# Magnetic imaging via single spin relaxometry

A. Finco, A. Haykal, R. Tanos, M. Rollo, F. Fabre, S. Chouaieb, W. Akhtar, I. Robert-Philip, V. Jacques

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

W. Legrand, F. Ajejas, K. Bouzehouane, N. Reyren, V. Cros

Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France

T. Devolder, J.-P. Adam, J.-V. Kim

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



Skymag 2021 online, April 1st 2021

slides available at https://magimag.eu

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



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Alternating magnetic moments

No net magnetization Weak signals

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# $\rightarrow$ Antiferromagnetic structures are difficult to image!

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

SHG



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



SHG



XMLD-PEEM



J.-Y. Chauleau et al. Nat. Mat. 16 (2017), 803
 P. Wadley et al. Nat. Nano. 13 (2018), 362







XMLD-PEEM



SP-STM

<sup>2 nm</sup> M. Bode *et al. Nature* 447 (2007), 190

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

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





Defect in diamond



Defect in diamond

- Optical manipulation and reading
- Ambient conditions



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Spin-dependent fluorescence





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Diamond AFM tip



5











NV center



















5



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



5

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

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- Use the different noise properties above domains and domain walls for imaging

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

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Thermal agitation Spin waves

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

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



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

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# Two ferromagnetic layers coupled antiferromagnetically

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

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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

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

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Perfect test system for noise imaging!

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

#### Detection of domain walls by relaxometry



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## Detection of domain walls by relaxometry





9











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



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• NV frequency below the gap: we are not sensitive to the spin waves in the domains.

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- NV frequency below the gap: we are not sensitive to the spin waves 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!

#### 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)

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0.8 0.9 1.0 norm. PL



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# Calculated noise map +300 nm+ +500 nm+ 0.9 1.0 0.8 norm. PL

 $1.2 \,\mu T^2$ 

0.45

 $\|\delta \mathbf{B}_{\perp,i}^2\|$ 

#### and antiferromagnetic skyrmions!



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



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





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## Summary

 $\rightarrow$  All optical detection of magnetic noise with NV centers



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 $\rightarrow$  Application to the imaging of magnetic textures in synthetic antiferromagnets



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## Acknowledgments

### L2C, Montpellier

Angela Haykal Rana Tanos Maxime Rollo Saddem Chouaieb Florentin Fabre Waseem Akhtar Isabelle Robert-Philip Vincent Jacques

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European Research Council





