Imaging non-collinear antiferromagnetic textures via single spin relaxometry

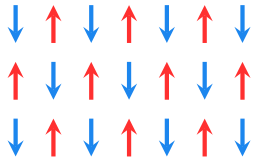
Aurore Finco

Laboratoire Charles Coulomb, Université de Montpellier and CNRS, Montpellier, France

MMM2020 online, 02-06 November 2020

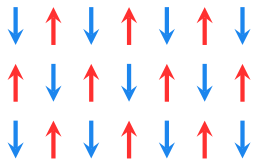
slides available at https://magimag.eu

Antiferromagnets



Alternating magnetic moments

Antiferromagnets



Alternating magnetic moments

- **Spintronics:** robust, fast, efficient
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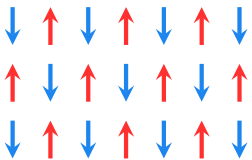

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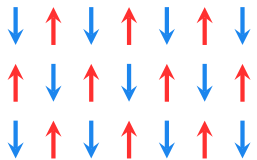

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→ *No net magnetization*

→ *Weak signals*

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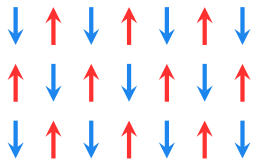

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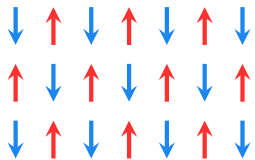

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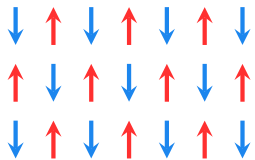

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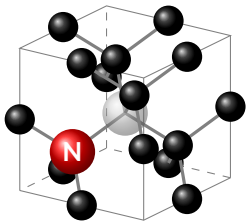
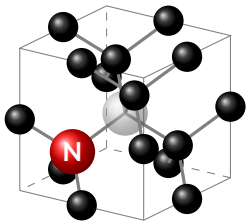
- **NV center magnetometry**: measurement of the stray field above the surface

NV centers as quantum sensors for weak magnetic fields



Defect in diamond

NV centers as quantum sensors for weak magnetic fields



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- Ambient conditions

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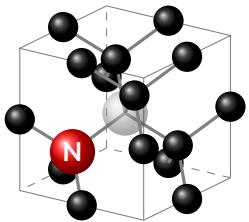

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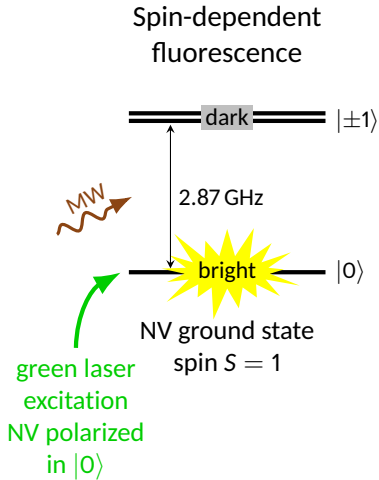

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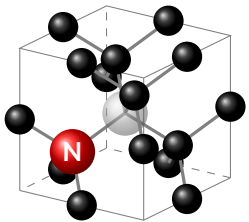

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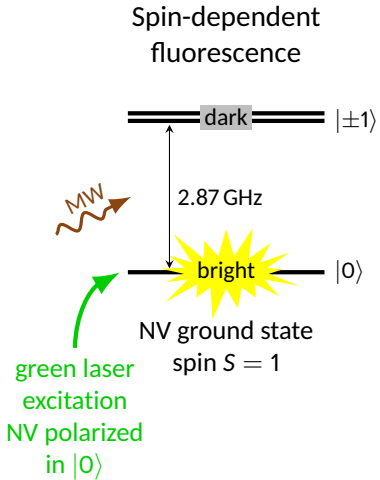

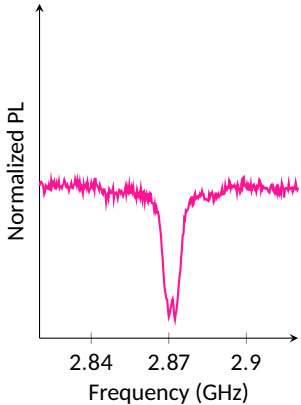

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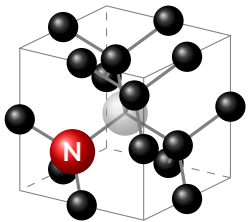

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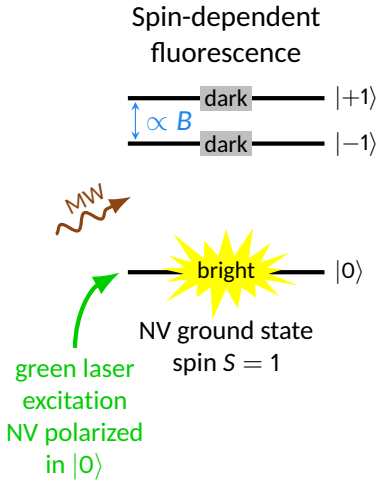

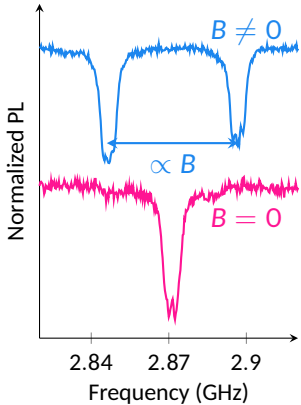

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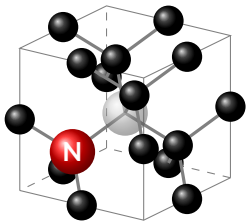

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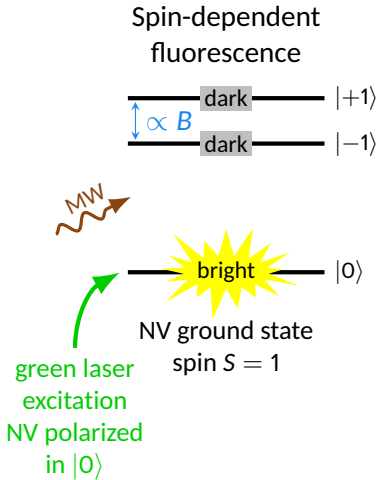
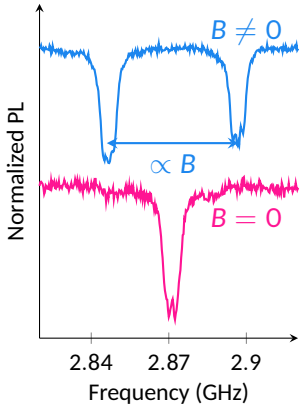
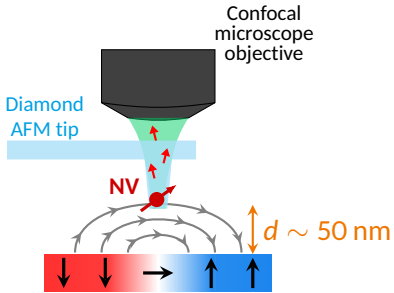
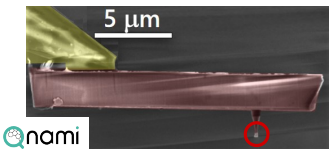




Sensibility: a few $\mu T/\sqrt{Hz}$

NV scanning magnetometry applied to antiferromagnets





Implanted single
NV center

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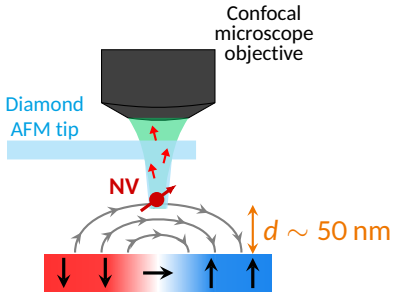

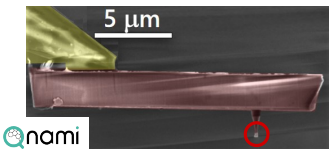

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Applications to ferromagnets: see talks
I3-06 and **O1-03**
about skyrmions and 2D materials
by Florentin Fabre

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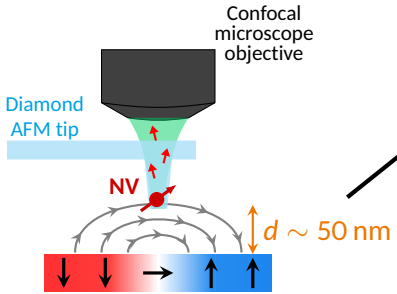
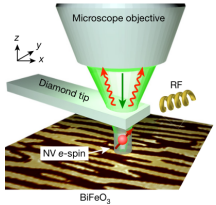
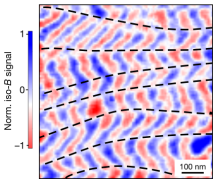


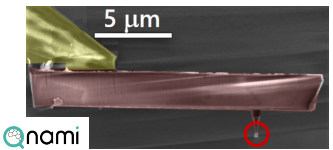
$BiFeO_3$: a room-temperature multiferroic





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

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



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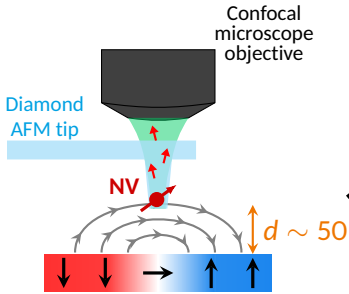

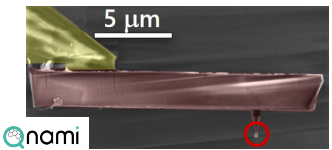

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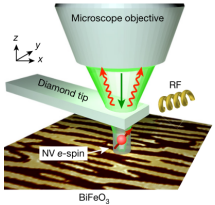

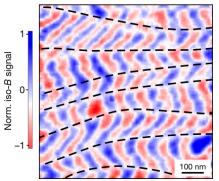

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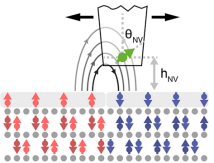
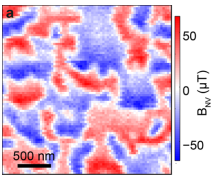
Cr_2O_3: a layered antiferromagnet





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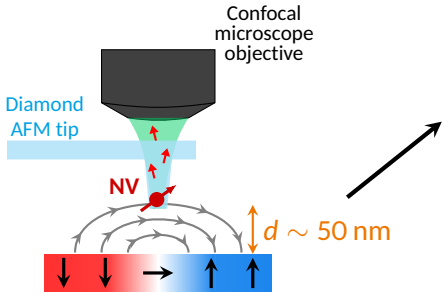

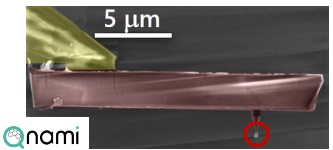

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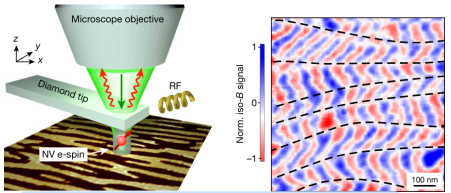

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Antiferromagnets with small uncompensated moments

What if this is not the case?

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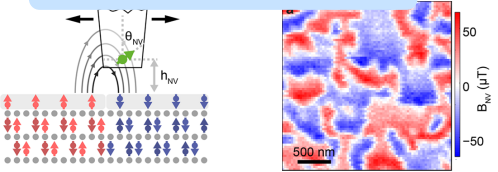

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Proposal: use relaxometry

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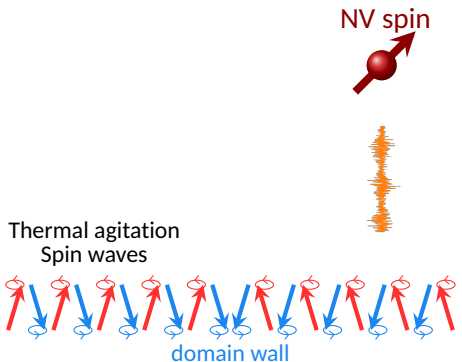

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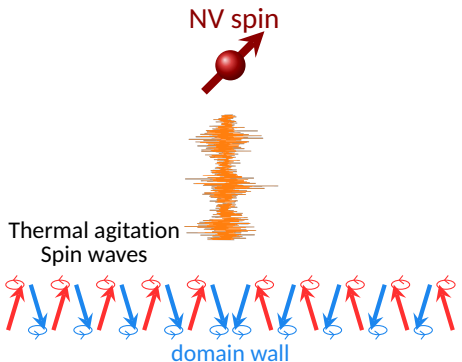


Outline

Collaborations: C2N: Thibaut Devolder, Jean-Paul Adam, Joo-Von Kim
UMR CNRS/Thales: William Legrand, Fernando Ajejas, Karim Bouzehouane, Nicolas Reyren, Vincent Cros

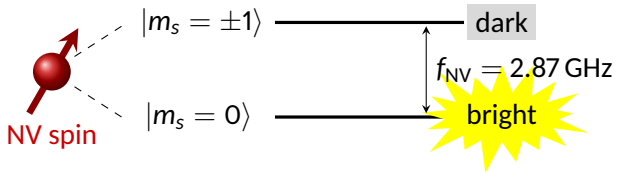
Experimental investigation of the NV center response to magnetic noise

Application to the detection of domain walls in a synthetic antiferromagnet

Extension of the relaxometry mode to spirals and skyrmions

A. Finco *et al.* *arXiv:2006.13130 [cond-mat]* (2020)

Detecting magnetic noise from the emitted PL



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Zeeman shift of the
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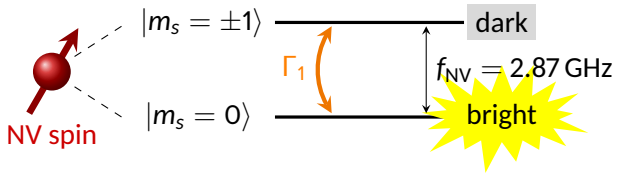

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magnetic field spectral density
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Acceleration of
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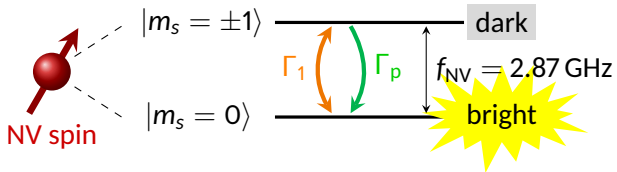

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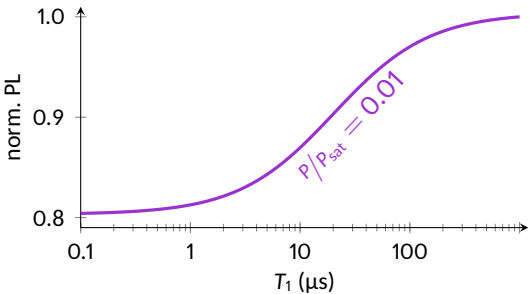

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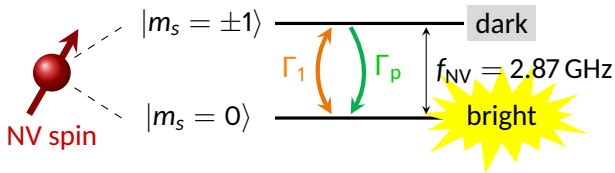

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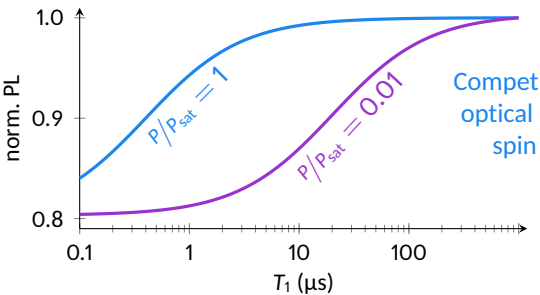
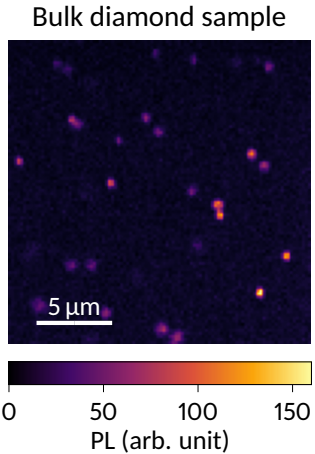


Competition between optical pumping and spin relaxation

Experimental investigation of the effect of magnetic noise

Collaboration C2N: Thibaut Devolder



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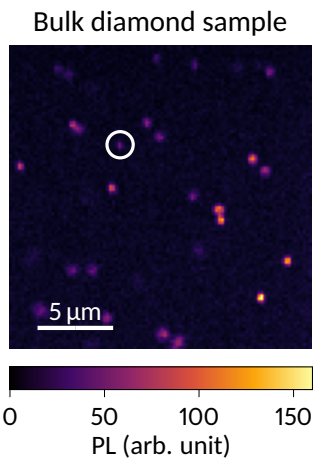

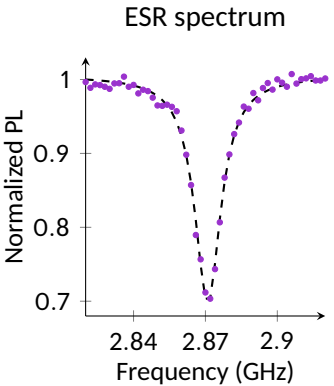

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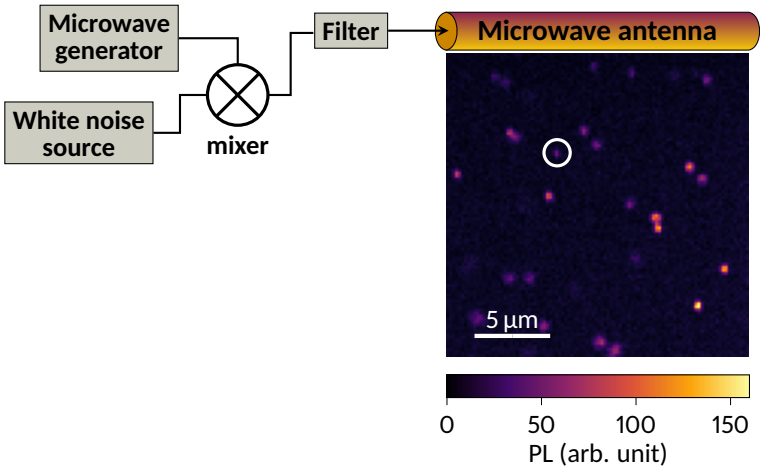

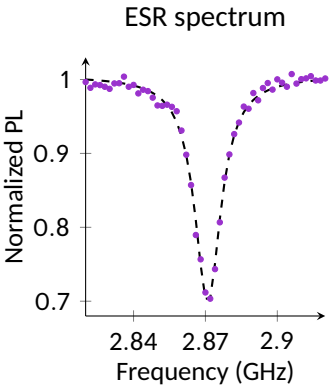

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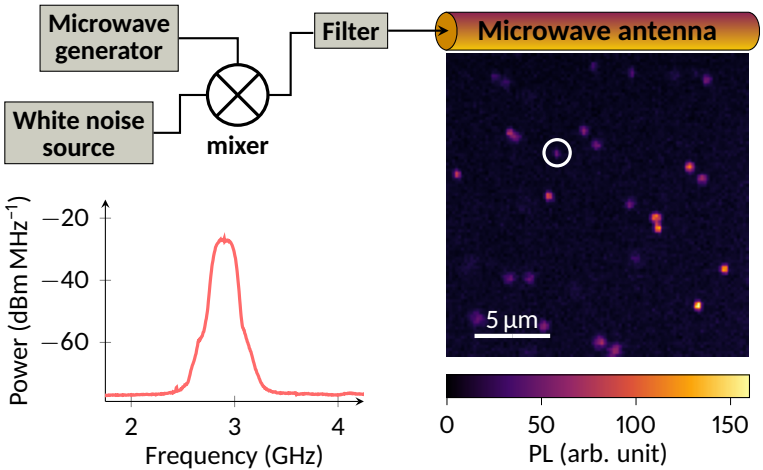

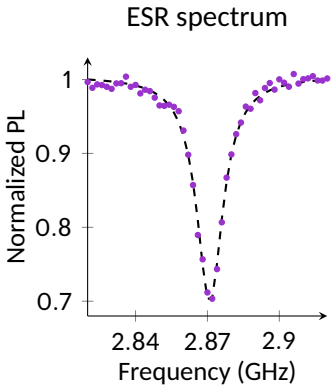

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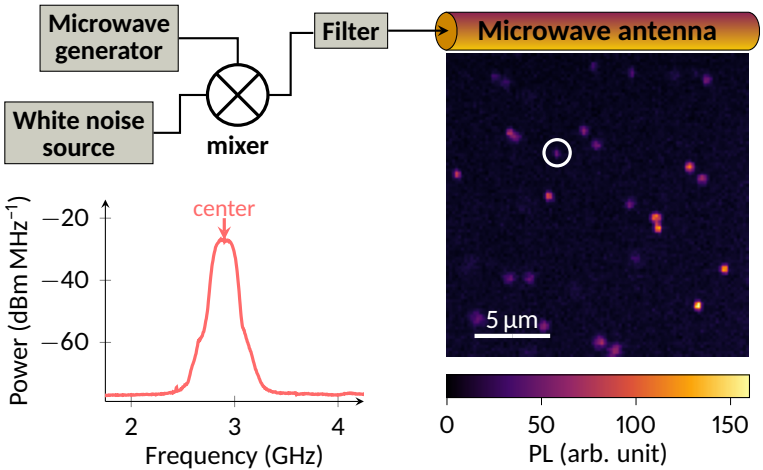

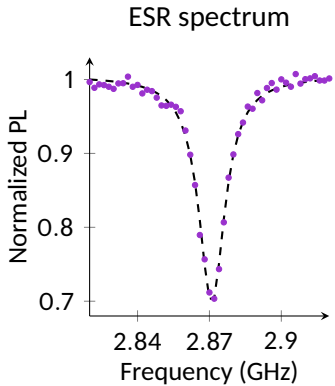

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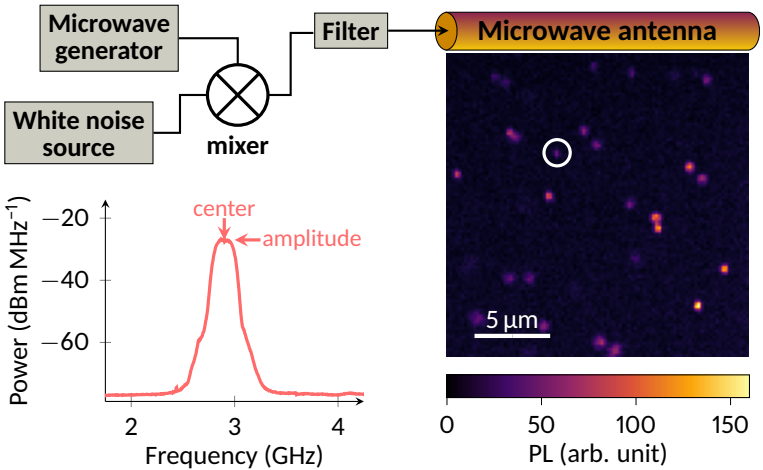

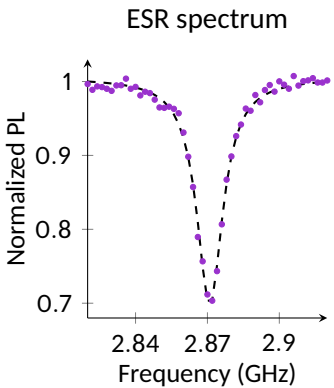

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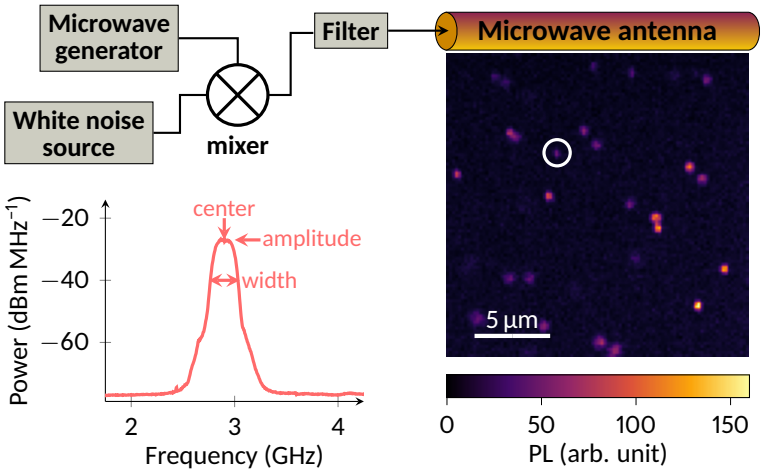
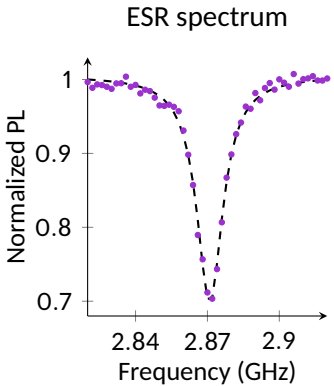
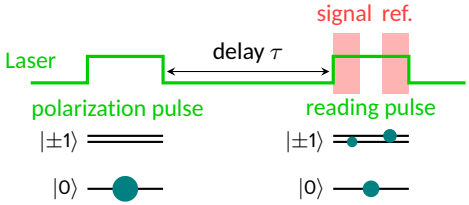




Acceleration of the longitudinal spin relaxation



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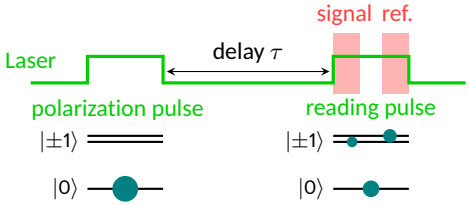

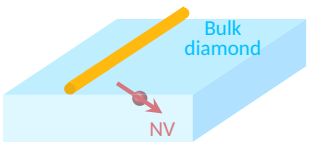

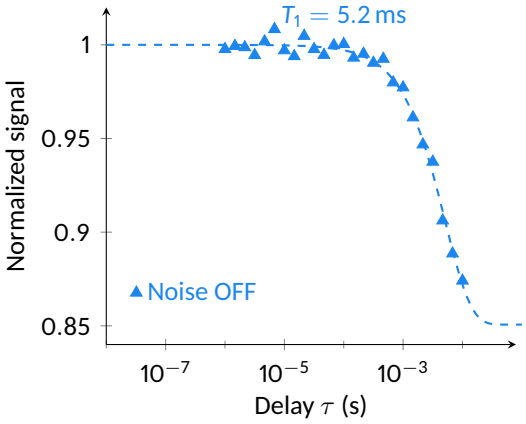

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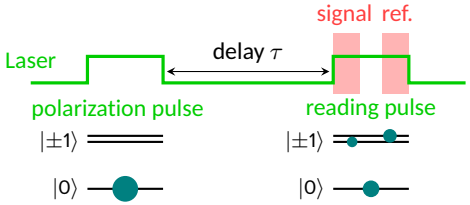
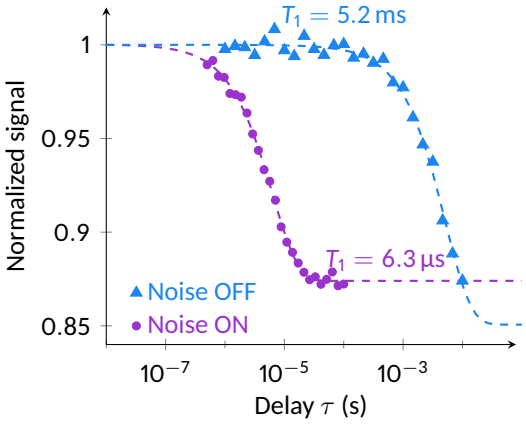
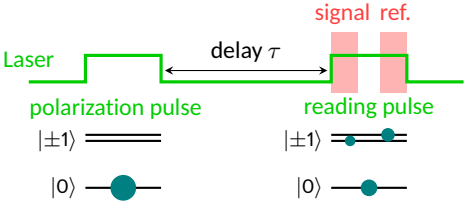
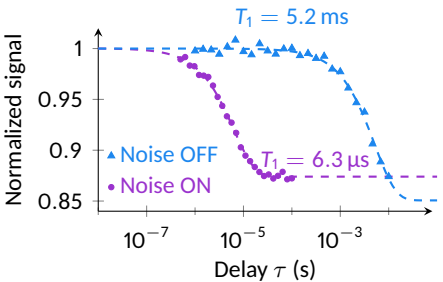




Noise window centered at 2.87 GHz

Acceleration of the longitudinal spin relaxation





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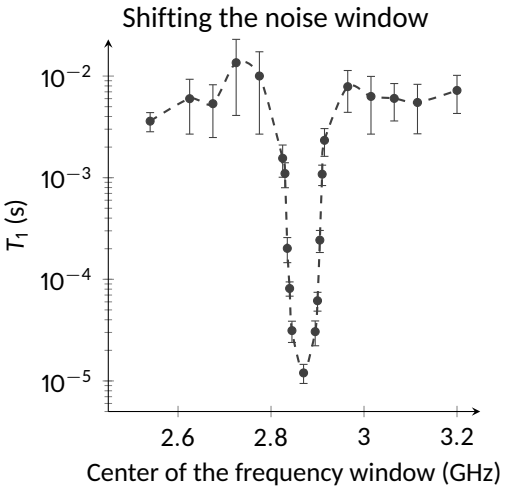

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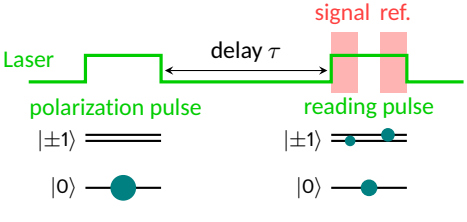

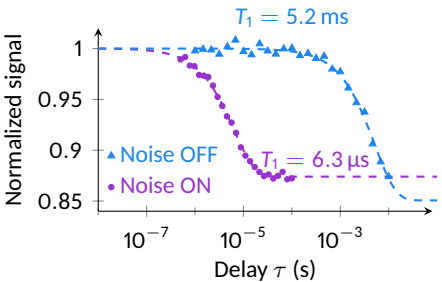

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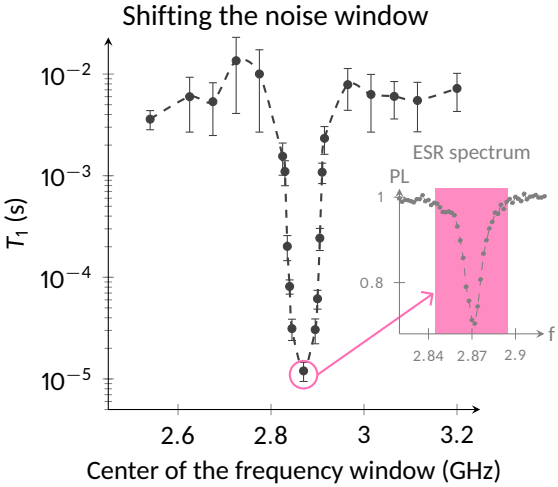

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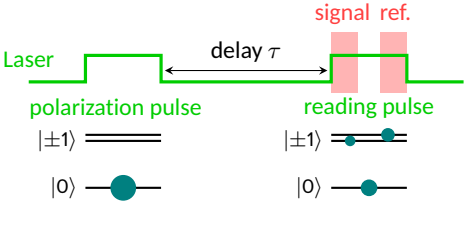

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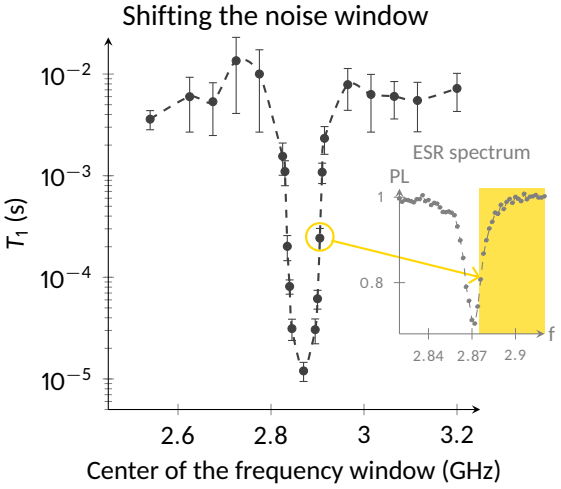

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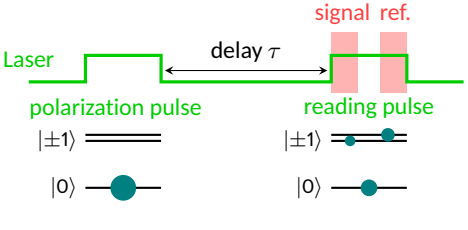

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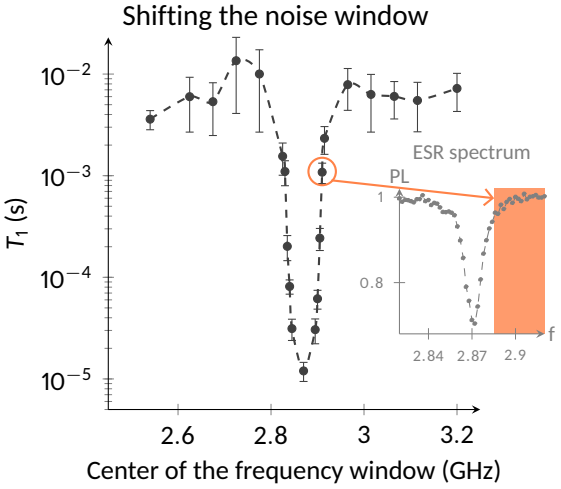

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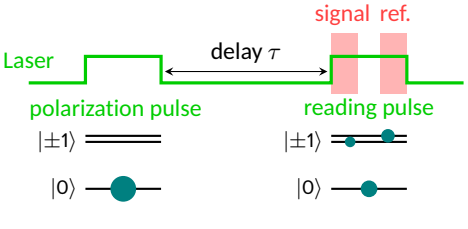

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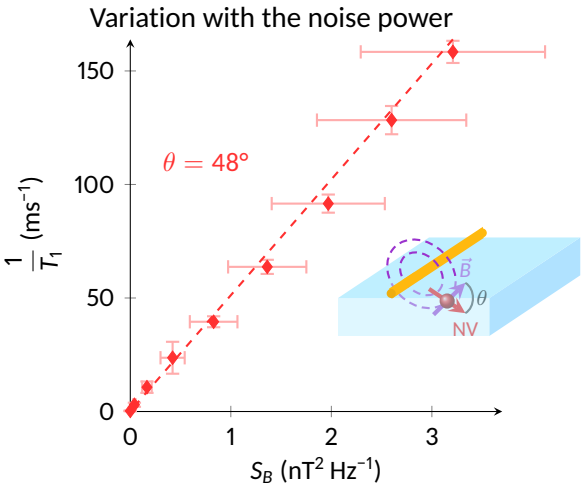
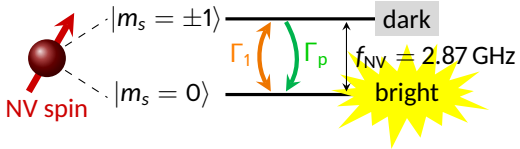
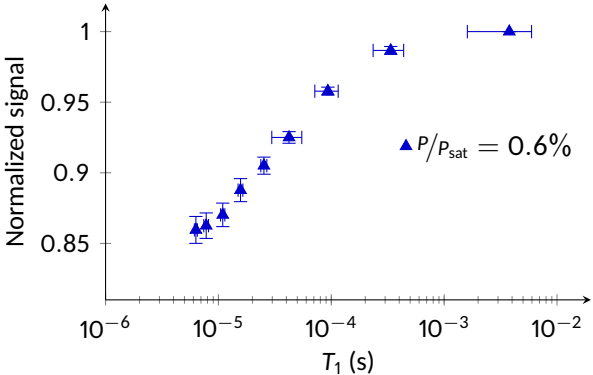


Effect on the emitted photoluminescence





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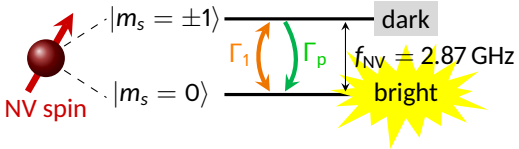

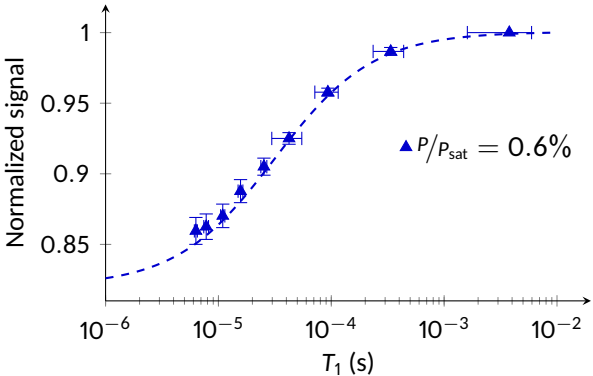

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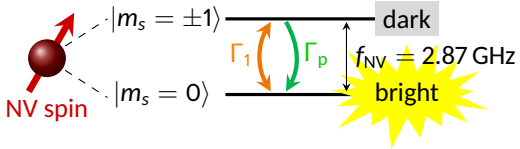

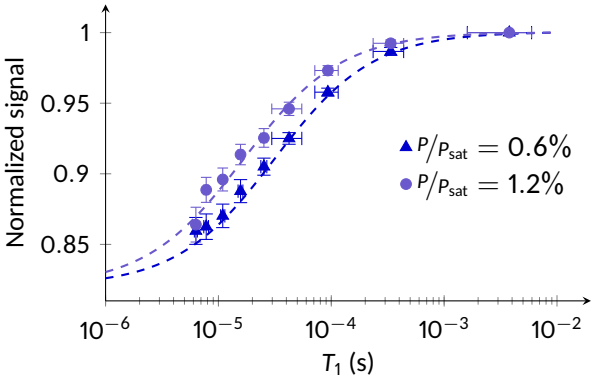

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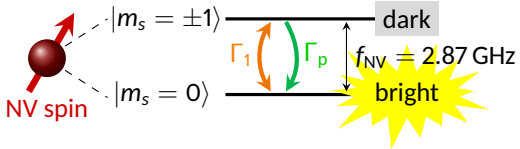

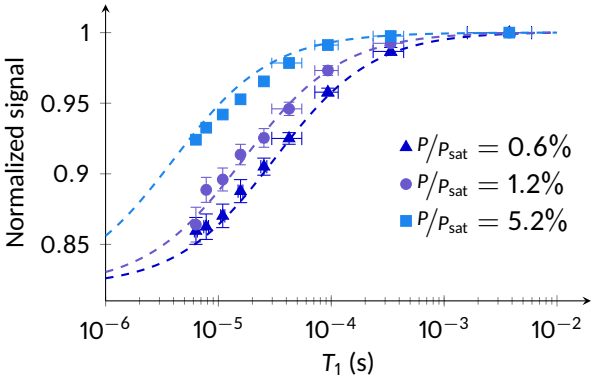

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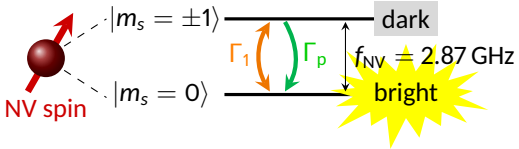

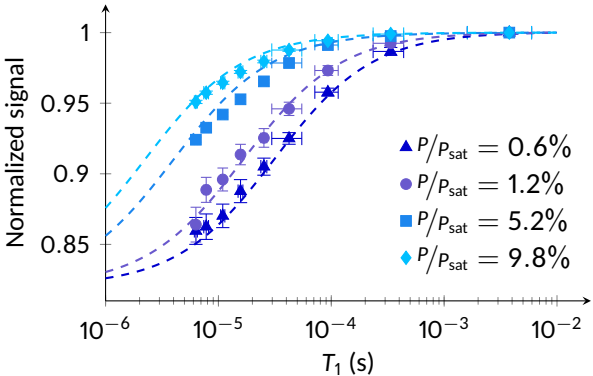

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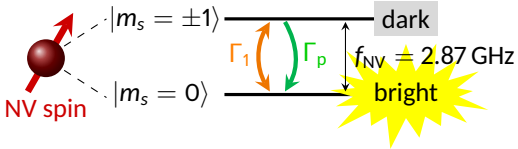
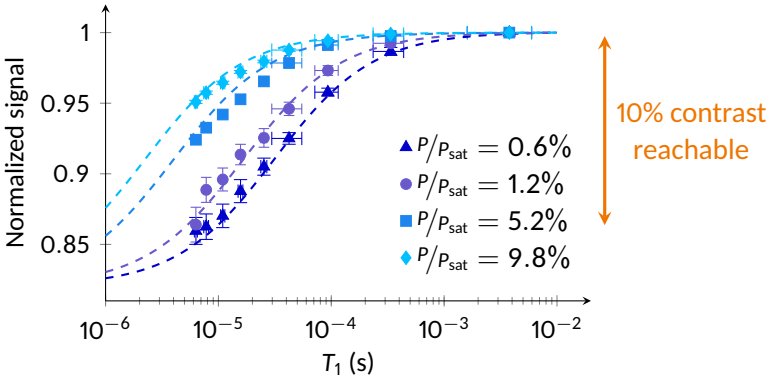


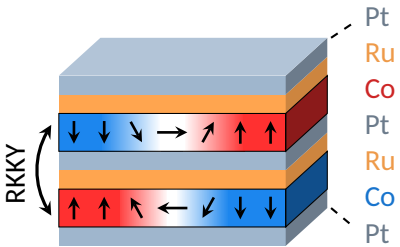


Synthetic antiferromagnets

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

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

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



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

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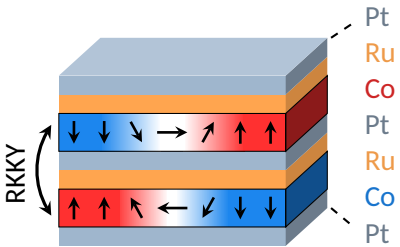
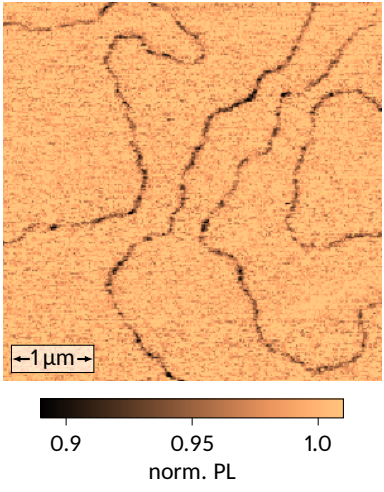
Two **ferromagnetic** layers coupled **antiferromagnetically**

- No net magnetic moment
- Small stray field (vertical shift)
- Compensation of the dipolar fields
  - Fast domain wall movement
    S.-H. Yang *et al.* *Nat. Nano.* 10 (2015), 221
  - Small skyrmions
    W. Legrand *et al.* *Nat. Mat.* 19 (2020), 34
- No skyrmion Hall effect
  T. Dohi *et al.* *Nat. Comm.* 10 (2019), 5153



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

Detection of domain walls by relaxometry



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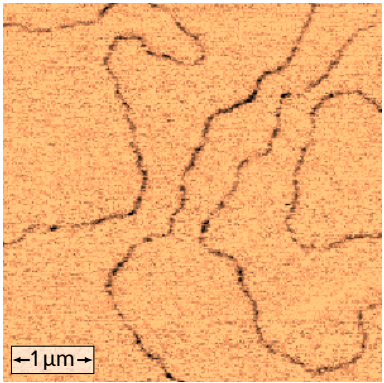

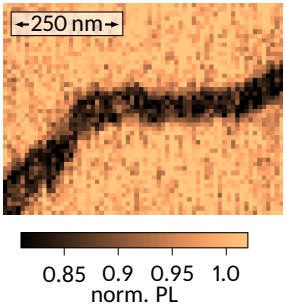

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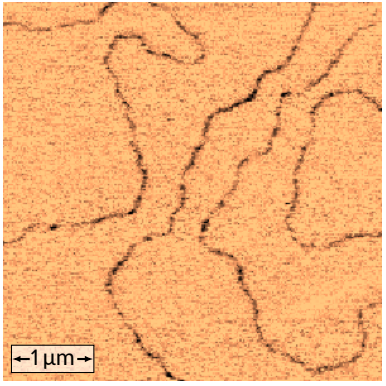

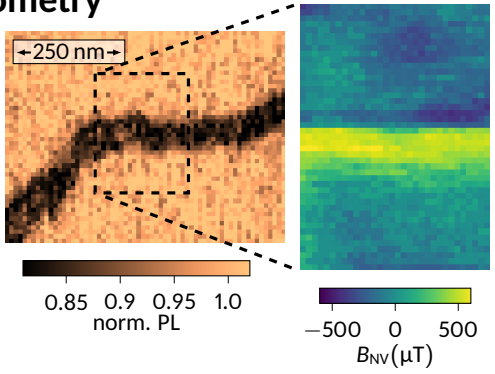

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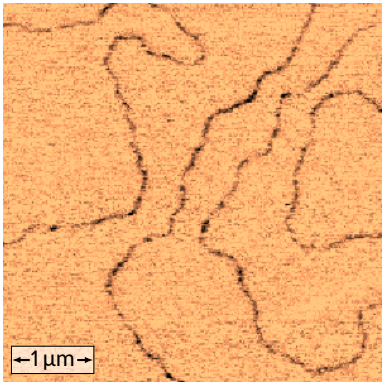
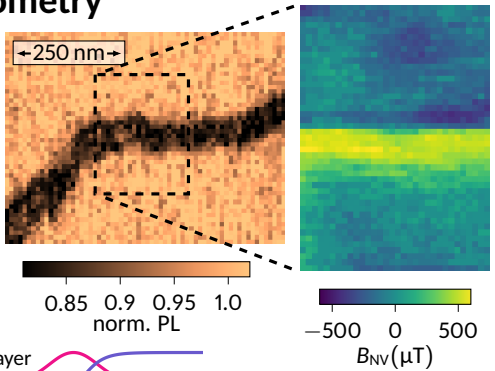
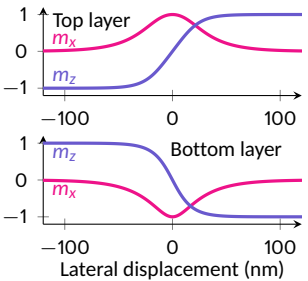
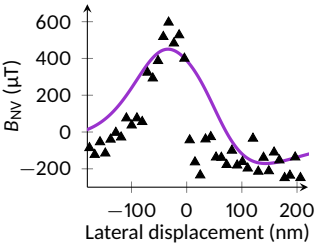
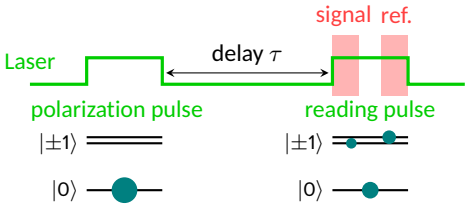








Local variation of the relaxation time



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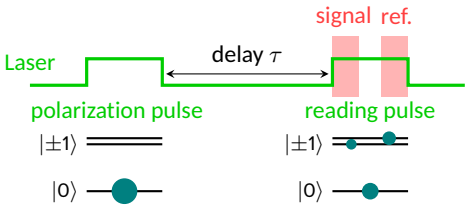
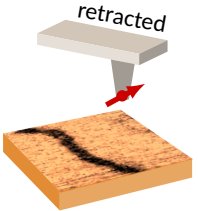
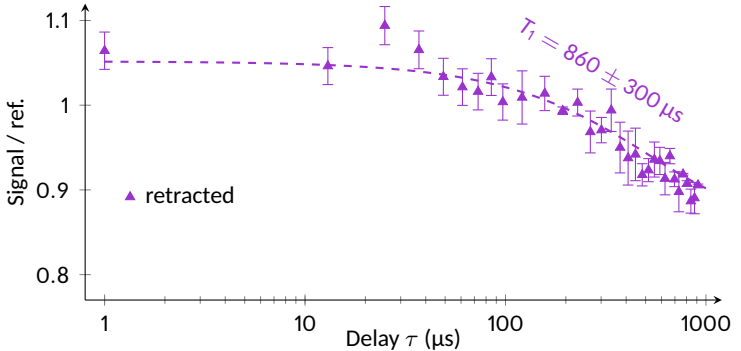
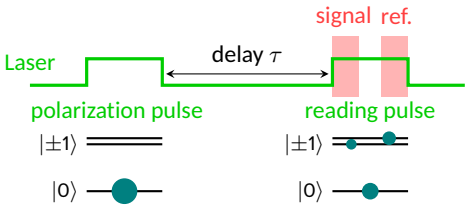
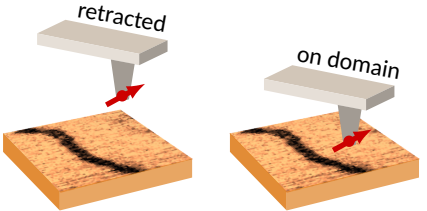


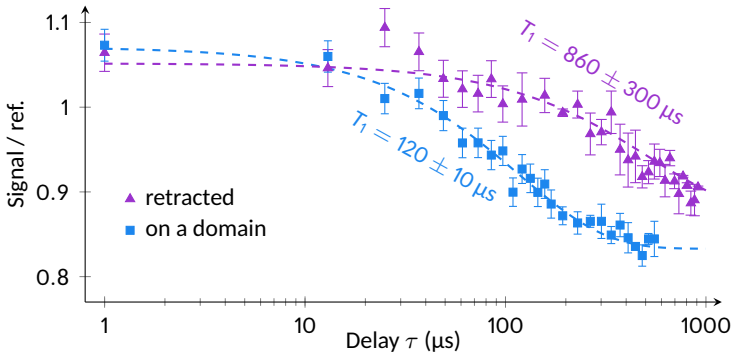




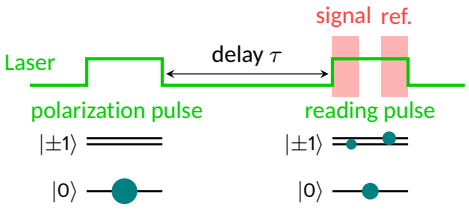
Local variation of the relaxation time

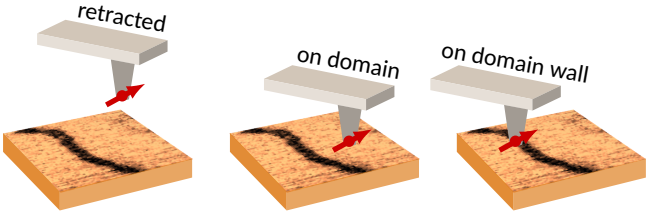


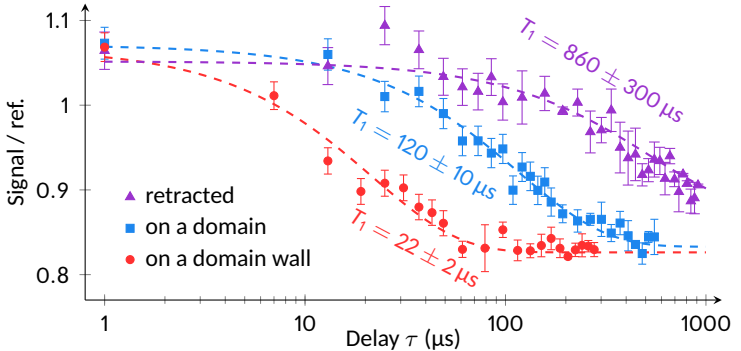




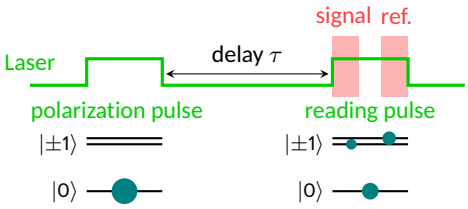
Local variation of the relaxation time

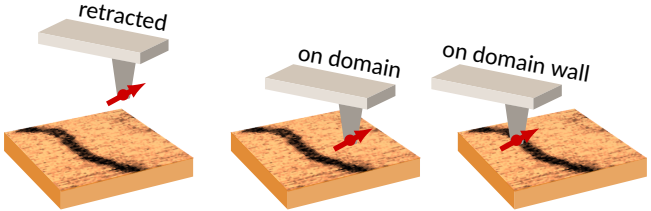






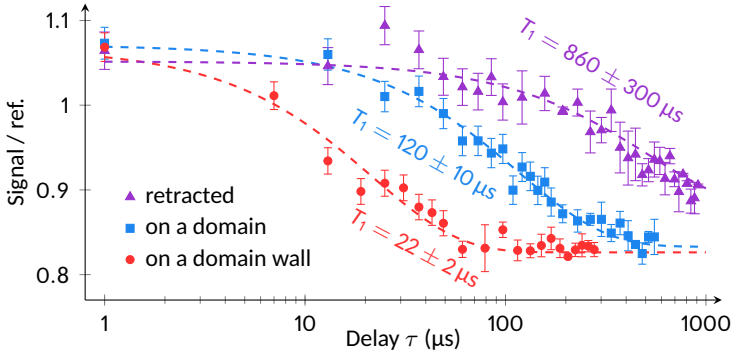
Local variation of the relaxation time



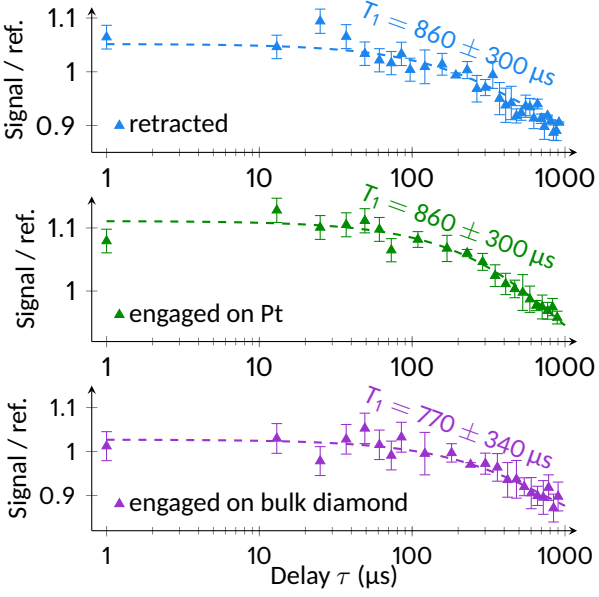


Clear diminution of T_1 above the domain wall

→ **Enhancement of the spin relaxation**

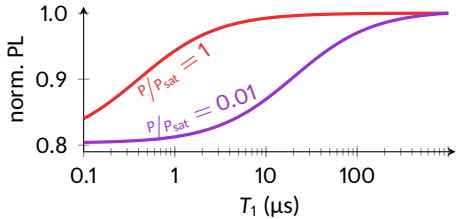


Magnetic origin of the noise

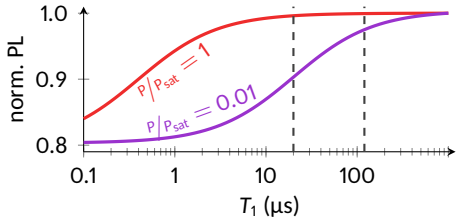


- Same T_1 with the tip retracted or engaged on Pt or bulk diamond
- We exclude Johnson noise (no effect on Pt)
- Also not an effect unrelated to the sample, like modification of the NV charge state

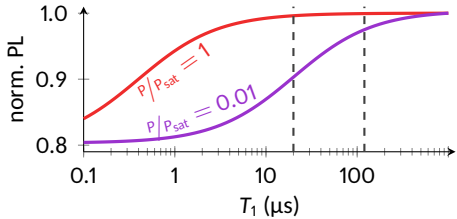
Dependence on the optical power

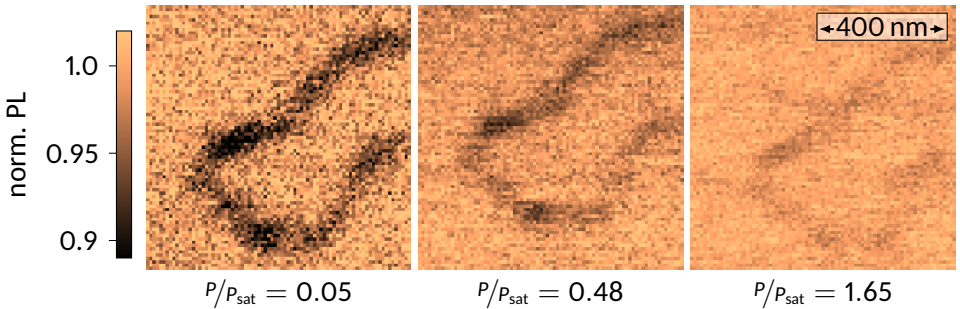


Dependence on the optical power



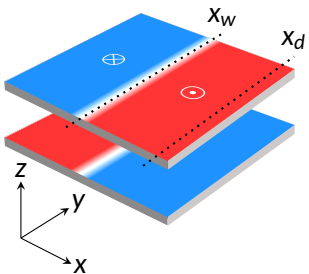
Dependence on the optical power





Origin of the noise: spin waves

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



Origin of the noise: spin waves

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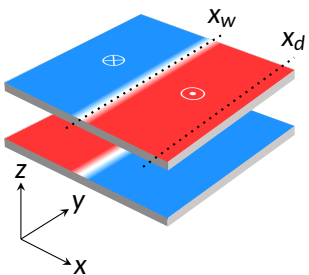
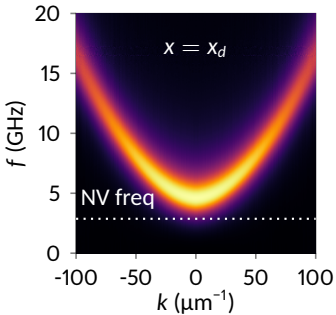
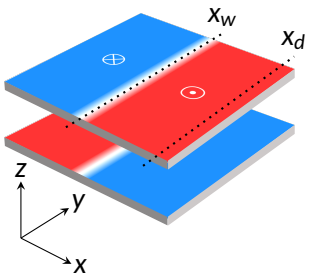


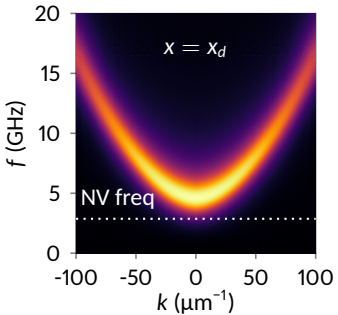


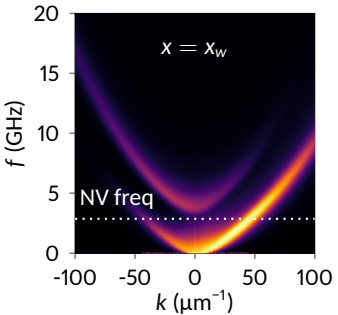
- NV frequency in the tail of the dispersion relation, almost below the gap: we are only sensitive to a few modes in the domains

Origin of the noise: spin waves

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







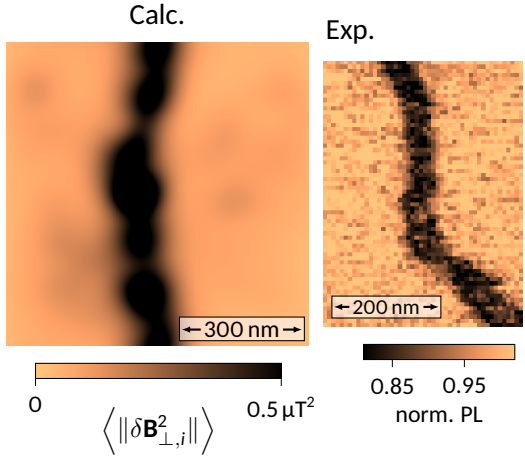
- NV frequency in the tail of the dispersion relation, almost below the gap: we are only sensitive to a few modes in the domains
- No gap in the domain walls, presence of modes at the NV frequency: **we are much more sensitive to the noise from the walls!**

Map of the detectable noise

Simulation of the expected noise map above a domain wall

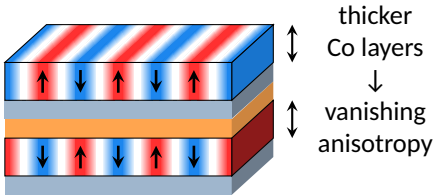
(at 2.87 GHz and at 80 nm from the surface)

- Disorder in the static magnetic configuration (anisotropy variations)
- Driving field at 2.87 GHz with random spatial variations
- Map obtained by averaging the resulting stray field for 100 realizations



More details: see talk N2-14 by Joo-Von Kim

Single-spin relaxometry on spin spirals



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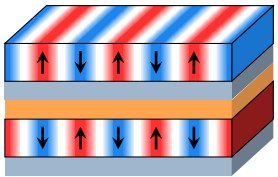
Single-spin relaxometry on spin spirals



thicker
Co layers
↓
vanishing
anisotropy

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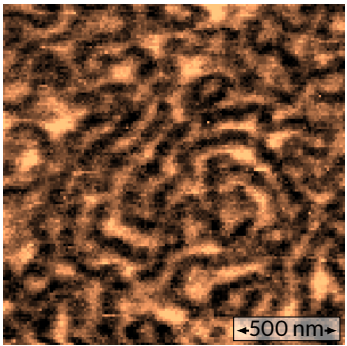
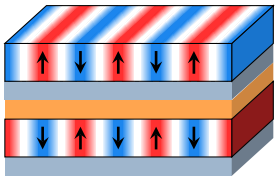


Single-spin relaxometry on spin spirals



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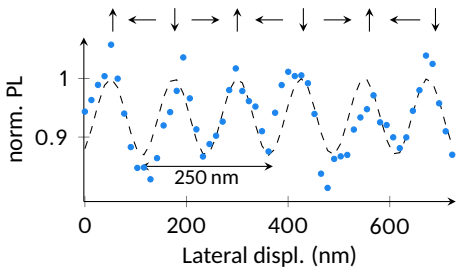
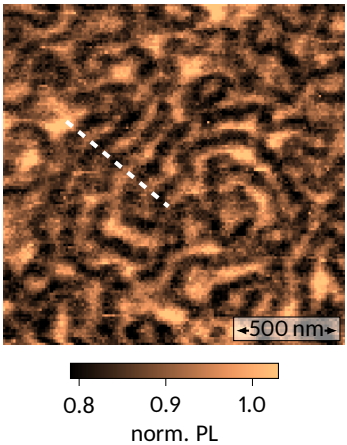
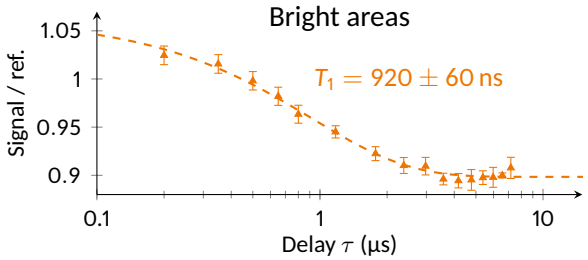
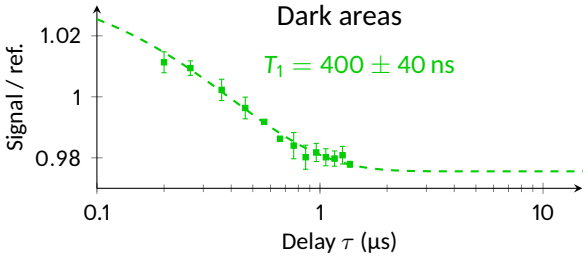


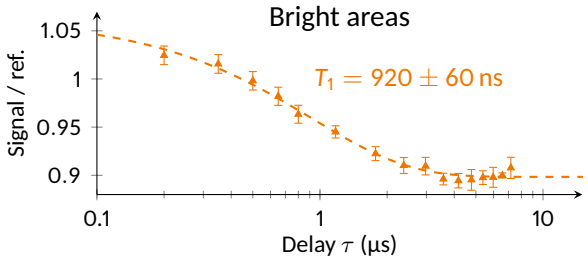


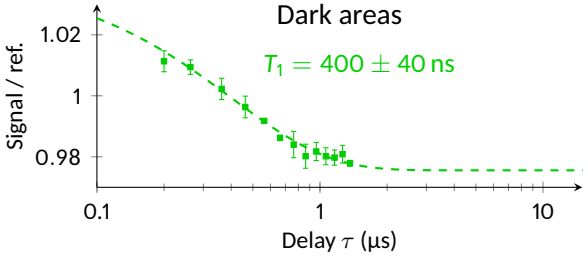
T1 measurements and expected noise map



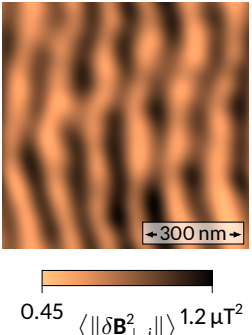


T1 measurements and expected noise map

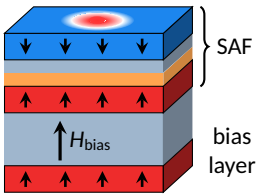




Calculated noise map



Antiferromagnetic skyrmions



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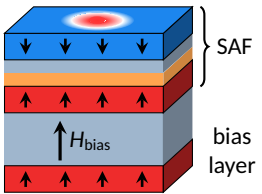
Antiferromagnetic skyrmions



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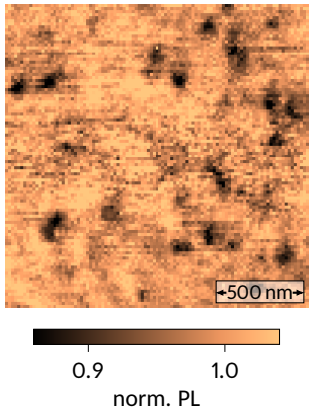
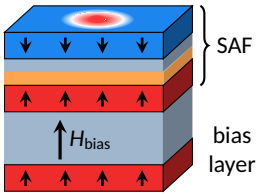


Antiferromagnetic skyrmions



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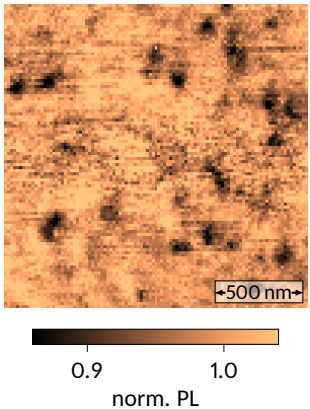
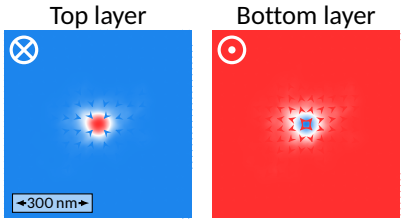
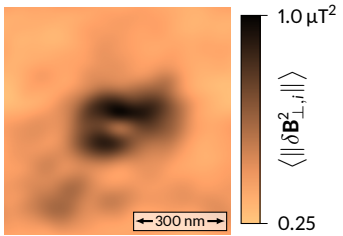
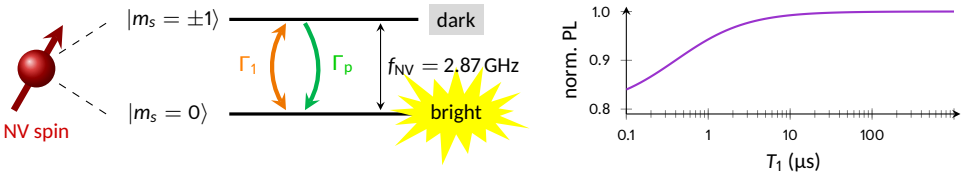




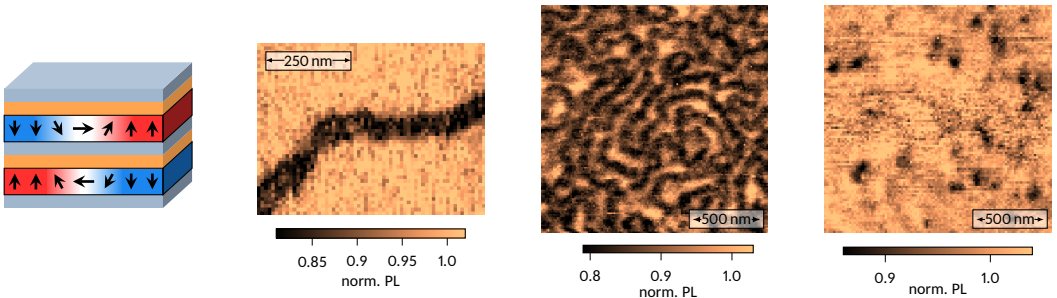


Summary

→ All optical detection of magnetic noise with NV centers



→ Application to the imaging of magnetic textures in synthetic antiferromagnets



A. Finco *et al.* *arXiv:2006.13130 [cond-mat]* (2020)

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