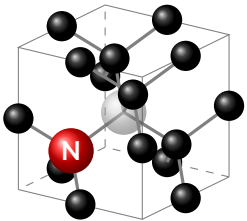

Defect in diamond

- Optical manipulation and reading
- Ambient conditions

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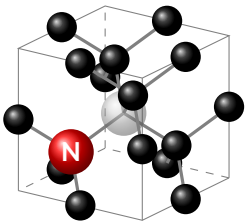

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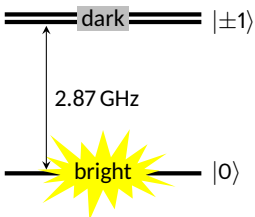
Spin-dependent fluorescence



NV ground state
spin $S = 1$

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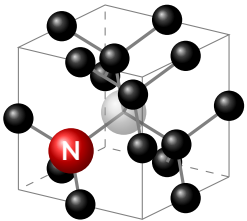

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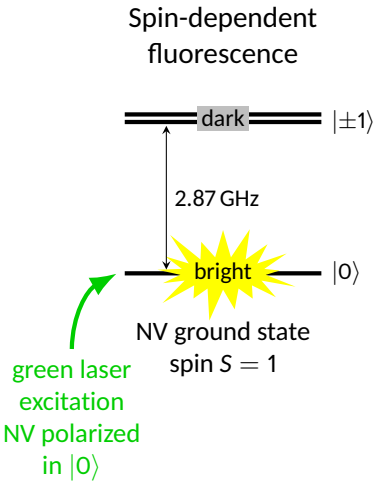

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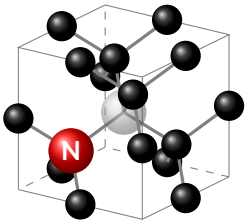

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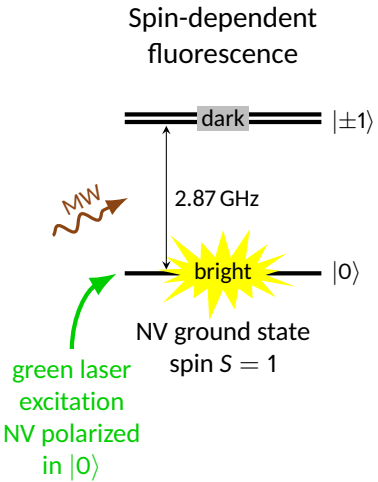

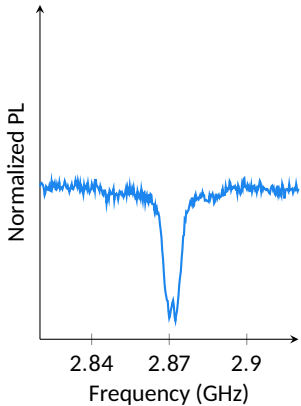

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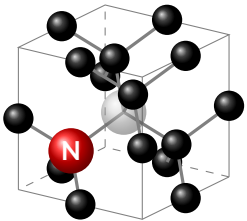

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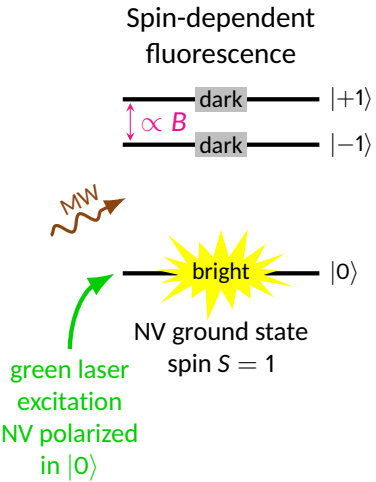

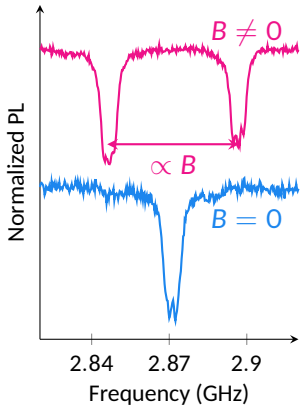

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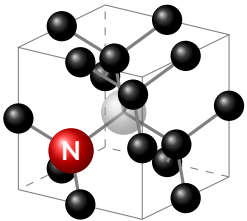

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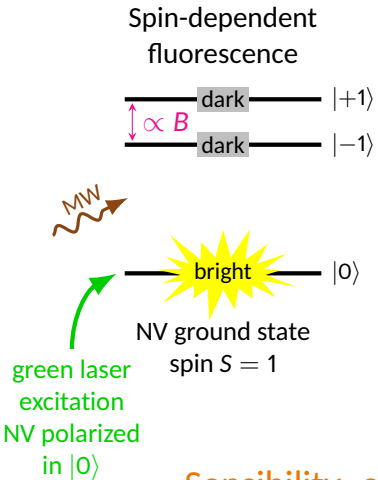
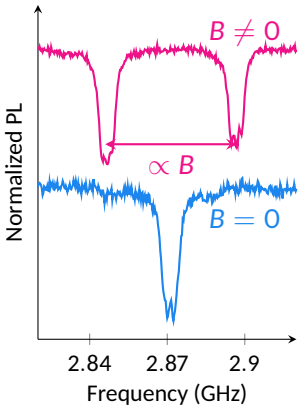
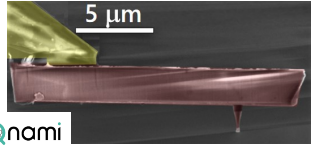




Sensibility: a few $\mu T/\sqrt{Hz}$

Quantitative scanning NV magnetometry on antiferromagnets

Diamond
AFM tip



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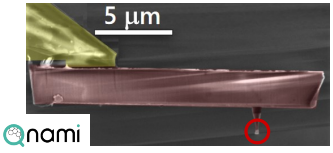

Implanted single
NV center

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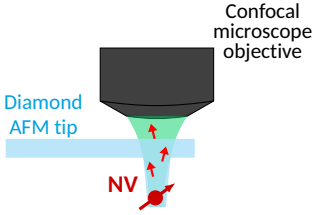

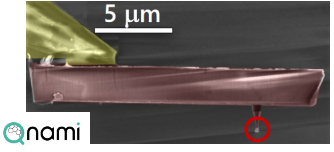

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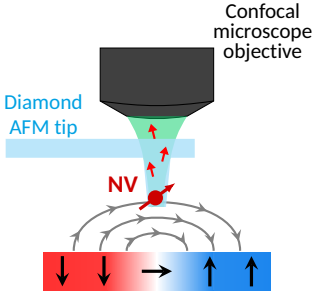

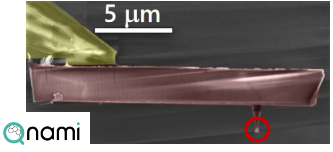

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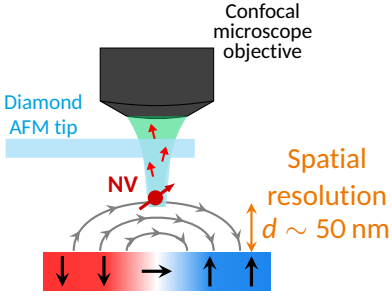

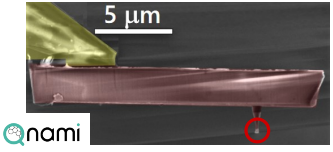

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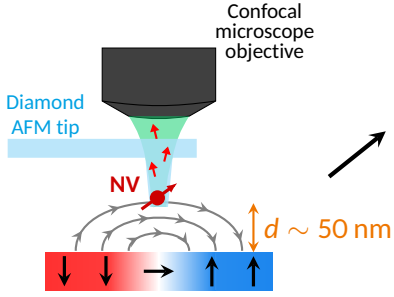
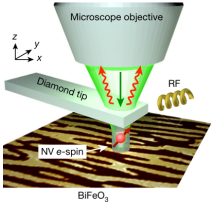
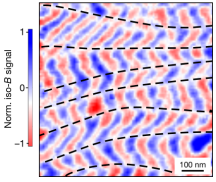


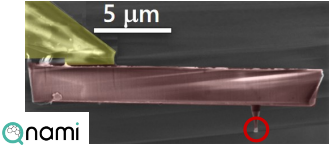
$BiFeO_3$: a room-temperature multiferroic





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

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



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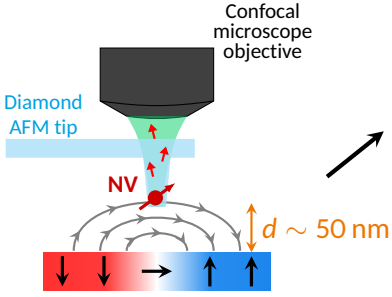

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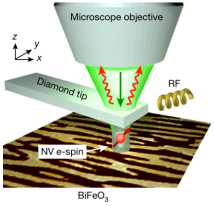

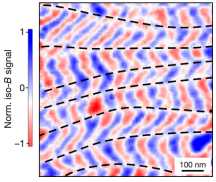

← ferroelectric DW

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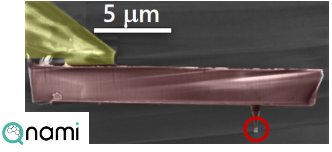

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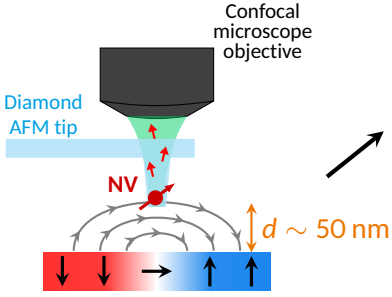

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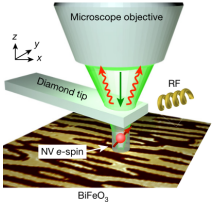

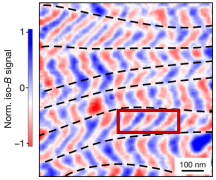

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Cycloidal modulation of the AFM order

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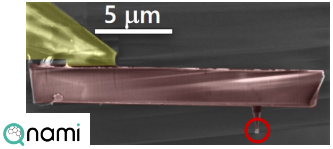

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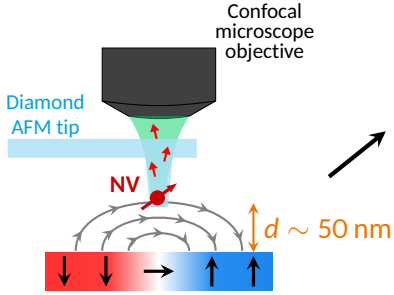

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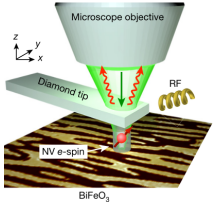

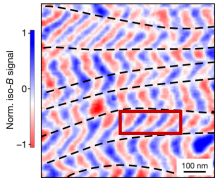

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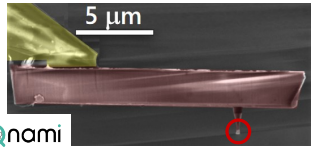
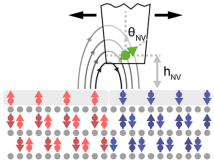
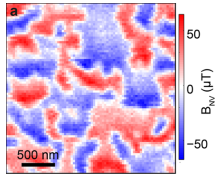


Implanted single NV center

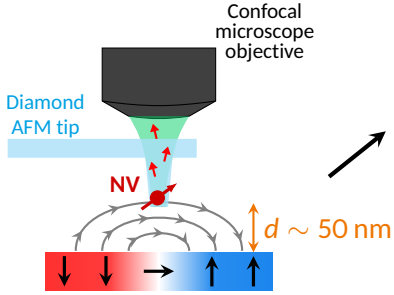
Cr_2O_3: a layered antiferromagnet





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

Quantitative scanning NV magnetometry on antiferromagnets



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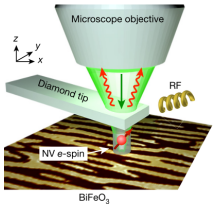

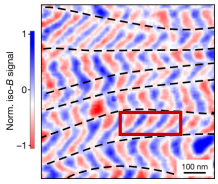

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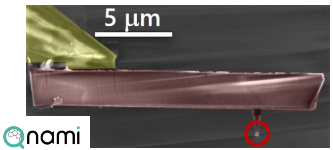

Implanted single NV center

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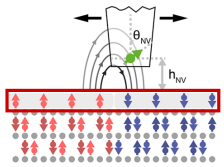

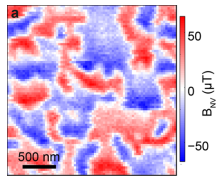

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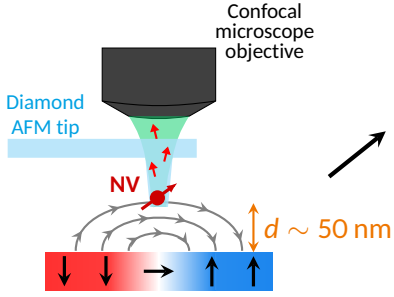
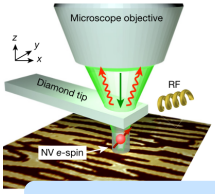
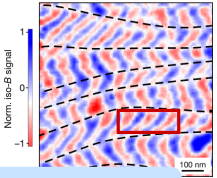


$BiFeO_3$: a room-temperature multiferroic





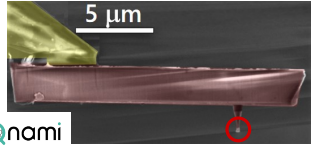
← ferroelectric DW

Cycloidal modulation of the AFM order

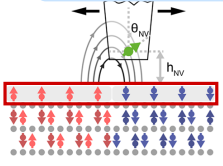
ature 549 (2017), 252
omm. 11 (2020), 1704

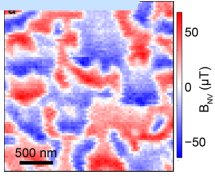
Antiferromagnets with small uncompensated moments

What if this is not the case?



Implanted single NV center





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

Use magnetic noise instead of stray field!

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Thermal agitation
Spin waves

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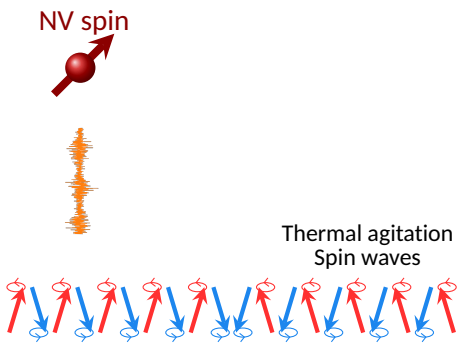

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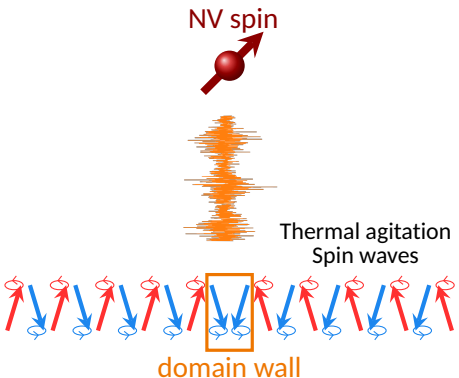
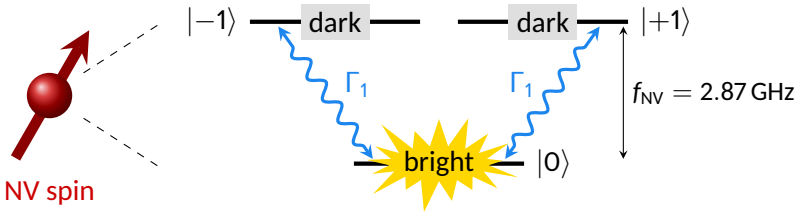


Effect of magnetic noise on the emitted PL



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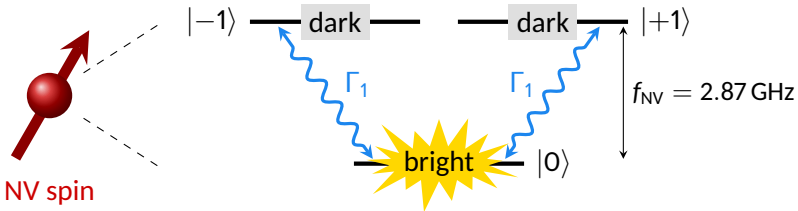

Relaxation rate $\Gamma_1 \propto S_{B_\perp}(f_{NV})$ magnetic field spectral density at the resonance frequency f_{NV}

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

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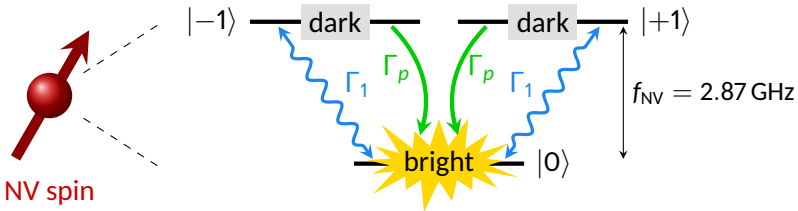

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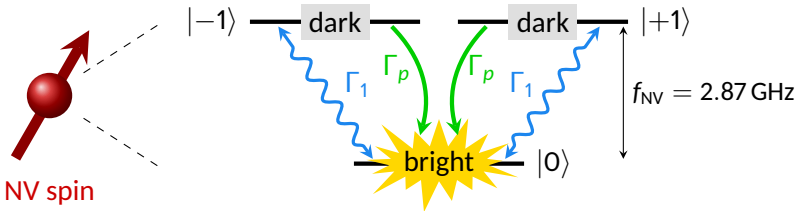

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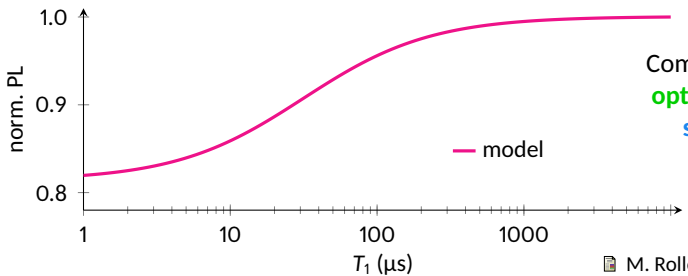

Competition between **optical pumping** and **spin relaxation**

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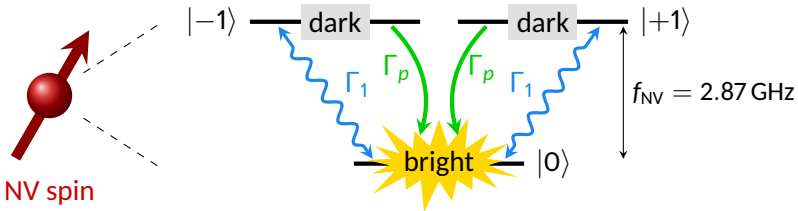

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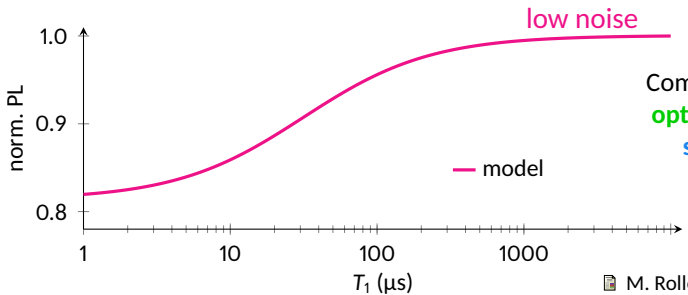

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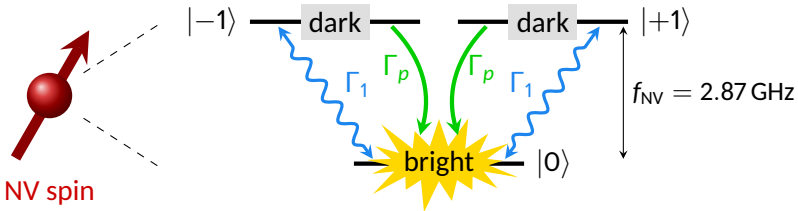

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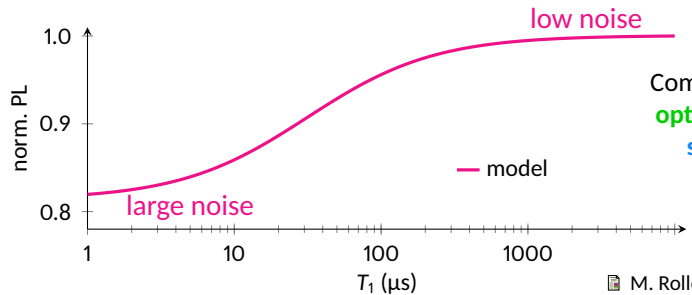

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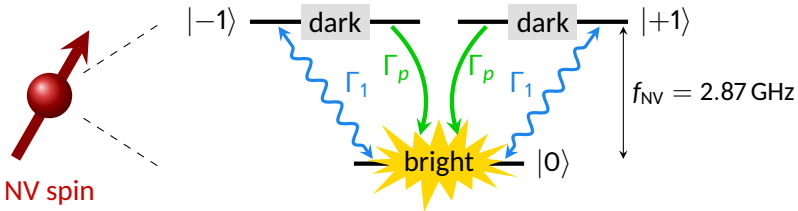

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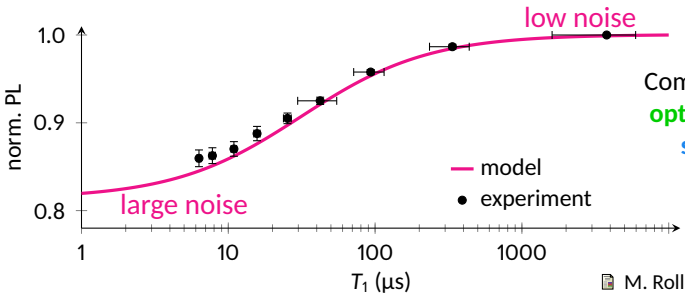

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Synthetic antiferromagnets

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

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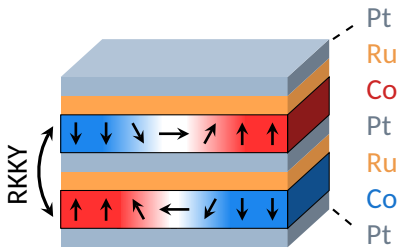

W. Legrand *et al.* *Nat. Mat.* 19 (2020), 34

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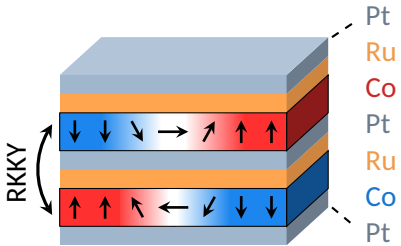

- No net magnetic moment
- Small stray field (vertical shift)
- Highly tunable properties

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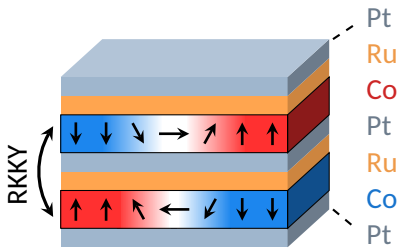

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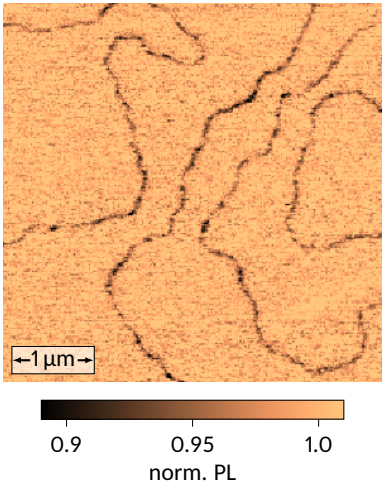
Perfect test system for noise imaging!

Detection of domain walls by relaxometry



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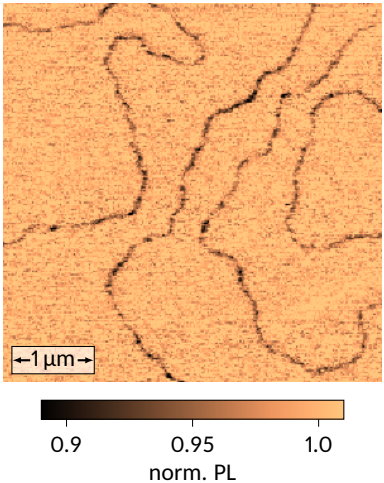

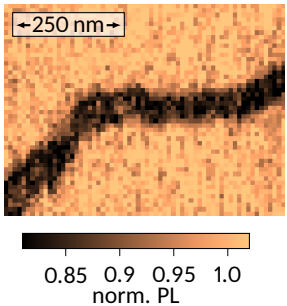

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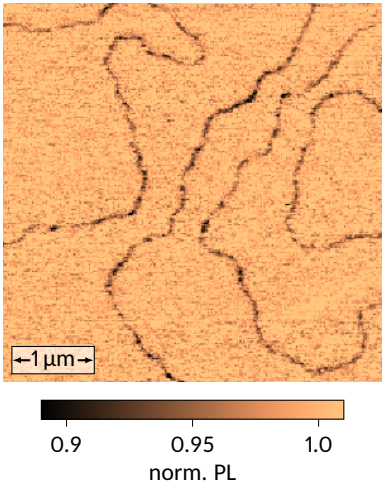
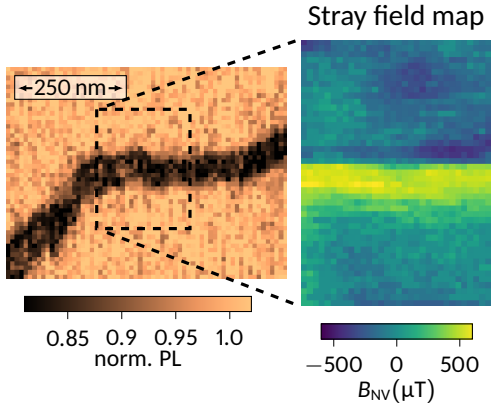
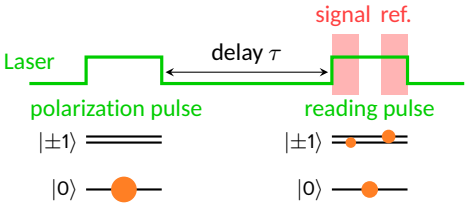




Acceleration of the NV spin relaxation on the walls



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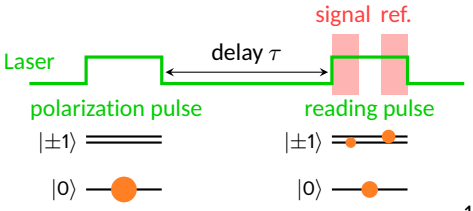

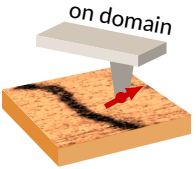

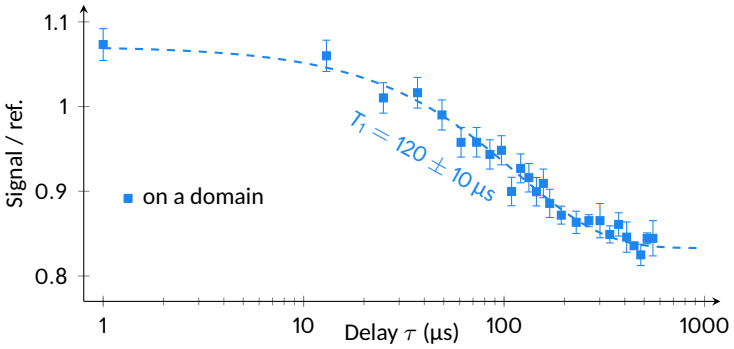

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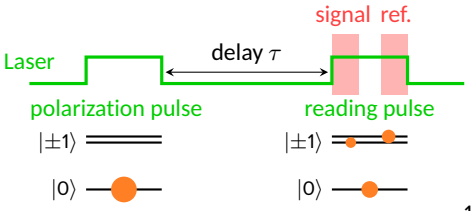

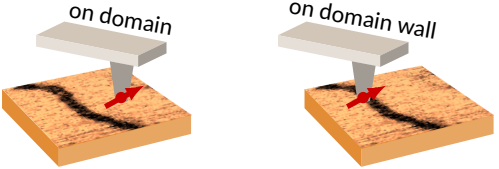

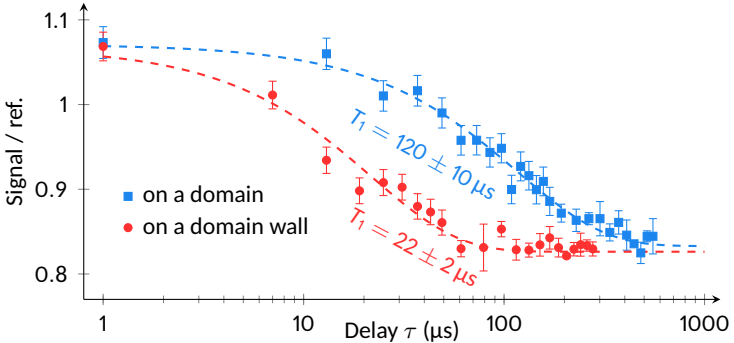

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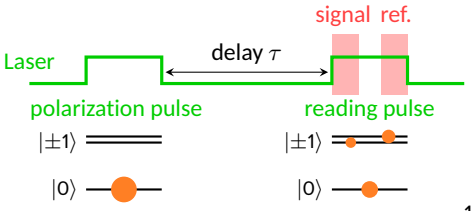
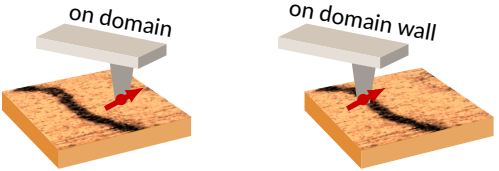
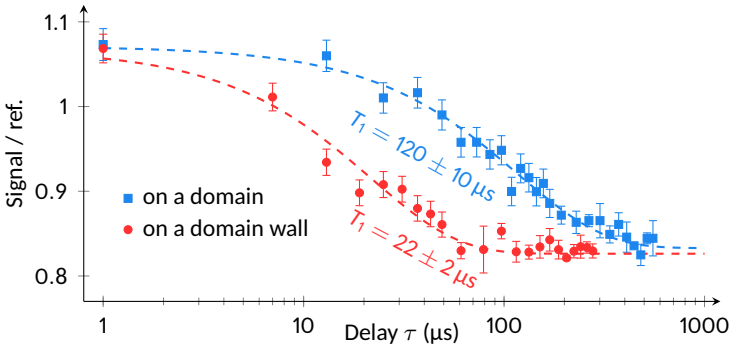


Clear diminution of T_1 above the domain wall





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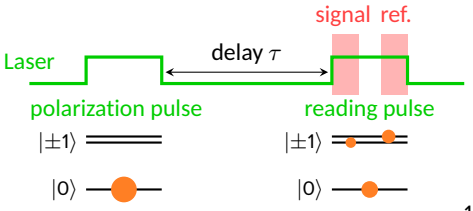

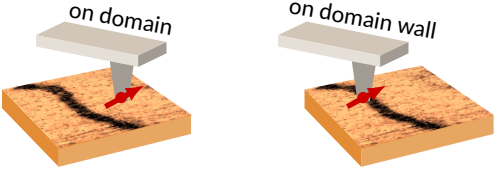

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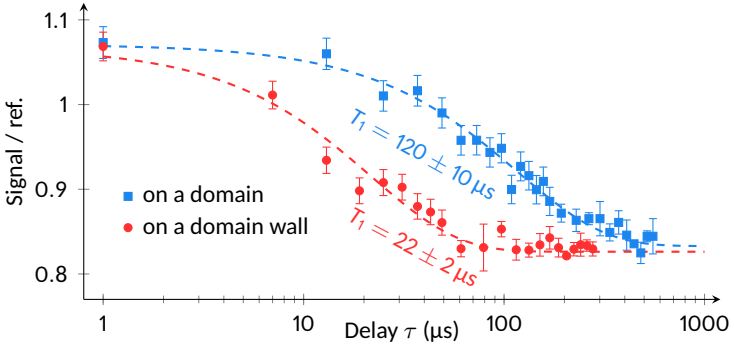
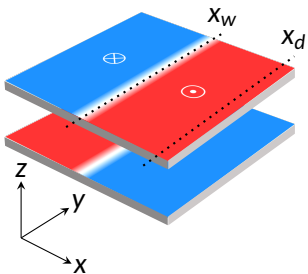
→ **Enhancement of the spin relaxation**



Origin of the noise: spin waves

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



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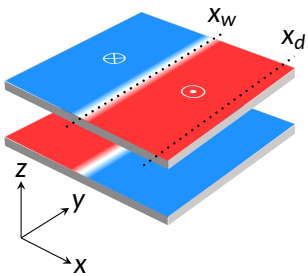

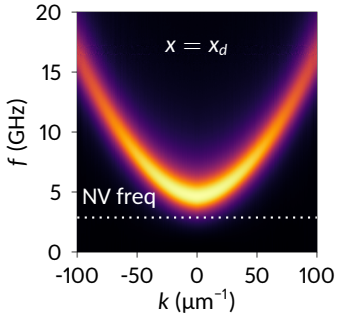

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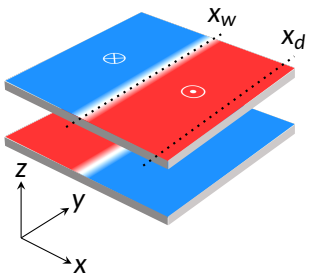

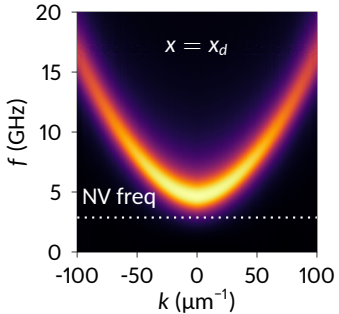

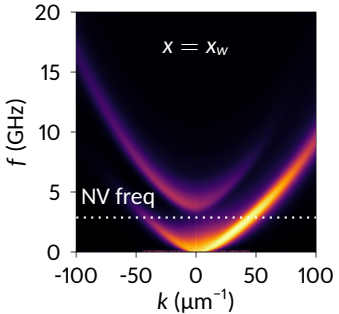

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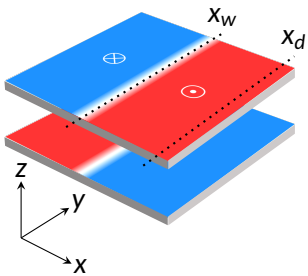

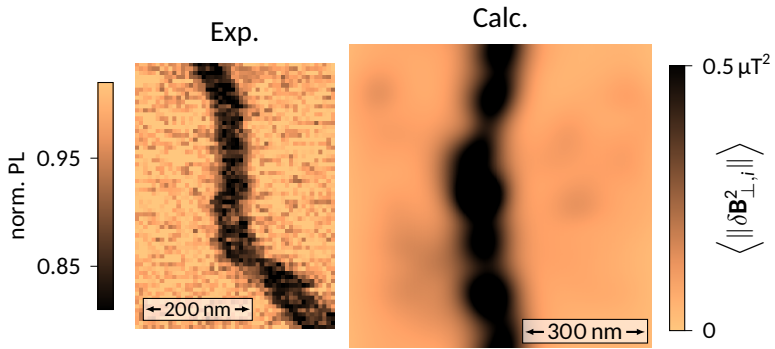

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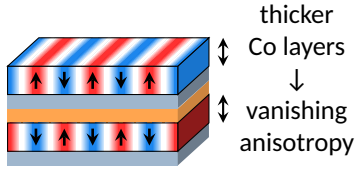
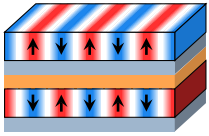


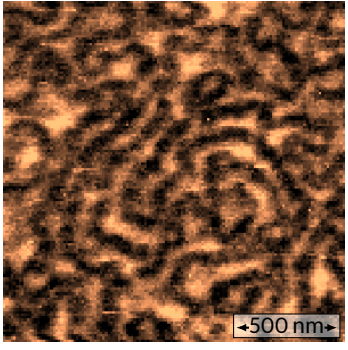
W. Legrand *et al*. *Nat. Mat.* 19 (2020), 34

Imaging a spin spiral



thicker
Co layers
↓
vanishing
anisotropy

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



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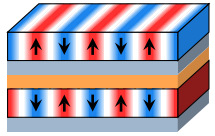

thicker
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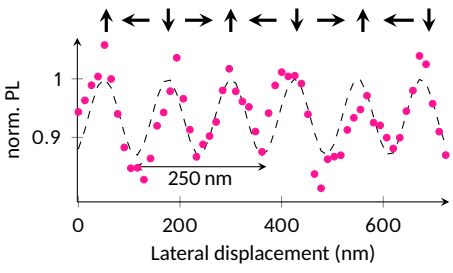
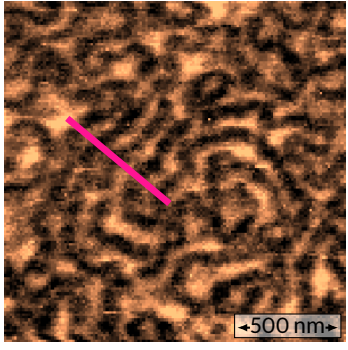
W. Legrand *et al*. *Nat. Mat.* 19 (2020), 34





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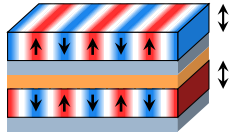

thicker Co layers ↓ vanishing anisotropy

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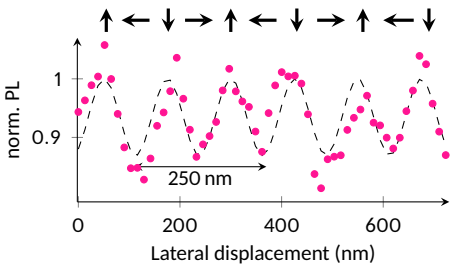
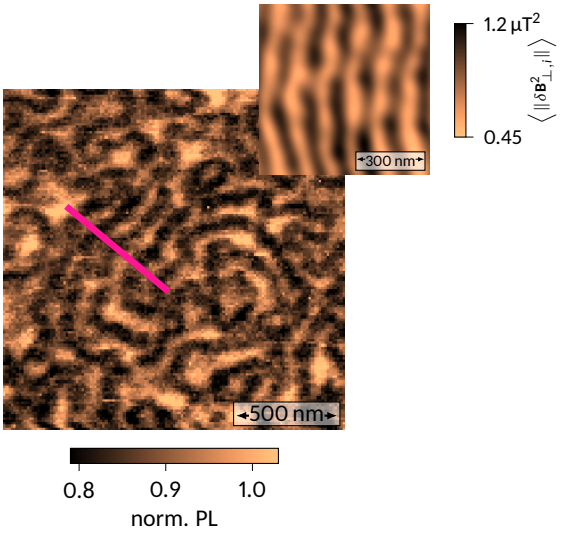
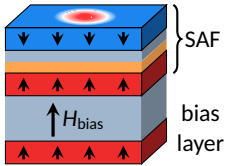


Calculated noise map



and antiferromagnetic skyrmions!



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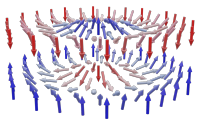

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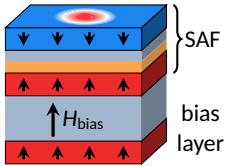

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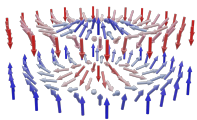

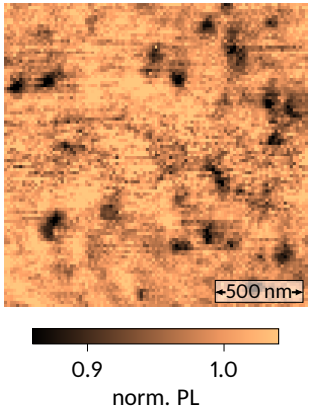

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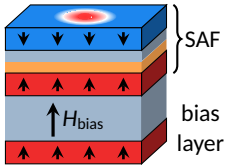

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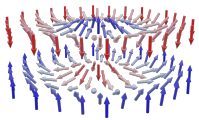
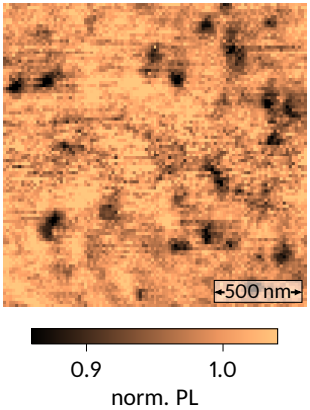
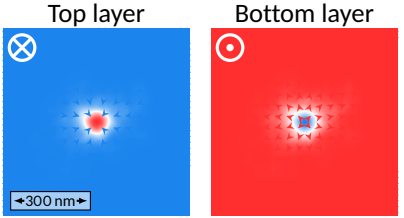
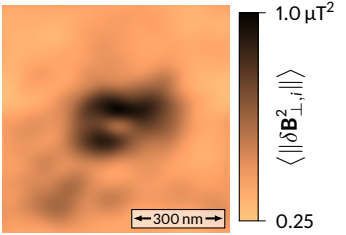


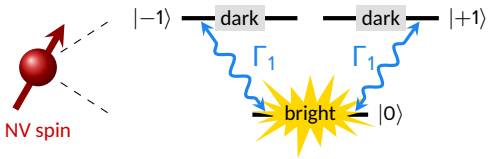


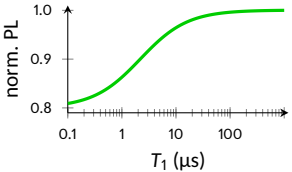




Summary

→ All optical detection of magnetic noise with NV centers





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Summary

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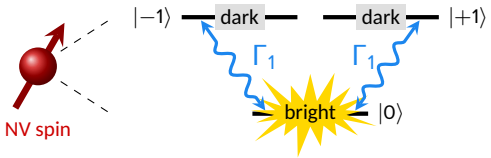

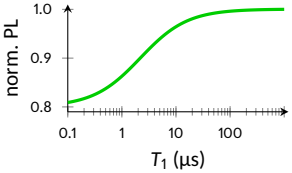

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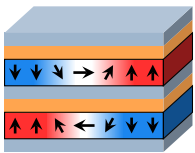
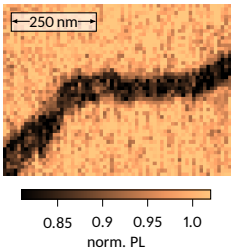
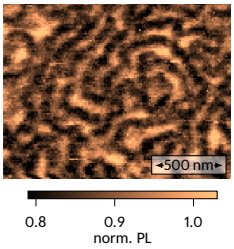
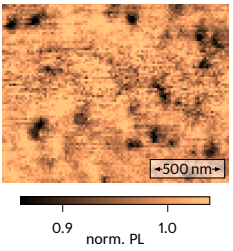
→ Application to the imaging of magnetic textures in synthetic antiferromagnets









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