Antiferromagnetic textures imaged by probing thermally excited spin waves

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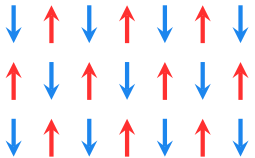
Magnonics 2022, August 1st

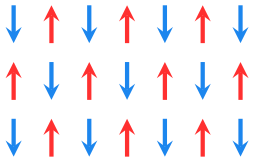
slides available at https://magimag.eu

Investigation of antiferromagnets



Alternating magnetic moments

Investigation of antiferromagnets



Alternating magnetic moments

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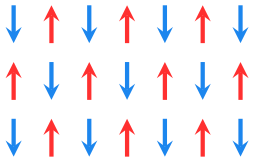

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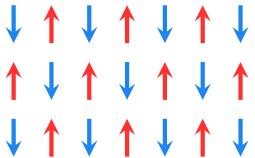

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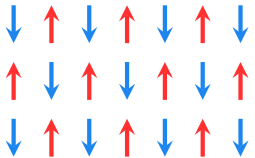

Alternating magnetic moments

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No net magnetization

Weak signals

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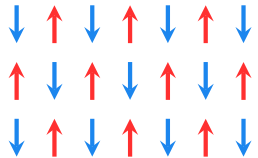

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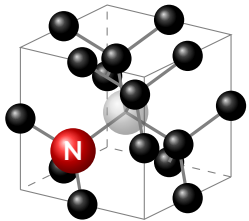
→ Antiferromagnetic structures are difficult to image!

- S.-W. Cheong *et al.* *npj Quantum Materials* 5 (2020), 1–10

NV centers as magnetic field sensors



Nitrogen-Vacancy defect
in diamond

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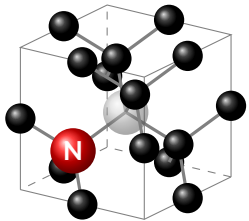

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- Ambient conditions

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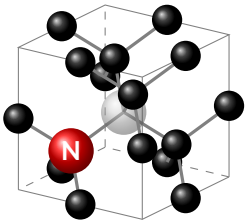

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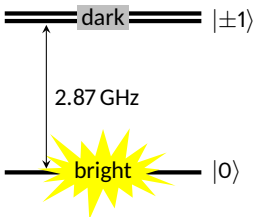
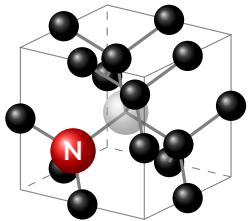
Spin-dependent
fluorescence



NV ground state
spin $S = 1$

NV centers as magnetic field sensors



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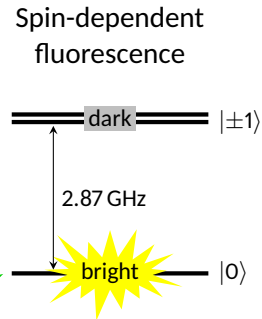

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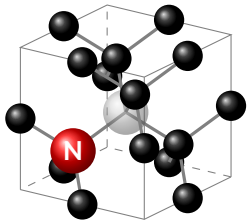

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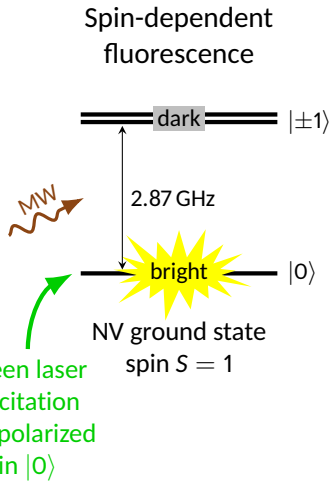

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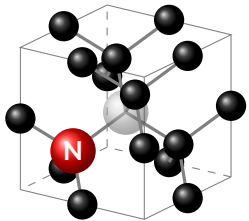

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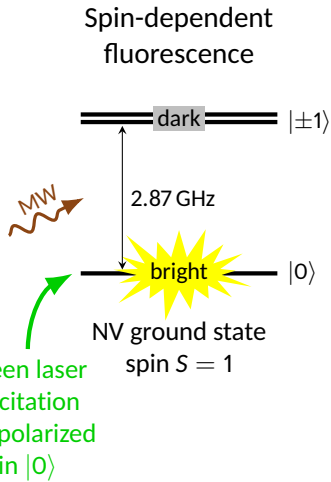

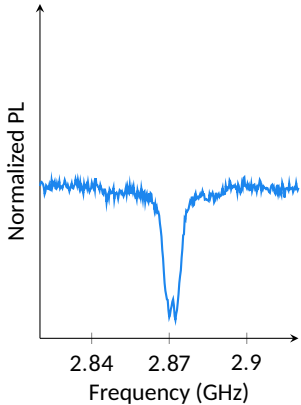

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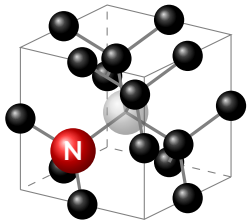

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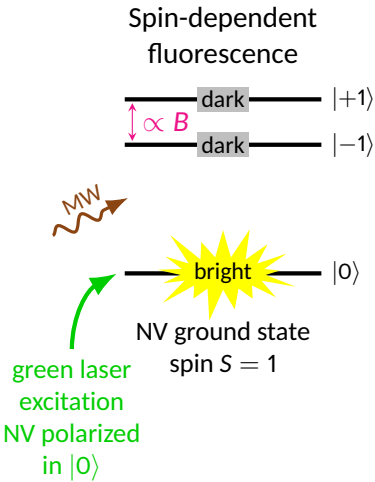

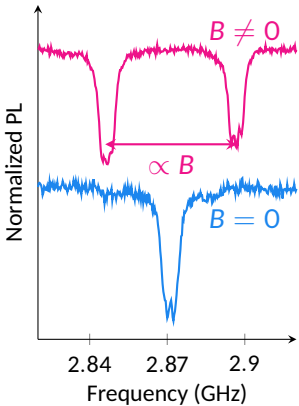

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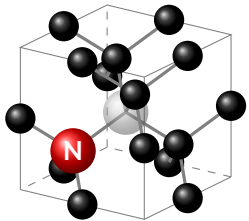

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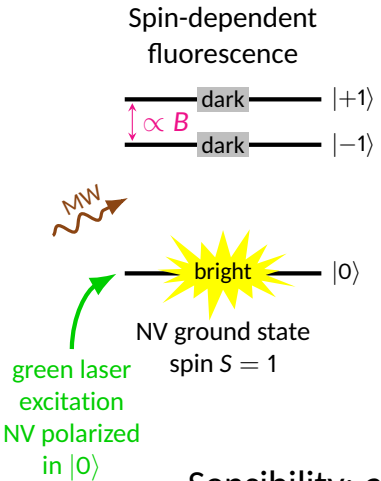
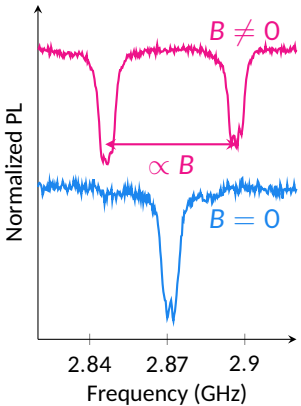


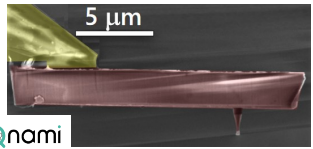


Sensibility: a few $\mu T/\sqrt{Hz}$

Probing of resonant excited spin waves

Scanning NV center microscopy

Diamond
AFM tip



P. Maletinsky *et al.* *Nature Nano.* 7 (2012), 320–324

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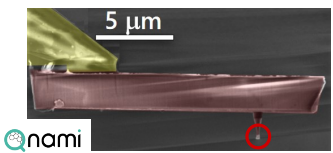

Implanted single
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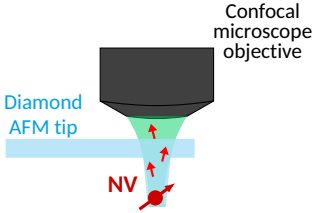

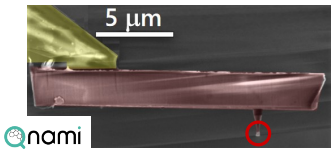

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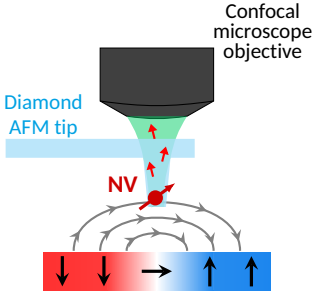

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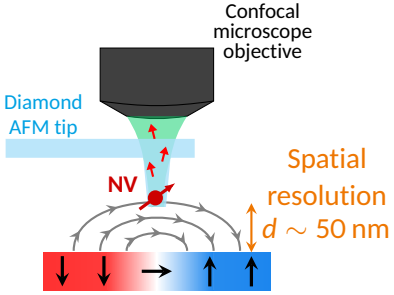

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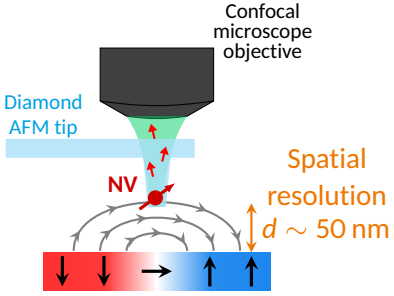

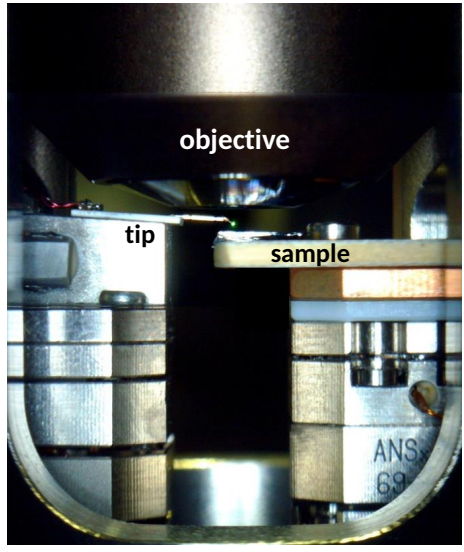

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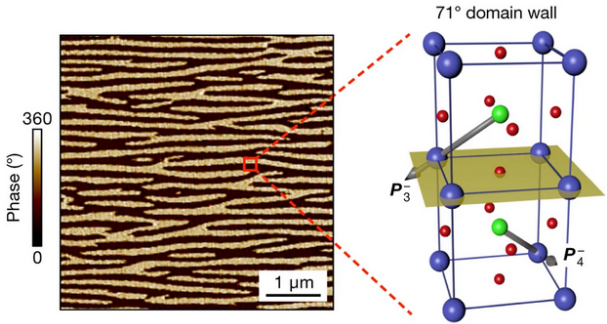
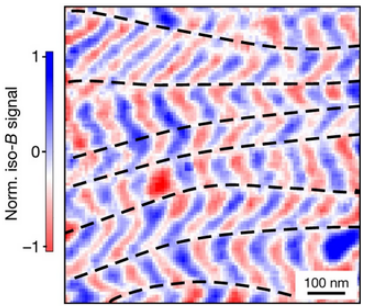
Quantitative imaging of canted antiferromagnetic textures

Example: antiferromagnetic cycloid in the multiferroic $BiFeO_3$

PFM image
Ferroelectric domains



NV magnetic image
Alternating cycloid propagation direction



Collaboration UMR CNRS/Thales: V. Garcia, S. Fusil

I. Gross *et al.* *Nature* 549 (2017), 252–256

Detection of magnetic noise rather than stray field

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

- Completely compensated antiferromagnets = **no static stray field** to probe
- But NV centers are also sensitive to **magnetic noise**!
- Use the different noise properties above domains and domain walls for imaging

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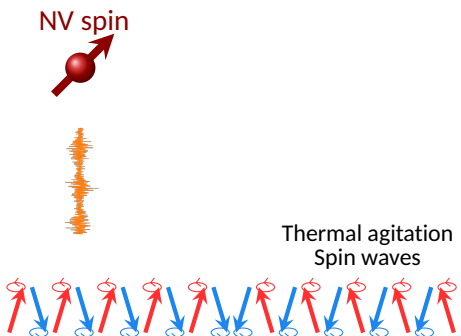

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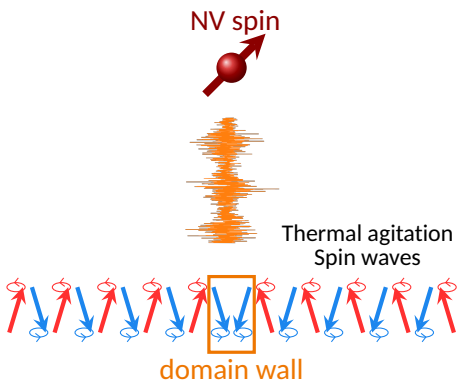
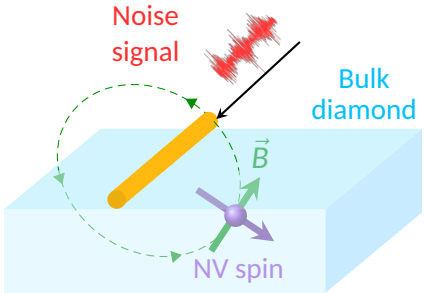


Other approach: relaxometry to probe magnetic noise



Collaboration C2N: T. Devolder

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

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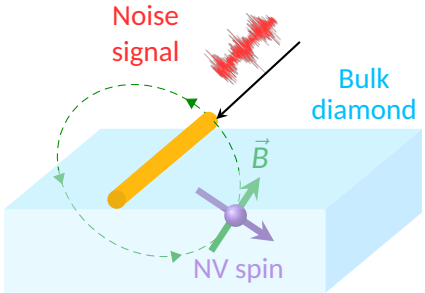

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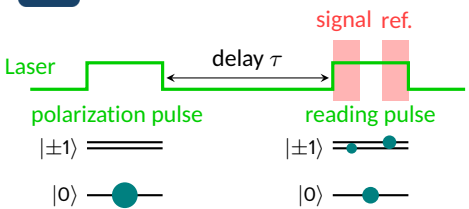

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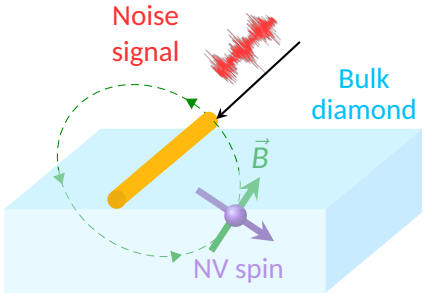

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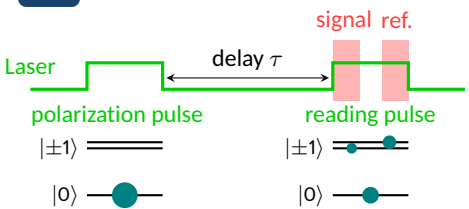

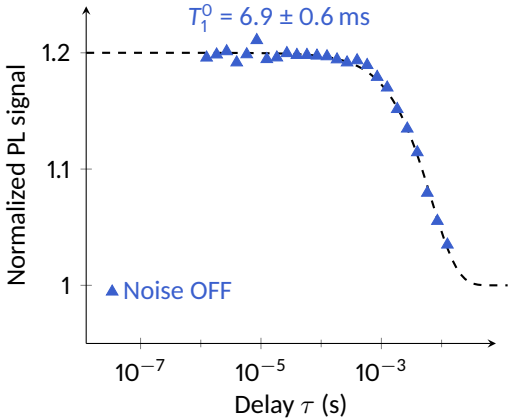

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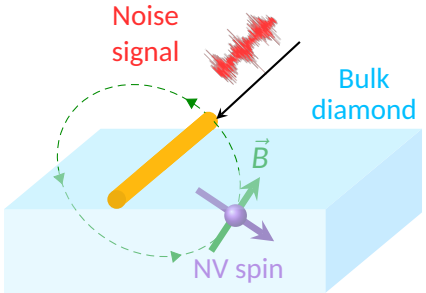

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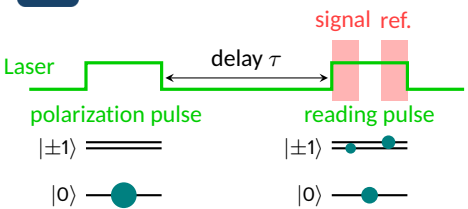
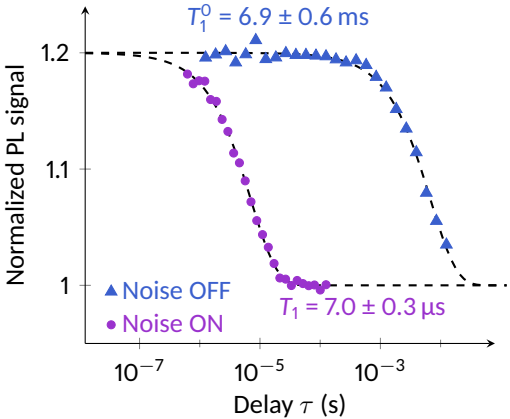
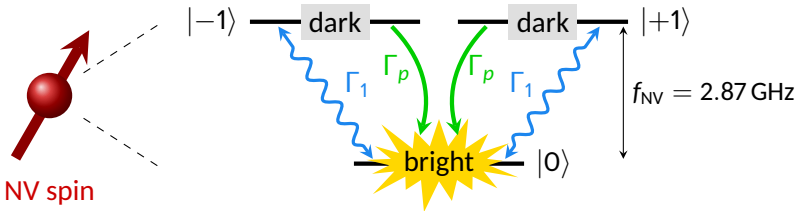




Noise spectrum centered at the NV transition frequency

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

Effect on the emitted photoluminescence



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

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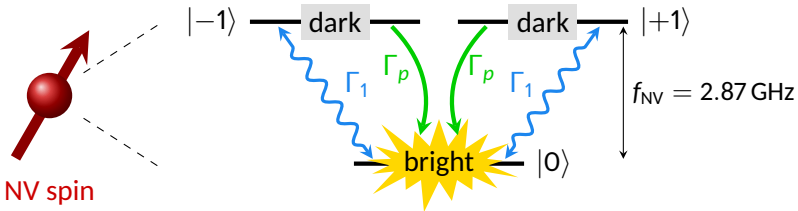

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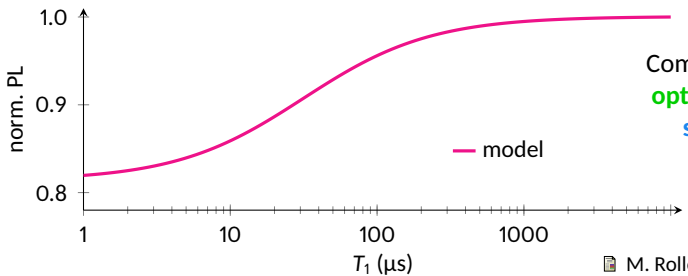
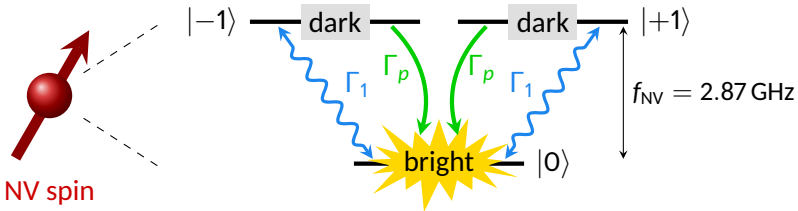


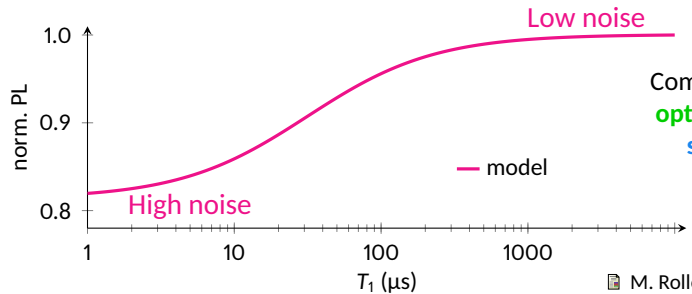
Competition between **optical pumping** and **spin relaxation**

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

Effect on the emitted photoluminescence



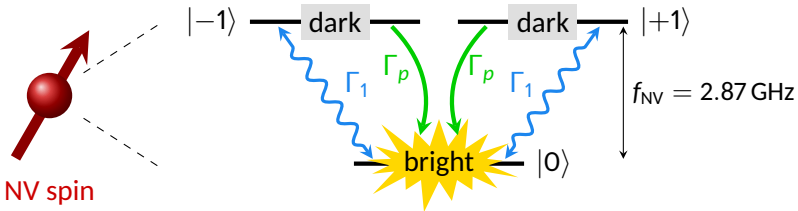
Relaxation rate $\Gamma_1 \propto S_{B_\perp}(f_{NV})$ magnetic field spectral density at the resonance frequency f_{NV}



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

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

Effect on the emitted photoluminescence



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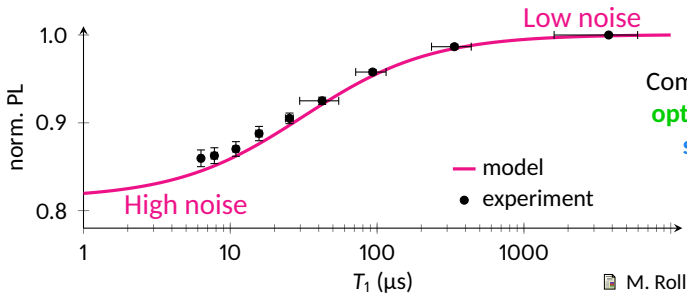


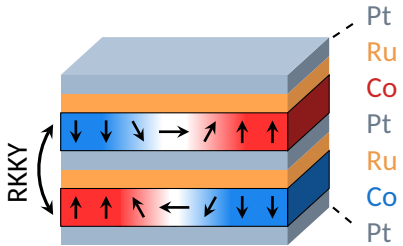
Competition between **optical pumping** and **spin relaxation**

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

Imaging of synthetic antiferromagnets

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

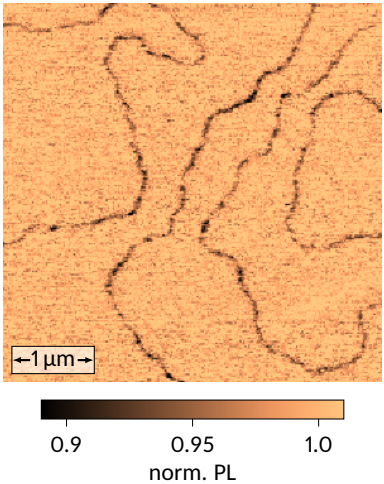
Two **ferromagnetic** layers coupled **antiferromagnetically**

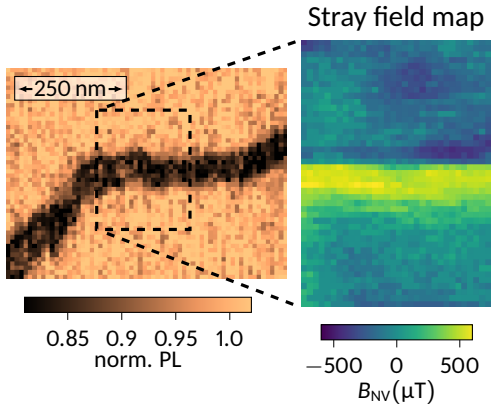


W. Legrand *et al.* *Nat. Mat.* 19 (2020), 34

- No net magnetic moment
- Compensation of dipolar effects
  → small skyrmions
- No skyrmion Hall effect
- Small stray field due to vertical spacing
  → test system for noise imaging

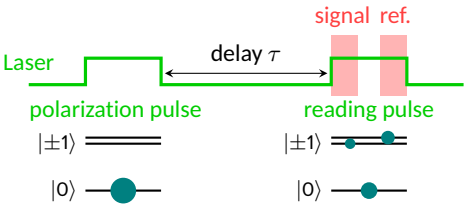
Detection of domain walls by relaxometry



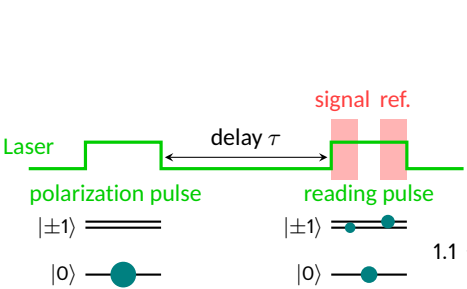


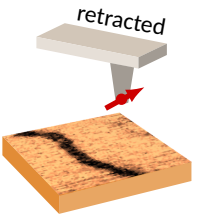
A. Finco *et al.* *Nat. Commun.* 12 (2021), 767

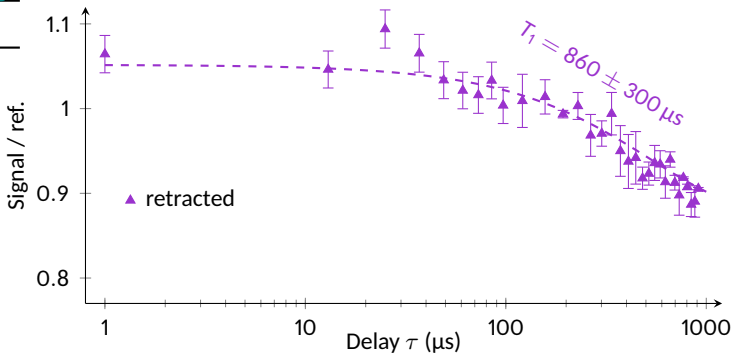
Local variation of the relaxation time



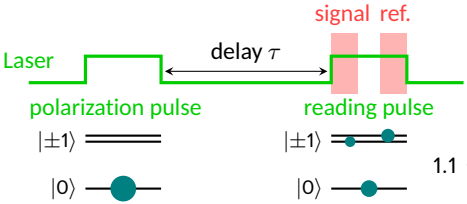
Local variation of the relaxation time

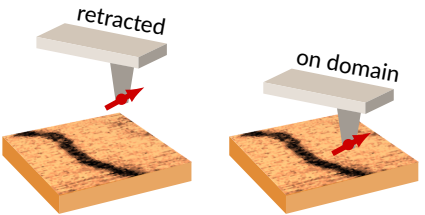


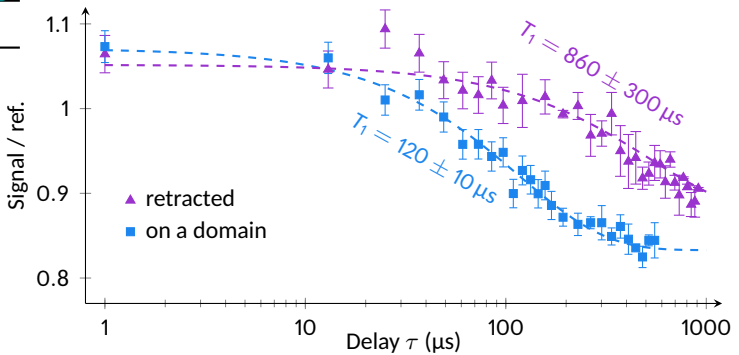




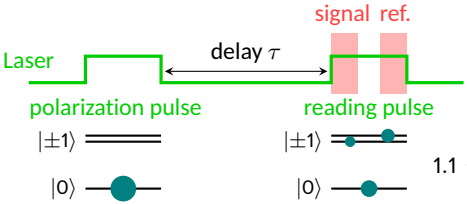
Local variation of the relaxation time

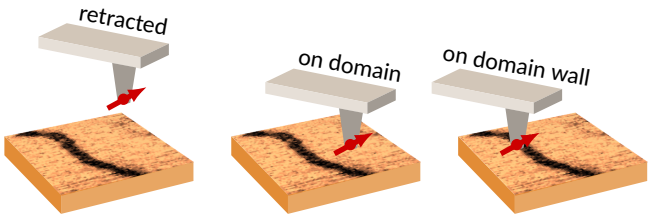


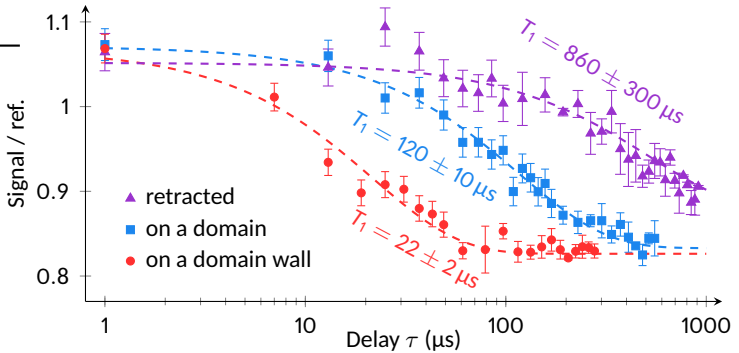




Local variation of the relaxation time







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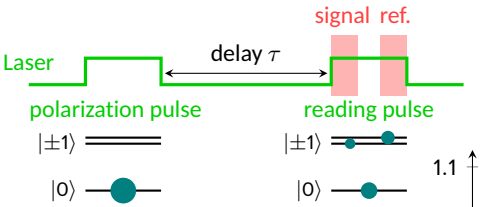
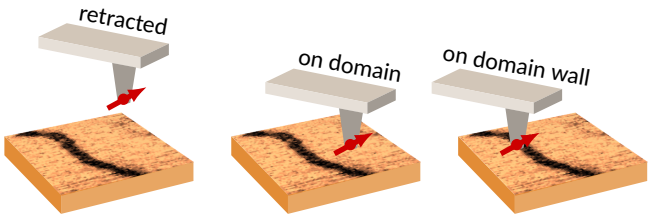
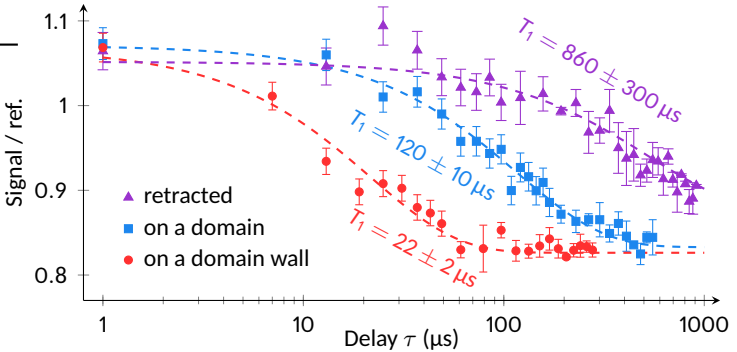




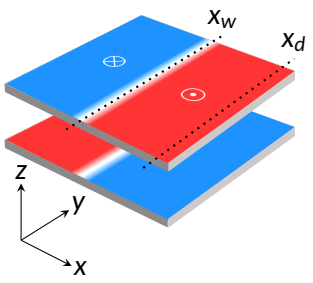
Clear diminution of T_1

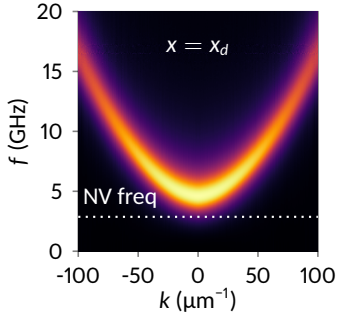
→ **Enhancement of the spin relaxation**

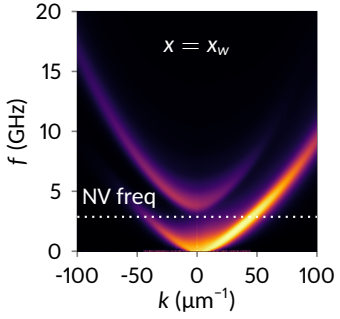


Origin of the noise: spin waves

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



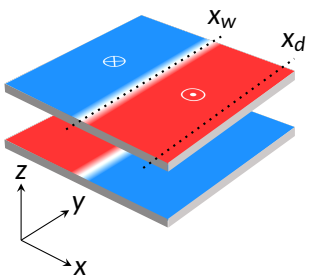


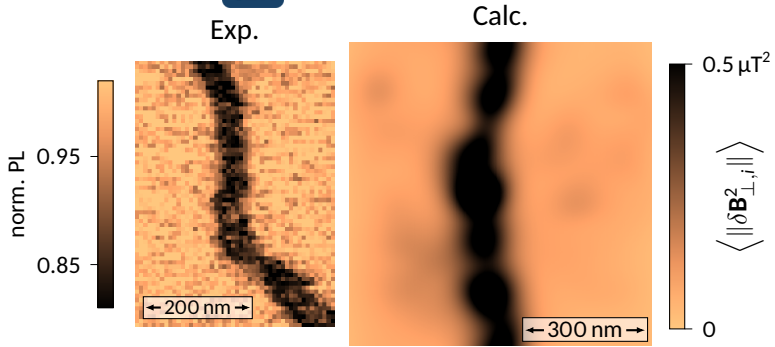


- NV frequency slightly below the gap, in the tail of power spectral density, which is the reason why we detect some noise when approaching the tip.
- No gap in the domain walls, presence of modes at the NV frequency: **the NV center is more sensitive to the noise from the walls!**

Origin of the noise: spin waves

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





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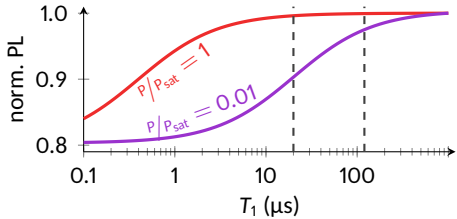
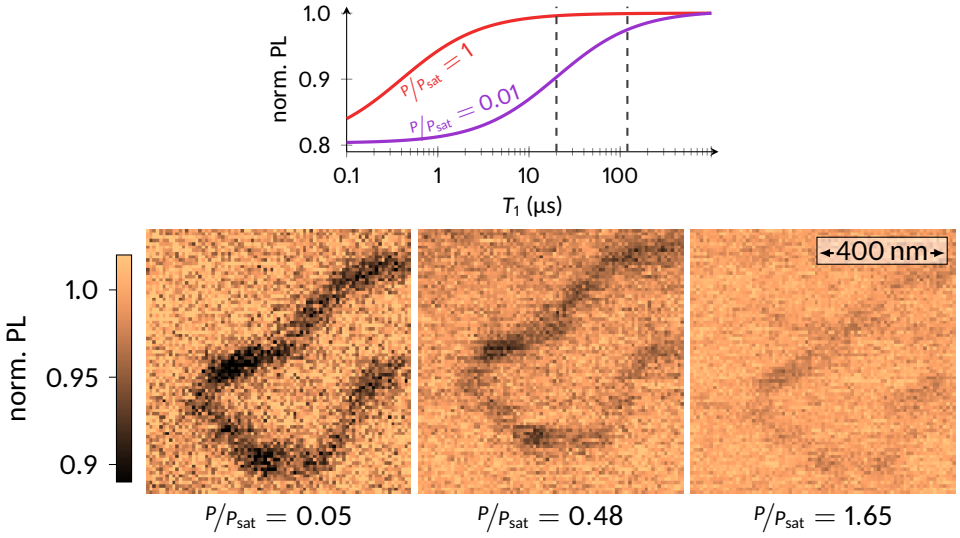
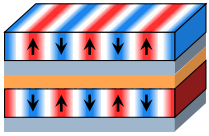
Dependence on the optical power



Dependence on the optical power



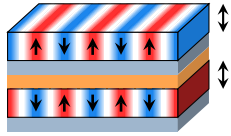
Imaging a spin spiral



thicker
Co layers
↓
vanishing
anisotropy

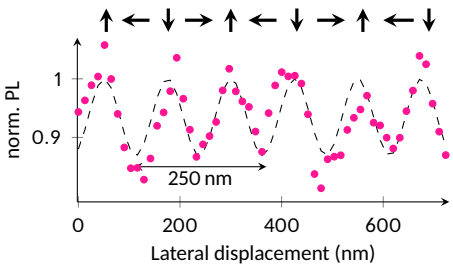
W. Legrand *et al*. *Nat. Mat.* 19 (2020), 34

Imaging a spin spiral

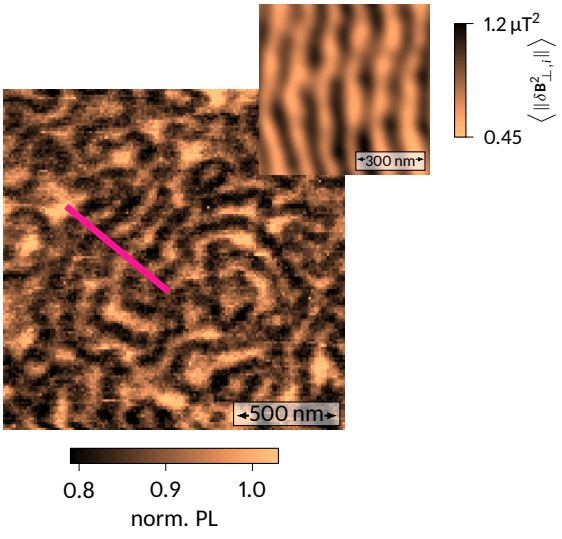


thicker Co layers ↓ vanishing anisotropy

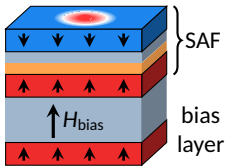
W. Legrand *et al.* *Nat. Mat.* 19 (2020), 34



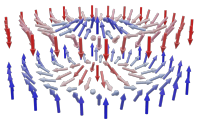
Calculated noise map



Skyrmions stabilized by a bias layer



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



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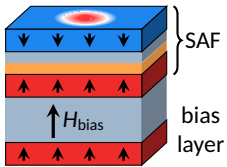
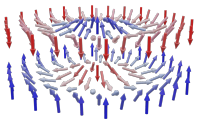
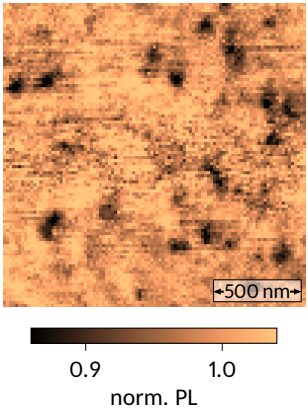
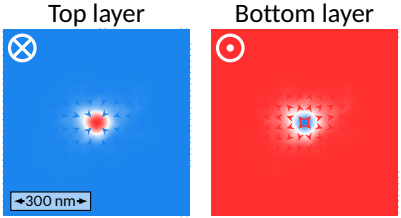
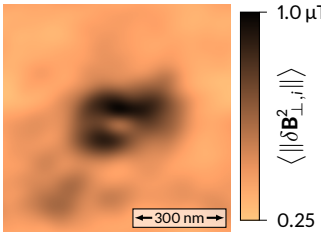


W. Legrand *et al.* *Nat. Mat.* 19 (2020), 34





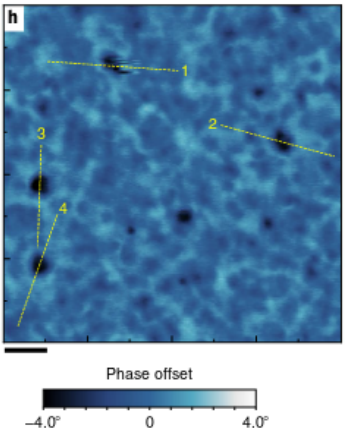




We are not probing the internal modes but the scattering of spin waves on the skyrmions

Are these really skyrmions?

MFM under oop field 110 mT



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

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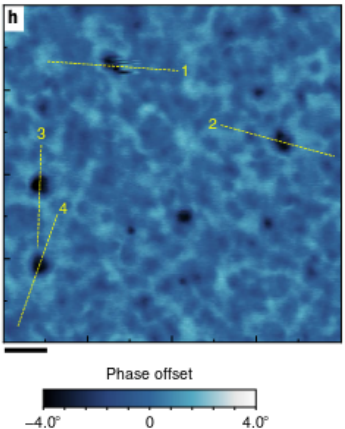
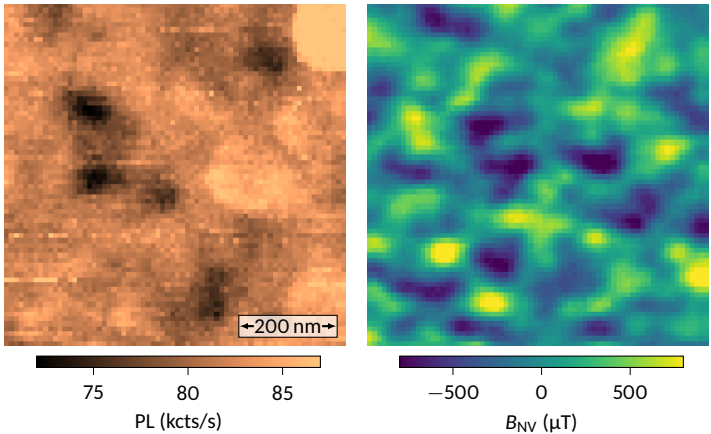


NV images (zero field)



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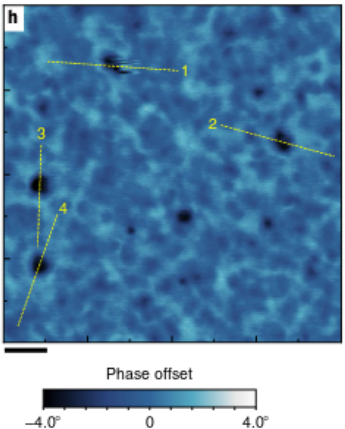
Large background fluctuations (roughness of the film)

Are these really skyrmions?

MFM under oop field 110 mT



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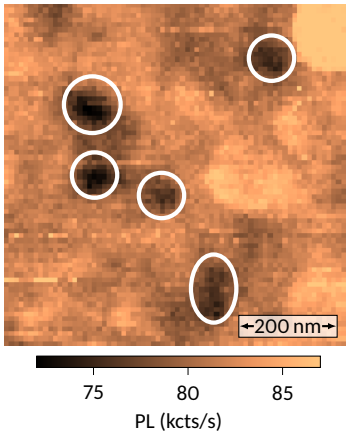

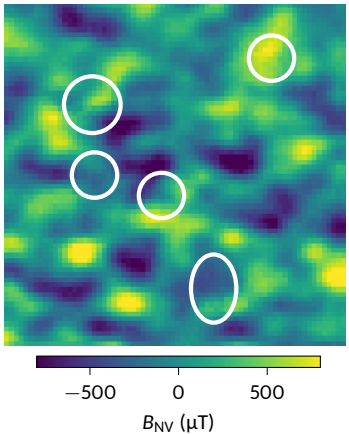

Large background fluctuations (roughness of the film)

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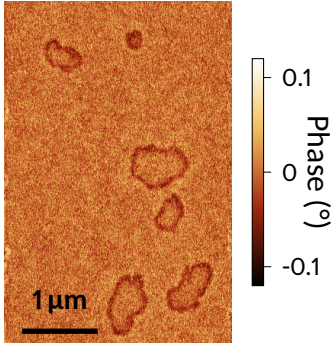
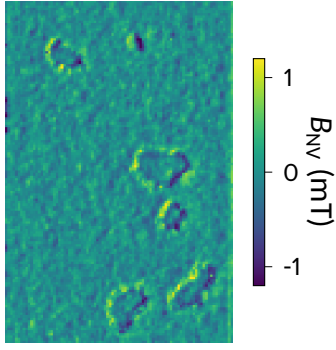
Stabilization by pinning in SAF without bias layer

- Similar samples without bias layer
- Oop field of about 150 mT applied

MFM



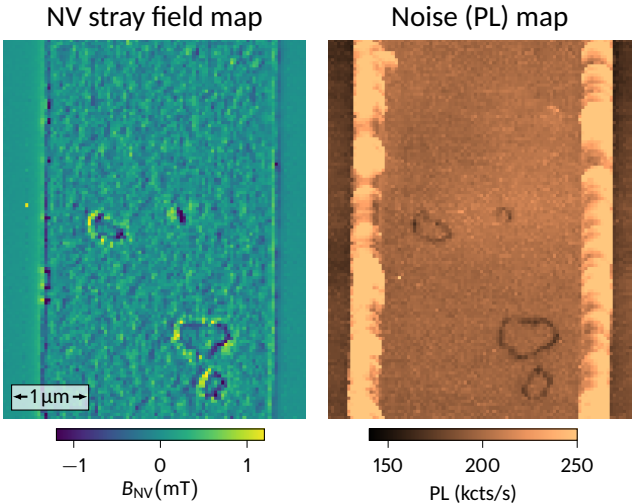
NV stray field map



spintec
SPIN IN ELECTRONICS

Van-Tuong Pham
Olivier Boulle

Combined magnetic stray field/magnetic noise imaging



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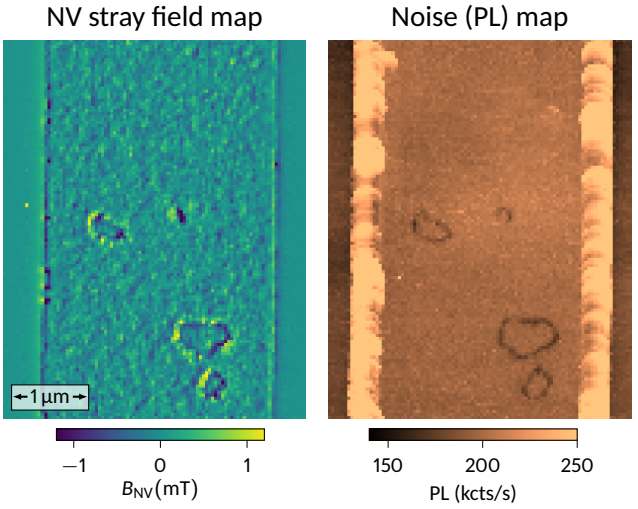
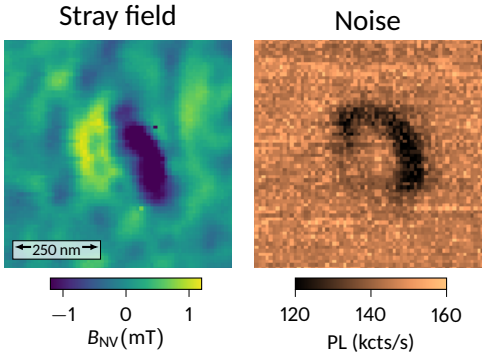
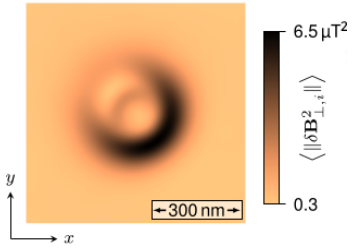


Could we get some insight about the skyrmions' internal structure?





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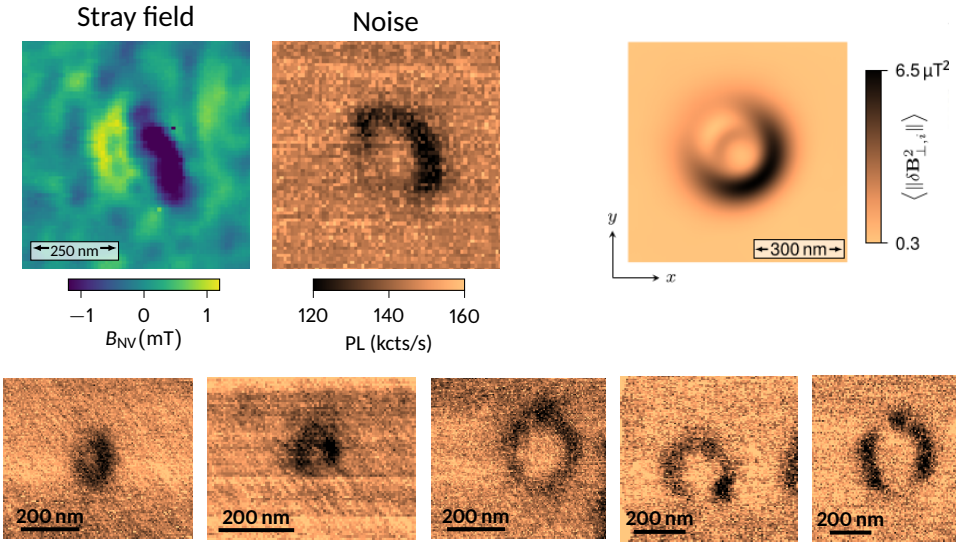
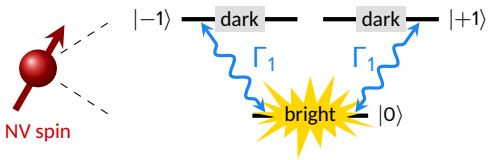
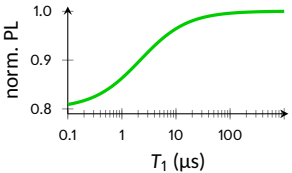


Work in progress…

Summary

→ All optical detection of magnetic noise with NV centers

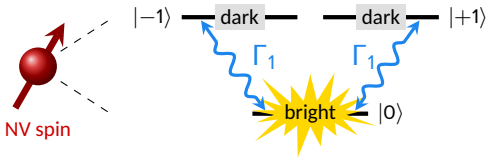


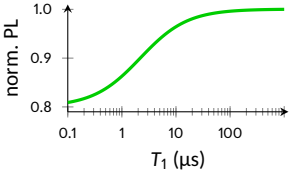


M. Rollo *et al.* *PRB* 103 (2021), 235418

Summary

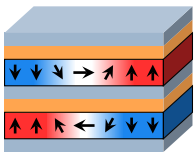
→ All optical detection of magnetic noise with NV centers

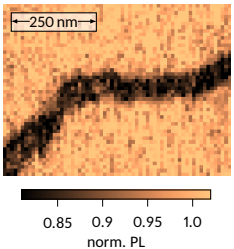


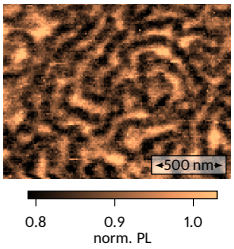


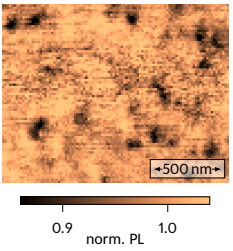
M. Rollo *et al.* *PRB* 103 (2021), 235418

→ Imaging of magnetic textures in SAF stacks from spin wave noise









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

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