Imaging spin textures in synthetic antiferromagnets with a scanning-NV magnetometer

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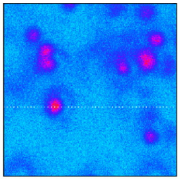
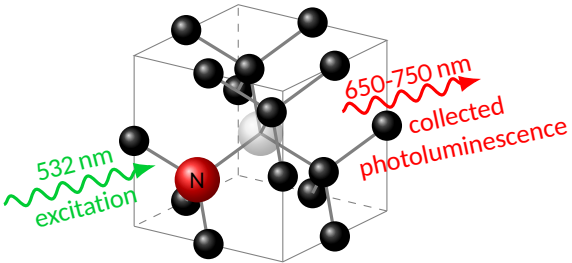
erc
IMAGINE

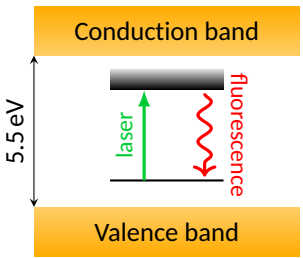
The Nitrogen Vacancy (NV) center in diamond

- Defect consisting of a N atom and a vacancy inside the C lattice
- Equivalent to an artificial atom with levels inside the diamond gap
- Detection of the photoluminescence of **single emitters** at room temperature



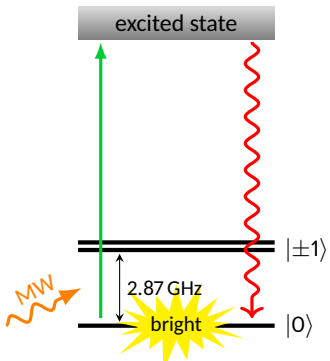
A. Gruber *et al.* *Science* 276 (1997), 2012–2014





Use the NV center as a precise magnetometer

Spin-dependent fluorescence



spin state $S = 1$

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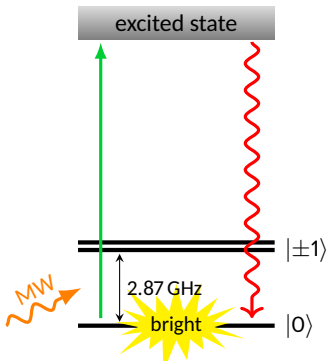

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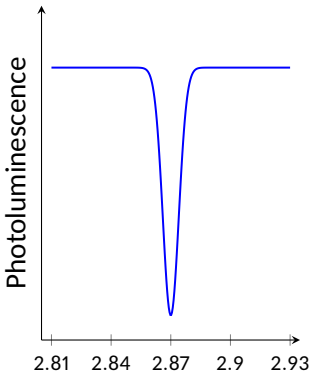
Optically Detected Magnetic Resonance



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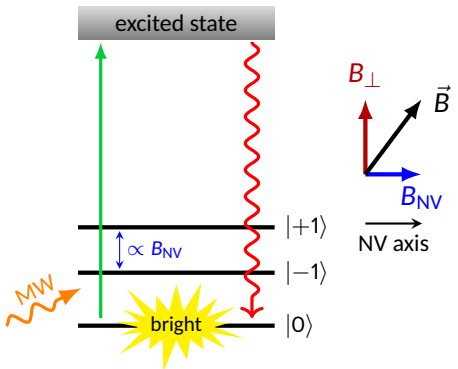

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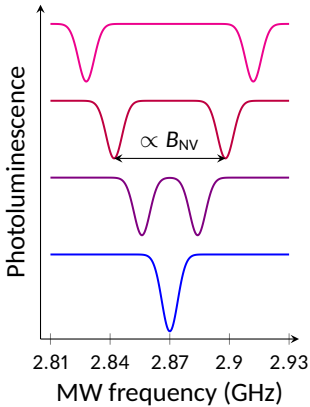

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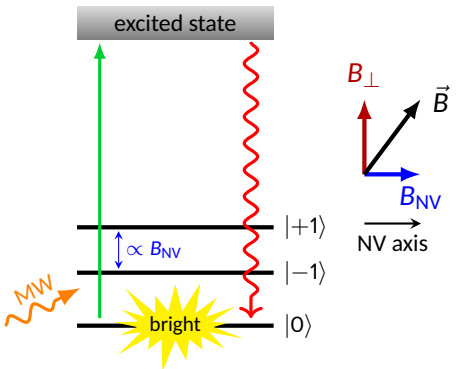

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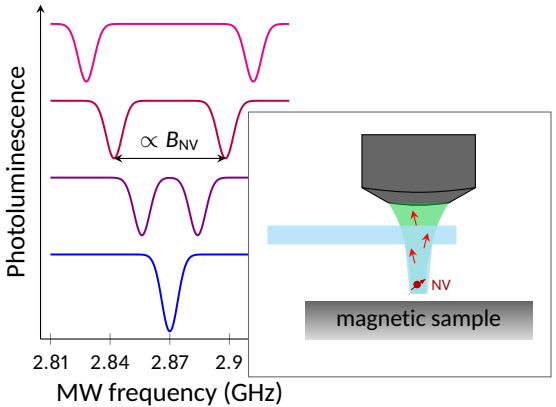
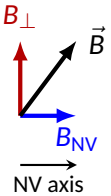
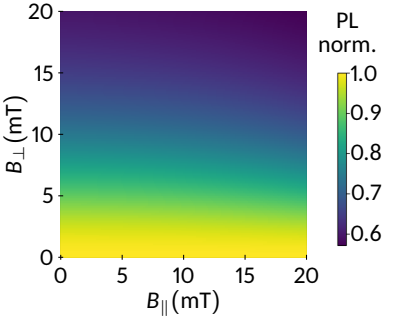


Qualitative measurement mode (“quenching”)

- Large $B_\perp$ → mixing of the spin states
- Decrease of the NV center photoluminescence





J.-P. Tetienne *et al.* *New Journal of Physics* 14 (2012), 103033

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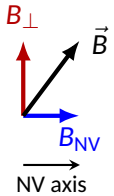
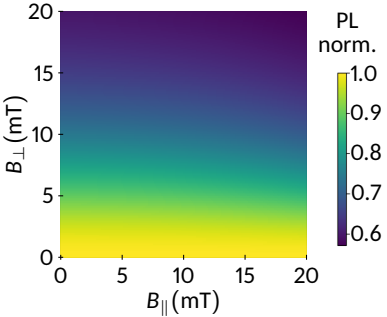
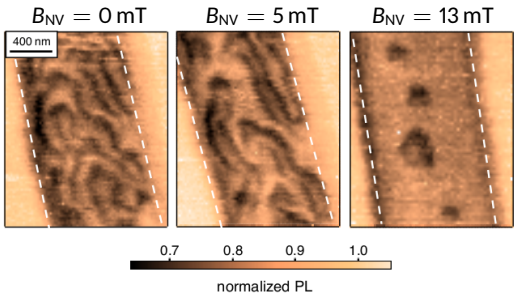




- Scanning and recording the photoluminescence at each pixel
- Localization of the areas producing stray field



J.-P. Tetienne *et al.* *New Journal of Physics* 14 (2012), 103033

W. Akhtar *et al.* *Physical Review Applied* 11 (2019), 034066

Two measurement modes available

Quantitative mode

$B_\perp < 5\,\mathrm{mT}$

- Gives access to the precise value of the stray field along the NV axis, sensitivity $1\,\mu\mathrm{T\,Hz^{-1/2}}$
- Need to measure a spectrum at each pixel to localize the resonance
- Requires a microwave excitation
- Slow, sensitive to drift

Antiferromagnetic cycloid in $BiFeO_3$

poster A. Haykal tomorrow

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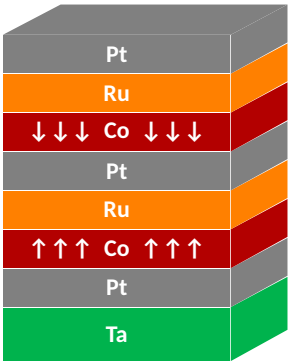
Qualitative mode
“Quenching”
$B_\perp > 5\,\mathrm{mT}$

- Localize the areas producing a large stray field
- Only need to record the photoluminescence at each pixel
- No microwave excitation required
- Strength of the measured field unknown

Synthetic antiferromagnets

Ferromagnetic layers coupled antiferromagnetically by the RKKY interaction through a non-magnetic Ru layer



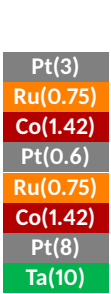
- Compensation of the dipolar stray field from each layer
  → stabilization of **smaller skyrmions**
- Compensation of the skyrmion Hall effect
  → movement parallel to the current

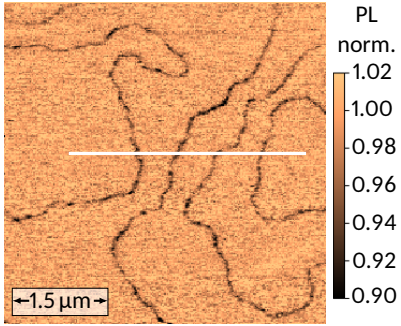
X. Zhang *et al.* *Nature Communications* 7 (2016), 10293

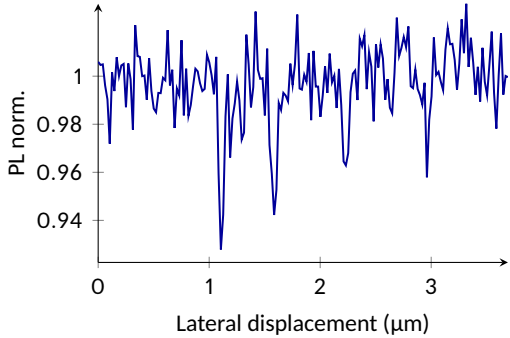
- Small stray field expected at the surface
  → Use NV magnetometry!

Domain walls in a SAF

- Sample with out-of-plane anisotropy, large antiferromagnetic domains
- Domain walls between oppositely magnetized areas measured **in quenching mode!**
- PL quenching rate 5 to 10 %







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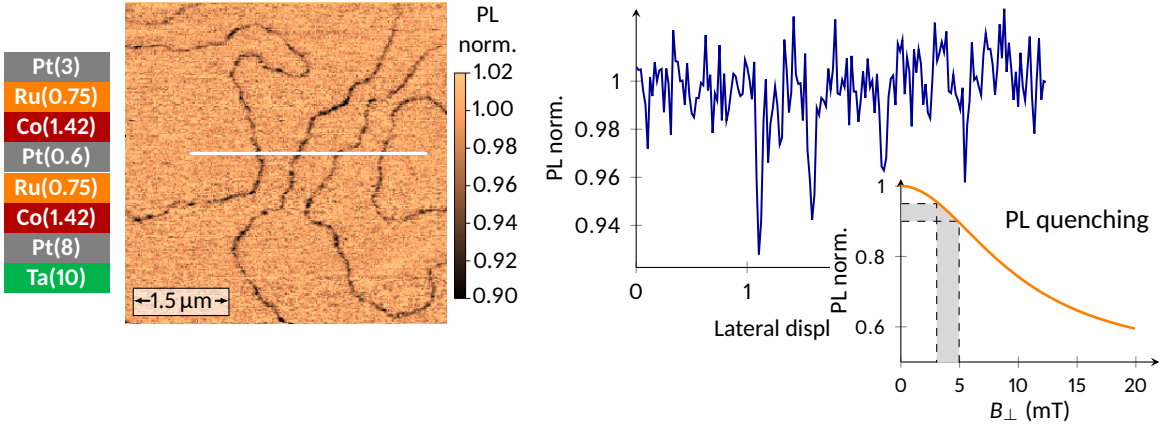
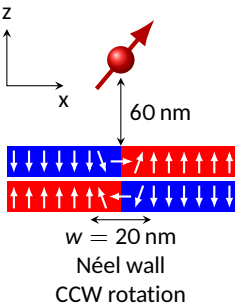
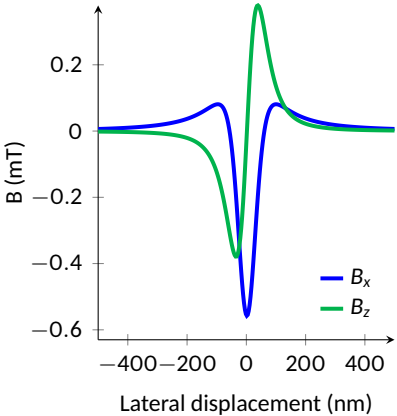


A not perfectly compensated SAF?



Stray field expected for a perfectly compensated state



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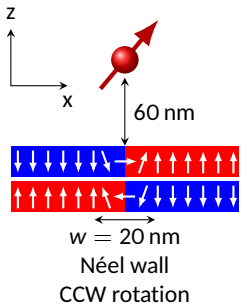

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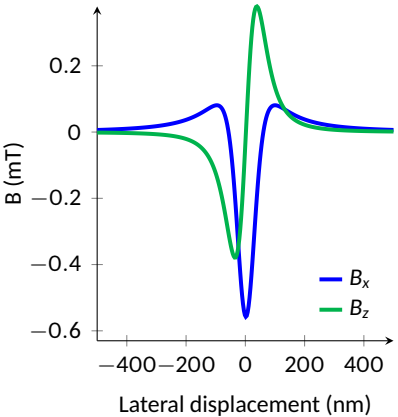
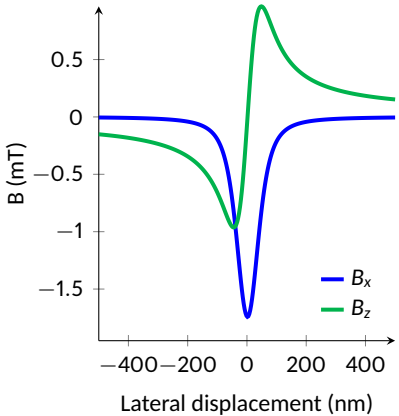
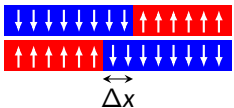


Stray field expected for 10% variation of M_s

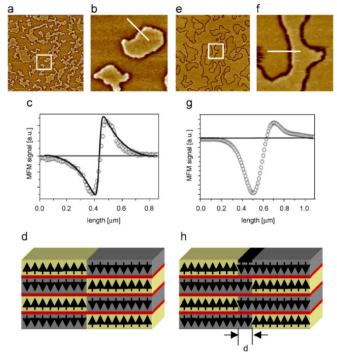


A shift between the layers?



- Creation of an uncompensated region at the wall → larger stray field
- Gain in dipolar energy
- Loss in interlayer exchange

Stacks of N AF coupled multilayers consisting of X FM coupled layers



N = 10, X = 5 N = 4, X = 7

O. Hellwig *et al.* *J. Magn. Magn. Mater.* 319 (2007), 13–55

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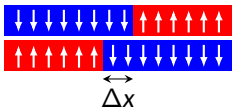

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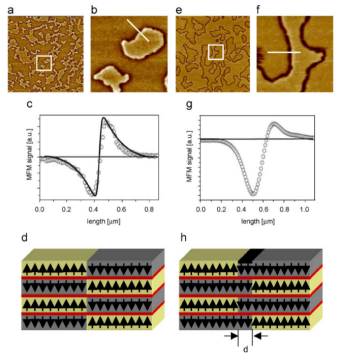

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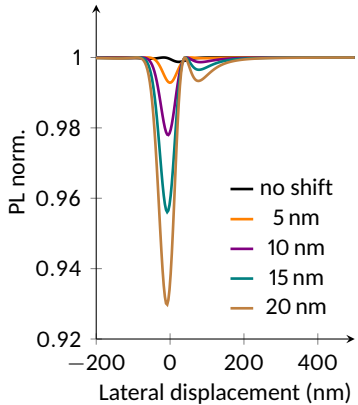
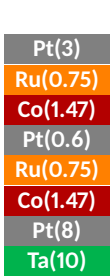
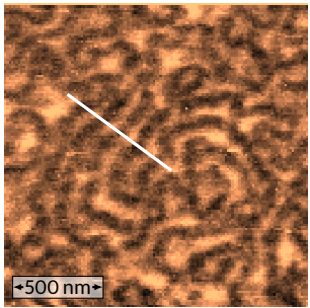
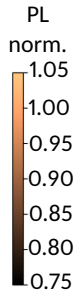
Simulation of the expected PL quenching in our system

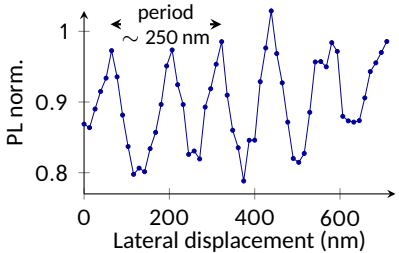


Same observations for spirals and skyrmions









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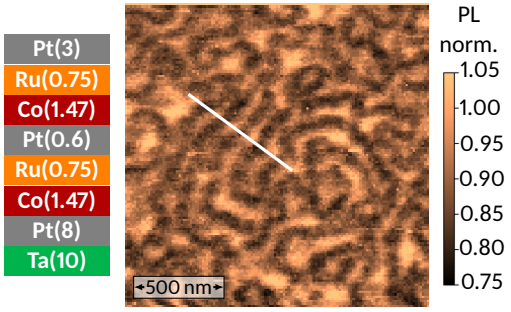

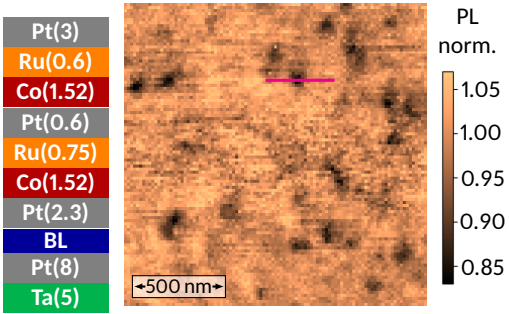

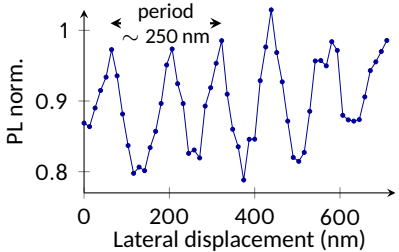

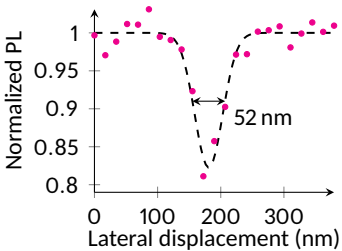

Quantitative measurements

- We observe the magnetic state in the SAF in quenching mode.
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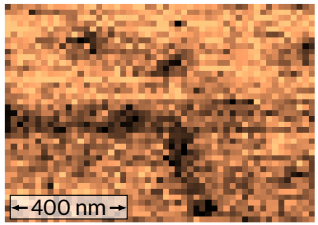
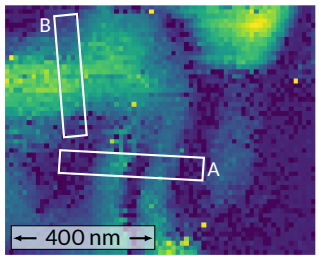
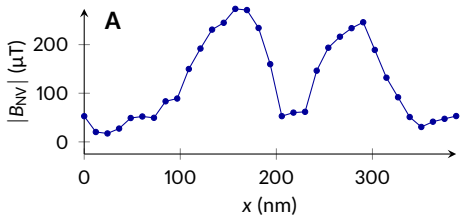
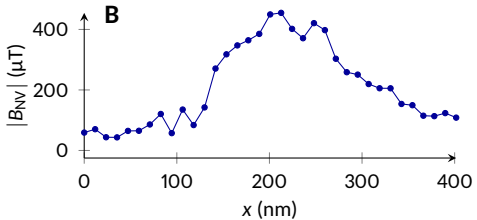


NV axis



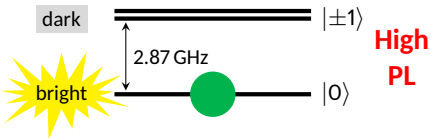
Preliminary results





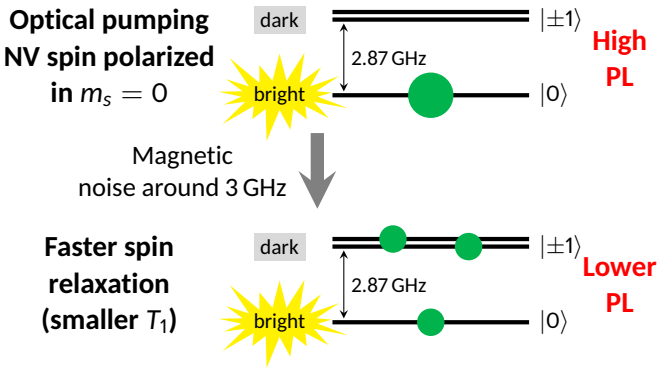
PL quenching induced by magnetic noise

Optical pumping
NV spin polarized
in $m_s = 0$

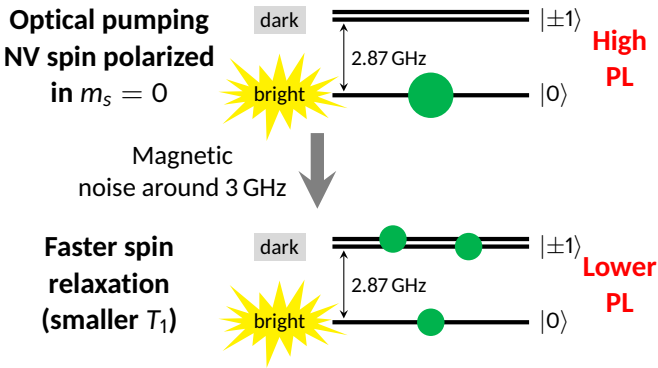


High PL

PL quenching induced by magnetic noise

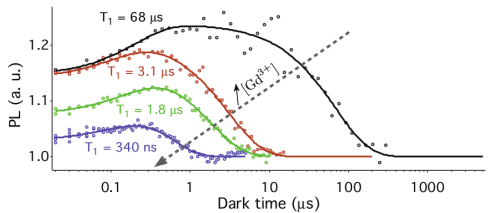


PL quenching induced by magnetic noise



Proof of principle

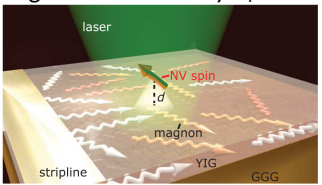
- Molecules containing Gd, producing magnetic noise with a large spectrum
- NV centers in nanodiamonds
- Decrease of T_1 when the nanodiamonds are in contact with the molecules



J.-P. Tetienne *et al.* *Physical Review B* 87 (2013), 235436

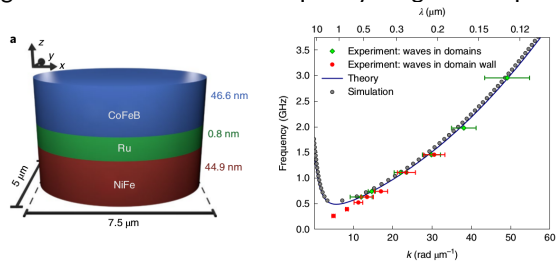
Are we detecting thermally activated magnons in the domain walls?

Thermal magnons detected by T_1 measurements



C. Du *et al.* *Science* 357 (2017), 195–198

Magnons in DW in the GHz frequency range in SAF pillars



V. Sluka *et al.* *Nature Nanotechnology* 14 (2019), 328–333

Planned experiments

- More quantitative measurements on the SAF
- Measurement of T_1 inside a domain and on a wall

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IMAGINE

TOPSKY

TEE Program