Stable Bloch point in helimagnetic nanostructures containing boundary between grains with different chirality

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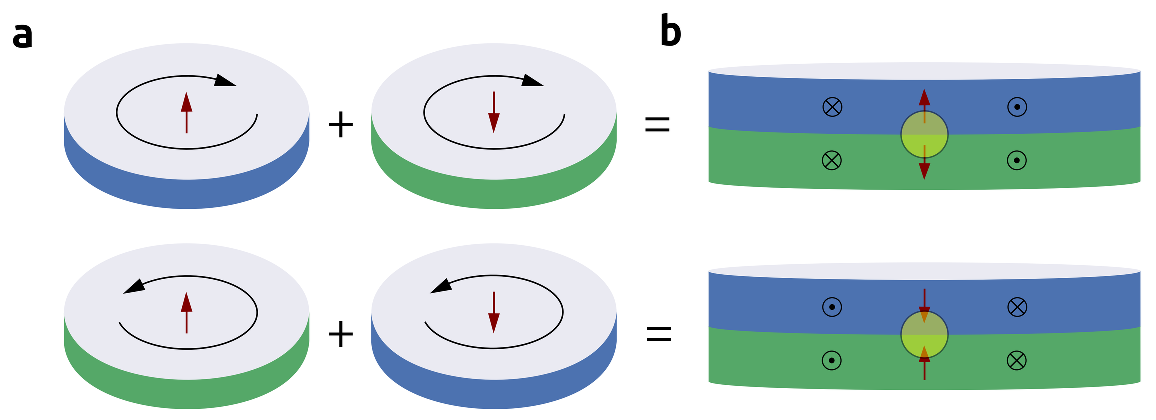
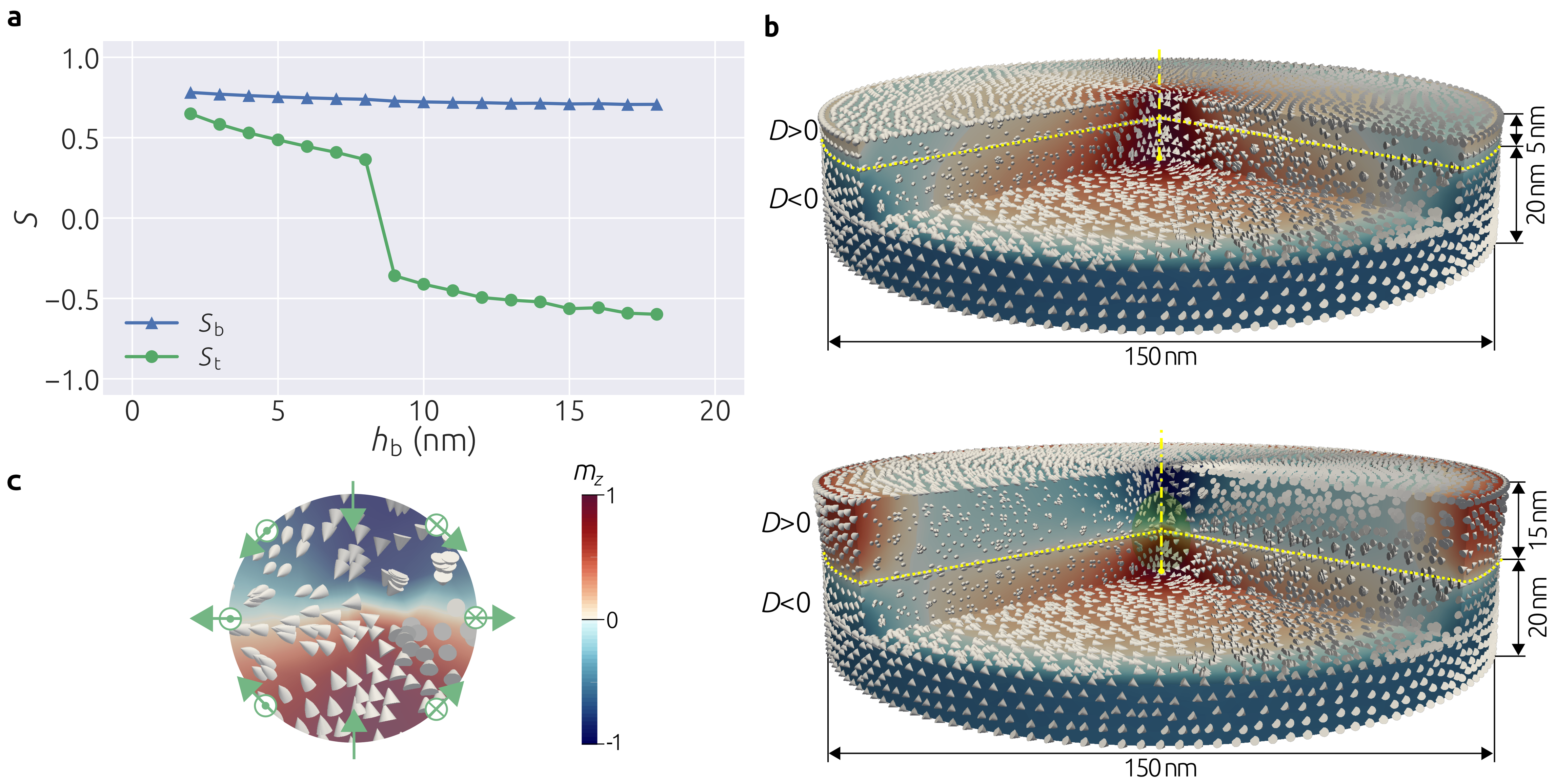
Introduction

- **Magnetic vortex** can have two different core orientations and two different chiralities, which results in **four states**.
- Stacking vortices with the same chirality but different core orientation, results in a magentisation configuration which is continuous everywhere except in the middle, where an **energetically expensive discontinuity** occurs - **Bloch point**.
- One of the vortices is going to change its core orientation and **expell the Bloch point from the system** in order to minimise its energy.
- **Adding Dzyaloshinkii-Moriya interaction** to the sample restricts the core-orientation relation and **only two states are allowed**.
- Motivated by this tought experiment, we perform a micromagnetic study to **find a stable Bloch point**.



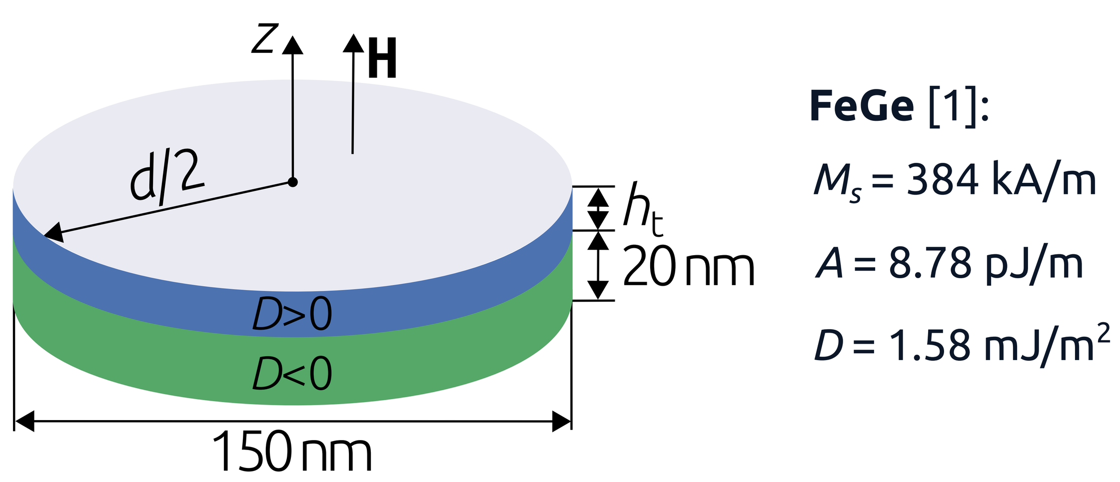
Stability

- We fix the thickness of the bottom layer and **vary the thickness of the top layer**, and compute the skyrmion number (Fig. **a**) in both layers.
- For the top layer thickness greater than 8 nm, **a stable Bloch point emerges** (Figs. **b** and **c**).



Methods

- **Geometry and material parameters**:



FeGe [1]:
M_s = 384 kA/m
A = 8.78 pJ/m
D = 1.58 mJ/m^2

- **Hamiltonian**:

$$w = A(\nabla \mathbf{m})^2 + D\mathbf{m}\cdot(\nabla\times\mathbf{m}) - \mu_0 M_\mathrm{s}\mathbf{H}\cdot\mathbf{m} + w_\mathrm{d}$$

(symmetric exchange, Dzyaloshinskii-Moriya, Zeeman, demagnetisation)

- **Dynamics** (LLG equation):

$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma_0^* \mathbf{m}\times\mathbf{H}_\mathrm{eff} + \alpha\mathbf{m}\times\frac{\partial \mathbf{m}}{\partial t}$$

(precession, damping)

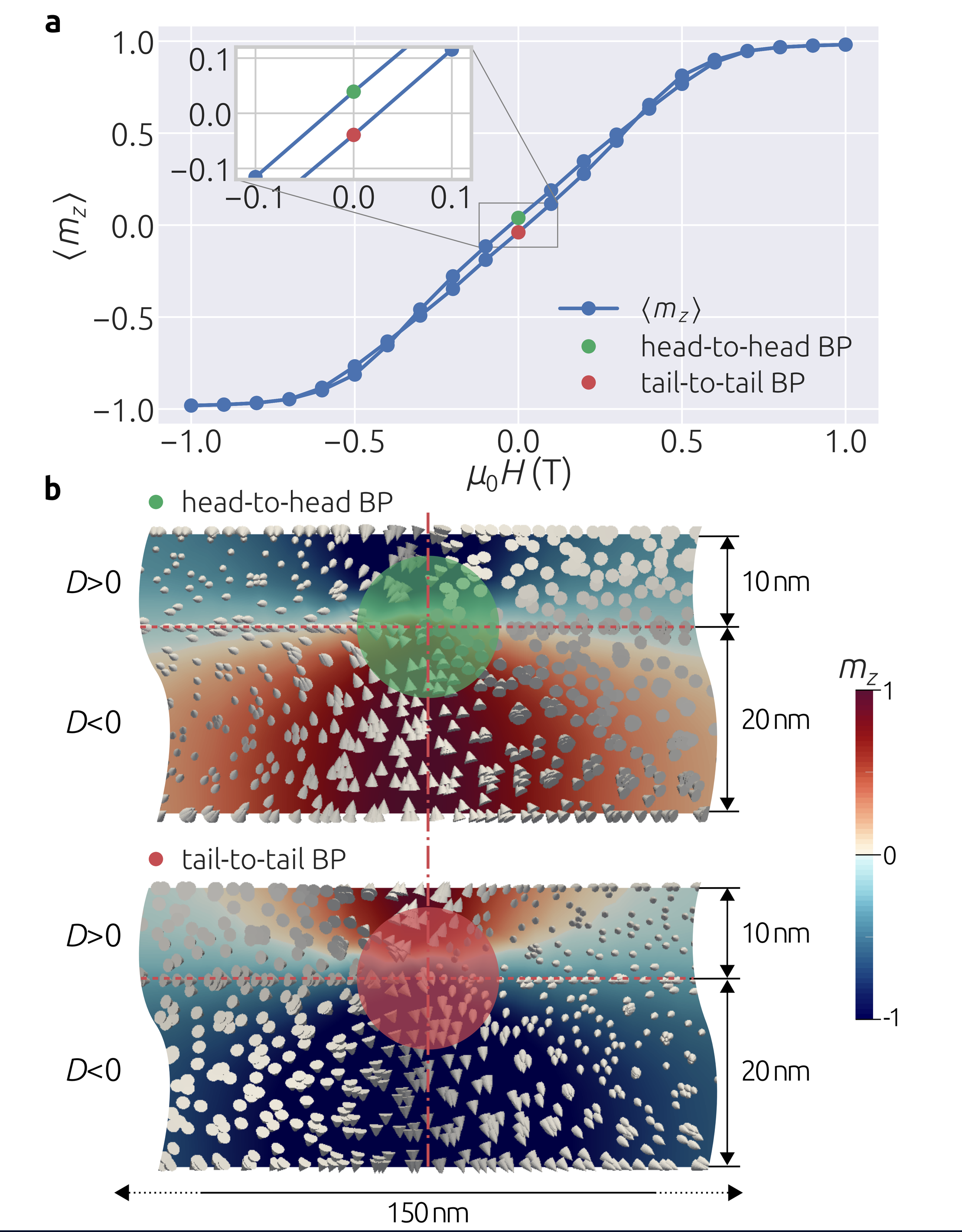
- **Skyrmion number**:

$$S = \frac{1}{4\pi t}\int \mathbf{m}\cdot\left(\frac{\partial \mathbf{m}}{\partial x}\times\frac{\partial \mathbf{m}}{\partial y}\right)\mathrm{d}^3 r$$

- Full **3D finite elements** simulation model
- No assumption about translational invariance in the out-of-plane direction
- **Full computation of demagnetisation energy**.
- Maximum mesh discretisation is 3 nm.

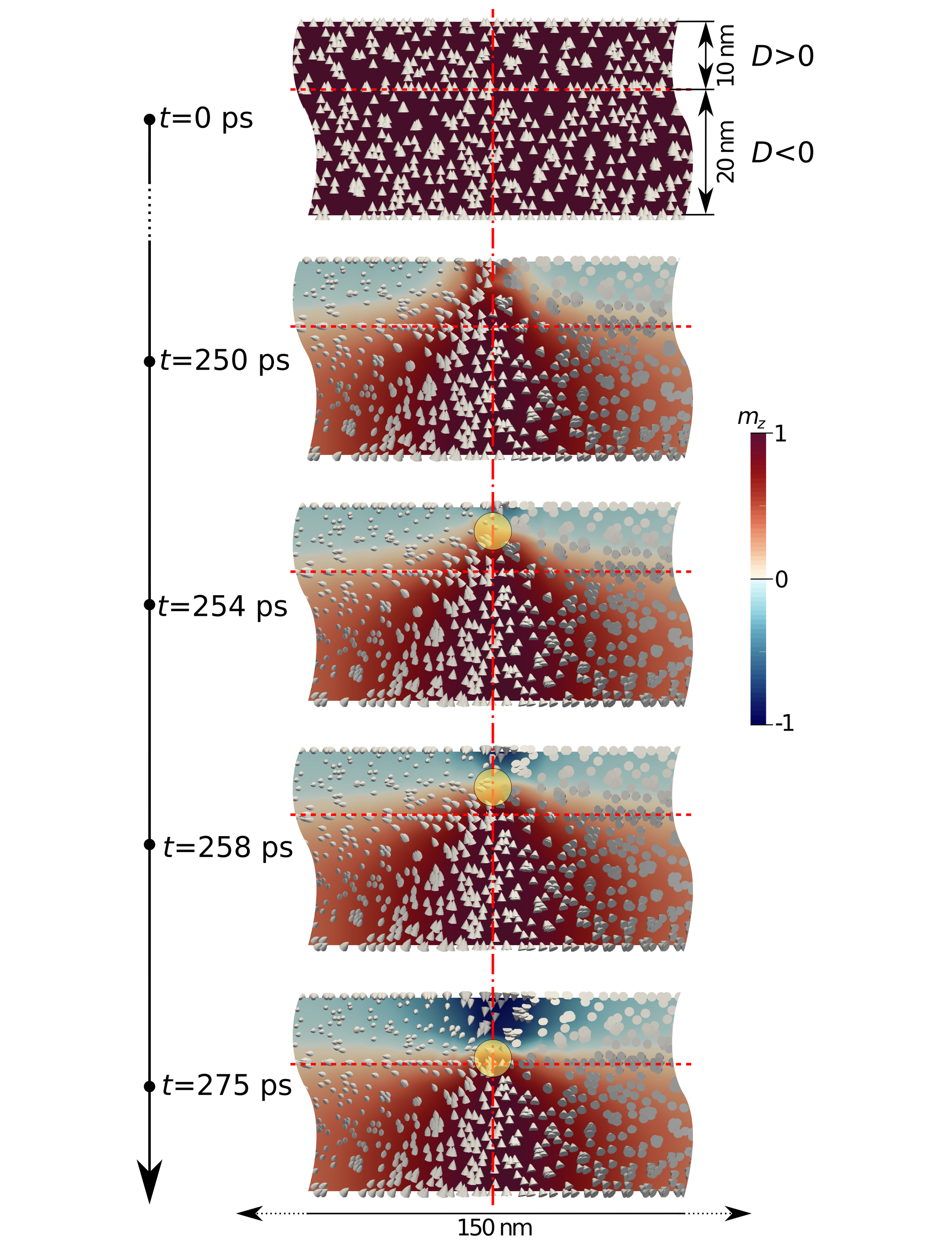
Hysteretic behaviour

- We **vary the external magnetic field** between -1.0 T and 1.0 T.



Creation

- We simulate **time evolution from the uniform state**.



Summary

- We find that **a stable Bloch point** emerges between grains with different chirality.
- We demonstrate the **existence of two different Bloch point configurations** (Head to Head BP and Tail to Tail BP) at zero external magnetic field.
- By exploring hysteretic behaviour, we demonstrate that **we can switch between HHBP and TTBP**.
- Finally, we demonstrate that in the relaxation process, the **Bloch point is created at the boundary**.

References

[1] M. Beg et al., *Scientific Reports* **5**, 17137 (2015).
[2] M. Beg et al. *Phys. Rev. B* **95**, 014433 (2017).
[3] E. Feldtkeller. *Z. Angew. Phys.* **19**, 530 (1965).
[4] W. Döring. *J. Appl. Phys.* **39**, 1006 (1968).
[5] C. Andreas et al. *J. Magn. Magn. Mater.* **362**, 7 (2014).

Acknowledgements

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