Proposal for a micromagnetic standard problem for materials with Dzyaloshinskii-Moriya interaction

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Introduction

- Simulations emerge as the **third pillar** of research and development in academia and industry, and correctness of simulation tools needs to be ensured.

- Magnetic **simulations with Dzyaloshinskii-Moriya interaction** (DMI) are becoming increasingly popular after the discovery of magnetic skyrmions and their promising features.

- **Standard problems** [1, 2, 3] are used to **test and provide confidence for the correctness** of newly developed and existing micromagnetic simulation tools.

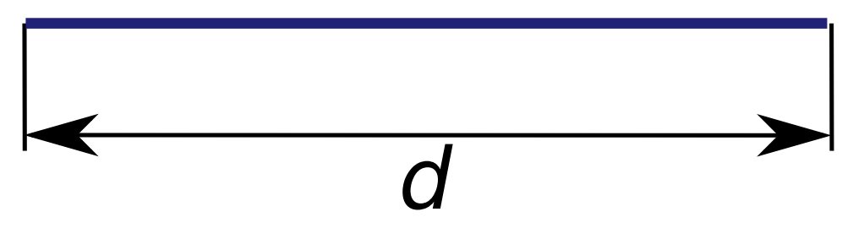
- There is **no set of standard problems** that can be used to test micromagnetic simulation tools that include Dzyaloshinkii-Moriya interaction.

- In this work, **we present simple 1D and 2D problems** where their solutions can be compared to the simulation results to support practical computational micromagnetics.

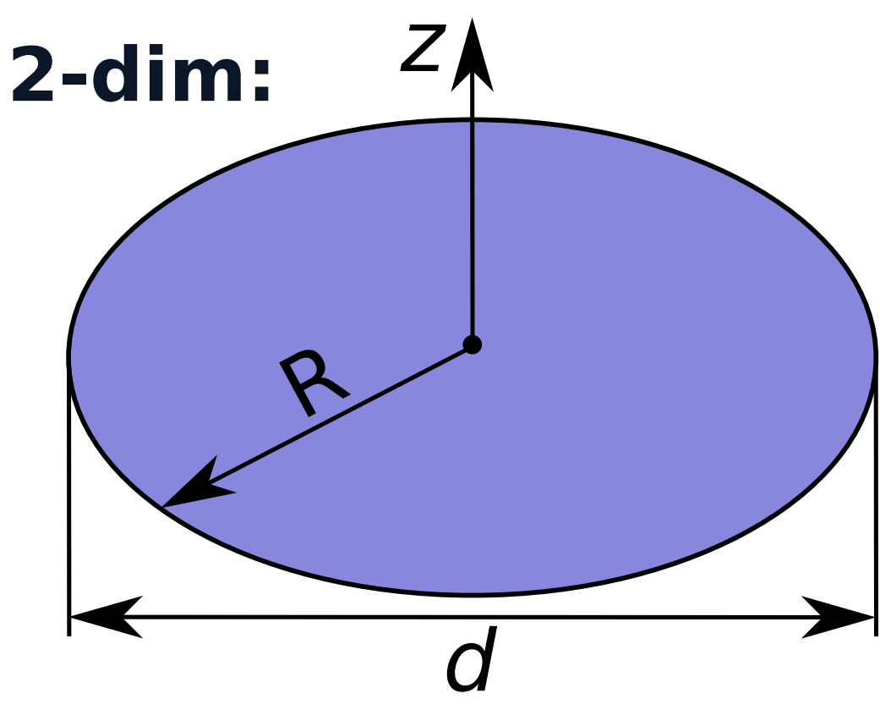
Methods

- **Geometries** and **material parameters**:

1-dim:



2-dim:



FeGe [4]:

M_s = 384 kA/m

A = 8.78 pJ/m

D = 1.58 mJ/m^2

- **Hamiltonian**:

exchange

Dzyaloshinskii-Moriya

$$w = A(\nabla \mathbf{m})^2 + D\mathbf{m} \cdot (\nabla \times \mathbf{m}) - K(\mathbf{m} \cdot \mathbf{u})^2$$

uniaxial anisotropy

- We run simulations using **OOMMF** [5] via our Python interface **JOOMMF** [6, 7].

- We use **our implementation of bulk DMI** extension for OOMMF [8].

- **No** assumption about **translational invariance** of magnetisation in any direction.

References

[1] http://www.ctcms.nist.gov/~rdm/mumag.org.html
[2] M. Najafi et al. *J. Appl. Phys.* **11**, 113914 (2009).
[3] A. Baker et al. *J. Magn. Magn. Mater.* **421**, 428 (2017).
[4] M. Beg et al. *Sci. Rep.* **5**, 17137 (2015).
[5] M. J. Donahue and D. G. Porter, OOMMF User's Guide, Version 1.0, Interag. Rep. NISTIR 6376, Natl. Inst. Stand. Technol. Gaithersburg, MD, 1999.
[6] M. Beg et al. *AIP Advances* **7**, 056025 (2017).
[7] http://joommf.github.io
[8] https://github.com/joommf/oommf-bulk-dmi
[9] S. Rohart and A. Thiaville. *Phys. Rev. B* **88**, 184422 (2013)
[10]https://github.com/fangohr/paper-2017-dmi-standard-problem

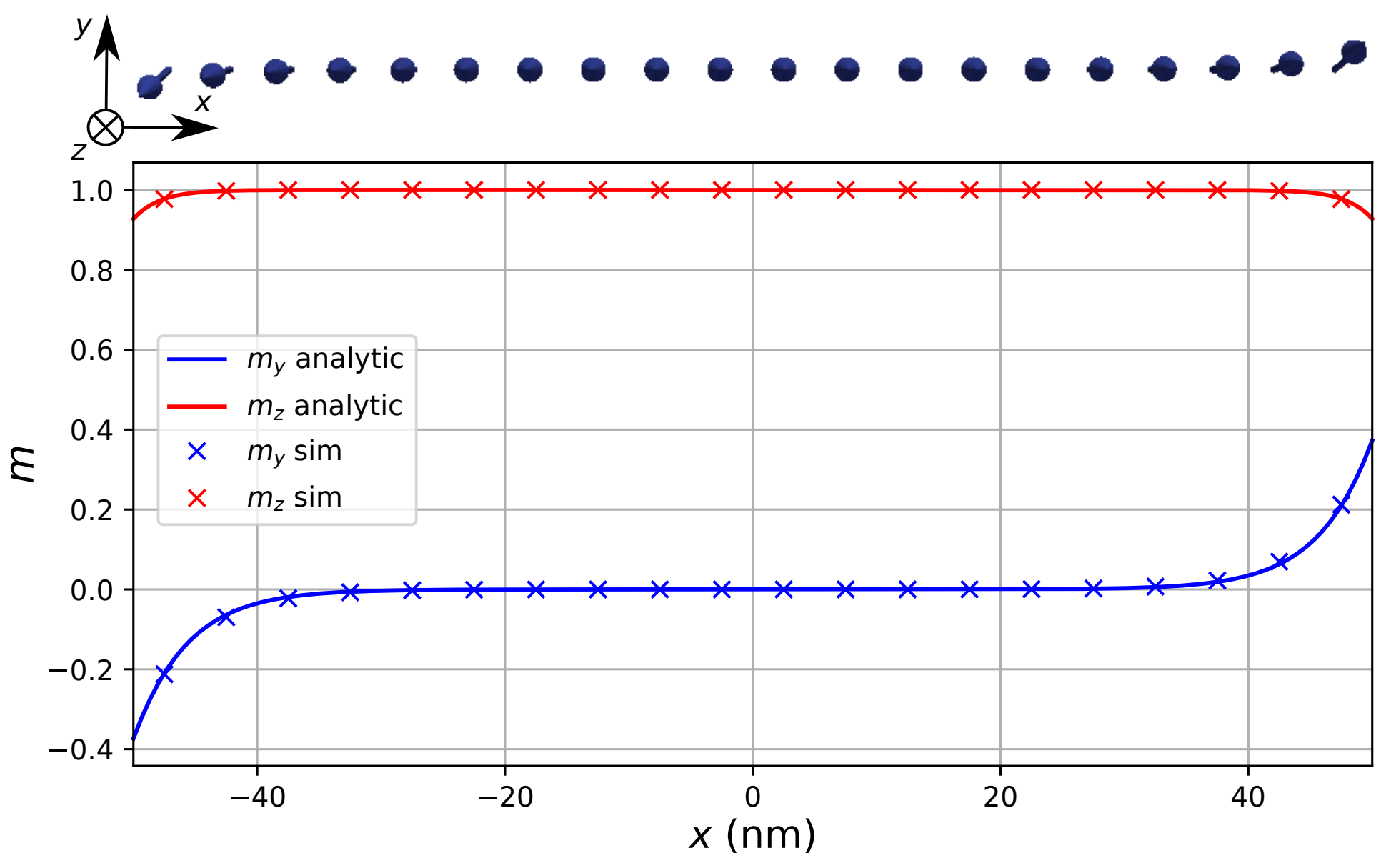
1D problems

Quasi-ferromagnetic state

- Due to the specific boundary conditions, magnetisation tilts at the edges of the one-dimensional sample (quasi-ferromagnetic).
- We solve the boundary value problem [9] using the shooting method.
- We include uniaxial anisotropy in the (0, 0, 1) direction.

$$\frac{\mathrm{d}^2\theta}{\mathrm{d}x^2} = \frac{\cos\theta\sin\theta}{\Delta^2}$$

$$\frac{\mathrm{d}\theta}{\mathrm{d}x} = -\frac{D}{2A}$$

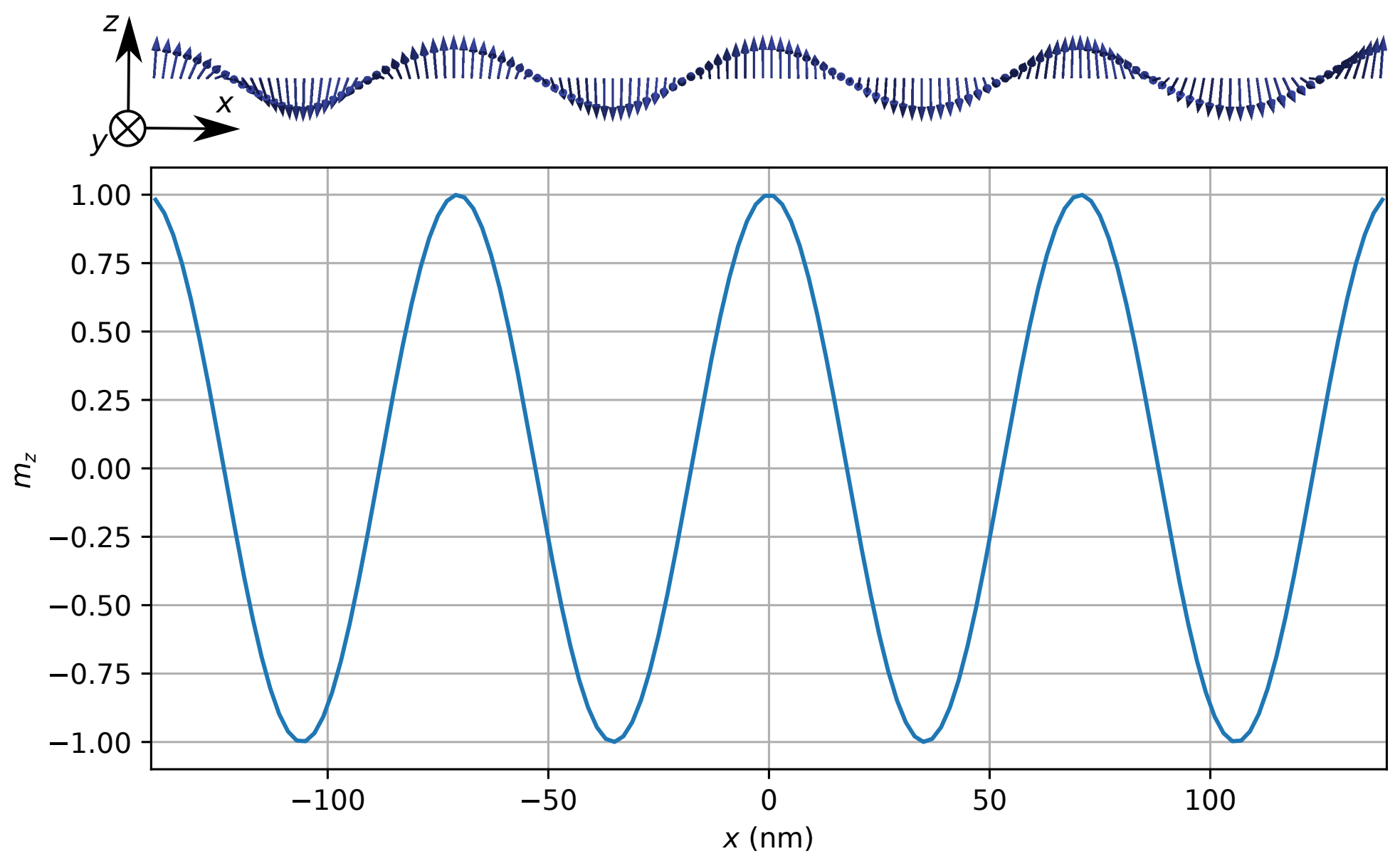


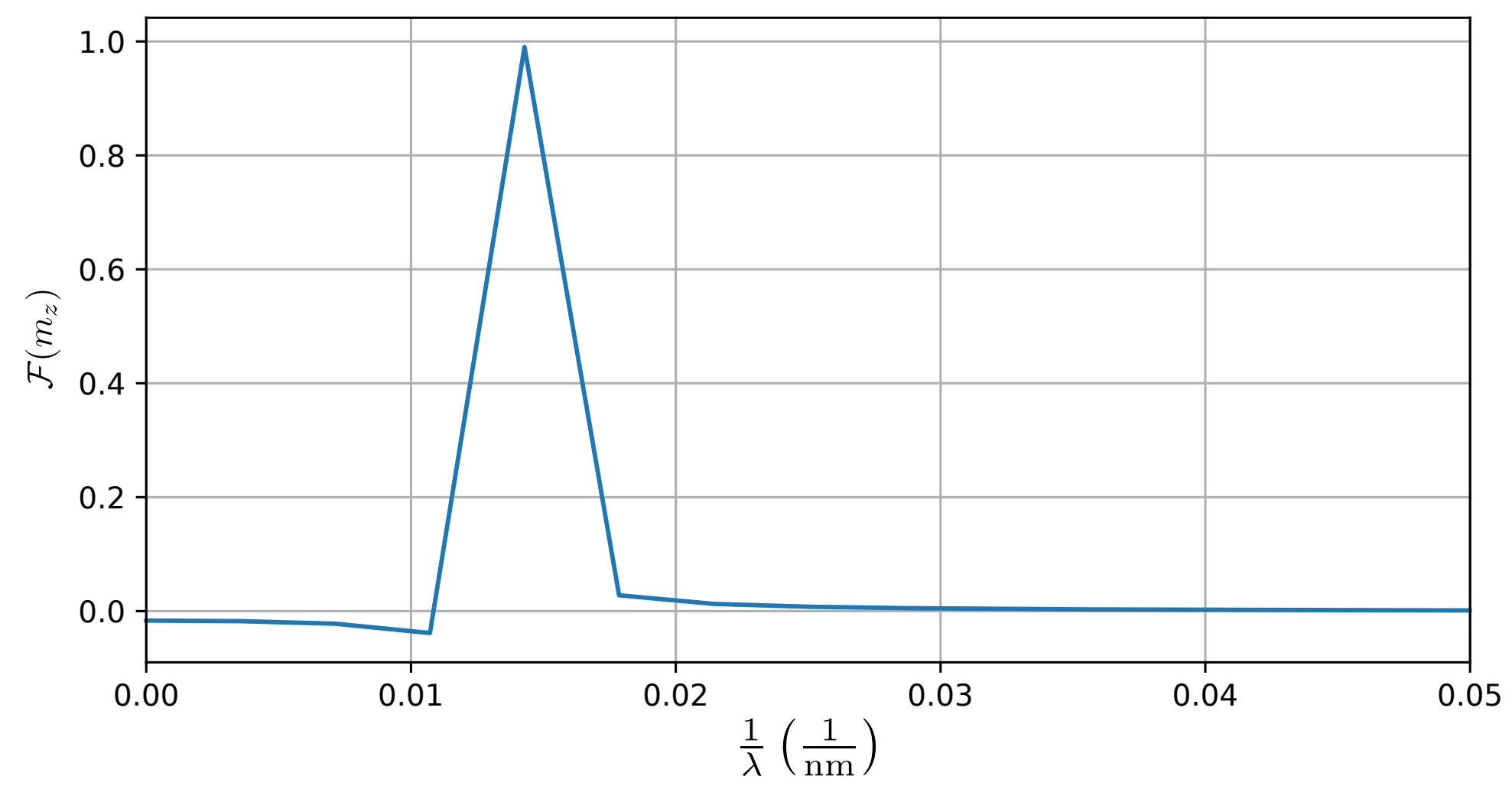
Helical state

- We have only symmetric exchange and DMI in the Hamiltonian.
- Due to a mutual competition, the helical state is formed.
- We know that the helical period should be:

$$\lambda = 4\pi\sqrt{\frac{A}{D}} = 70\,\mathrm{nm}$$

- By computing the Fourier transform, we can obtain the helical period.
- The helical period strongly depends on the length of the one-dimensional sample because the magnetisation configuration must always satisfy the specific boundary conditions.





2D problem

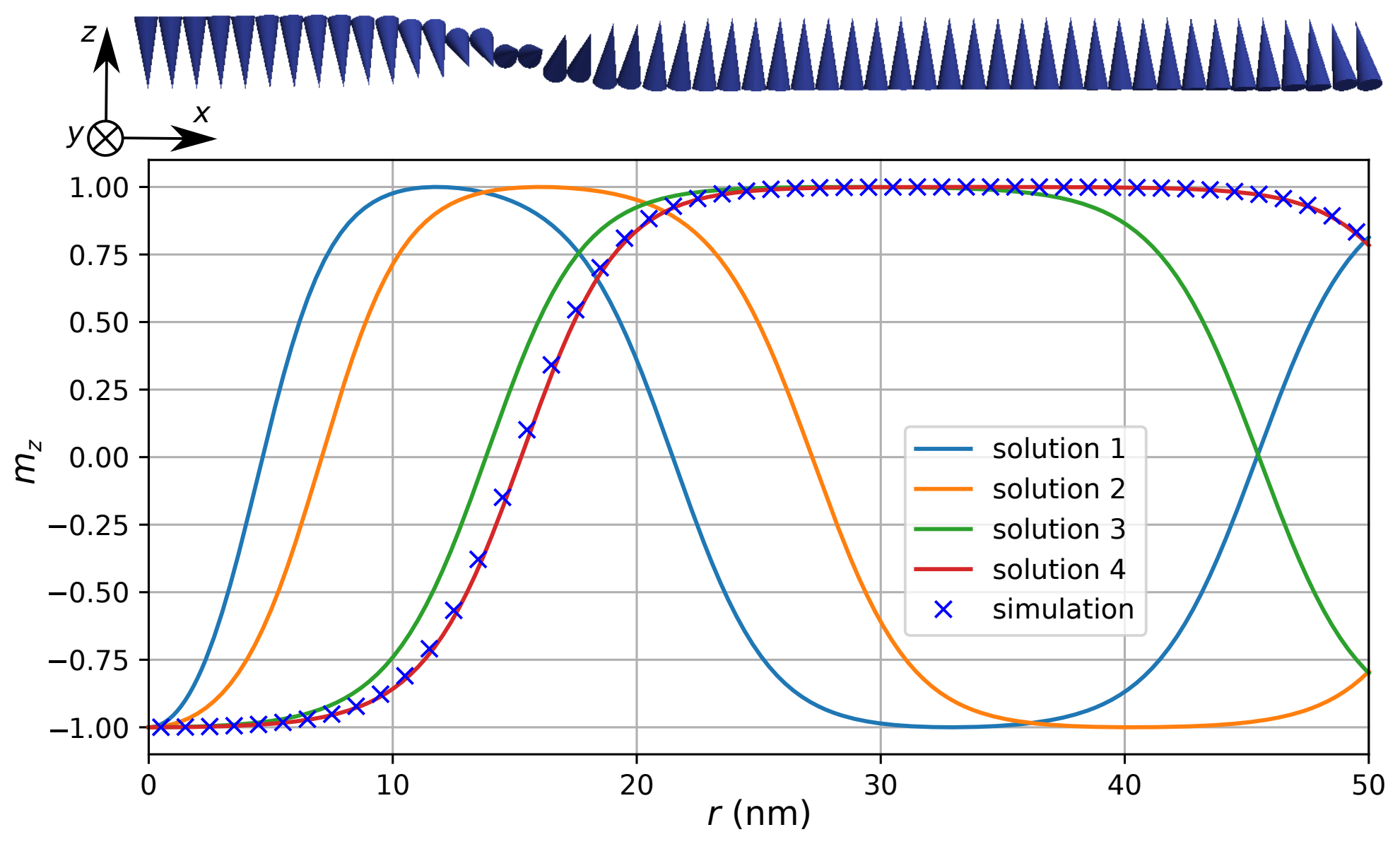
Isolated skyrmion

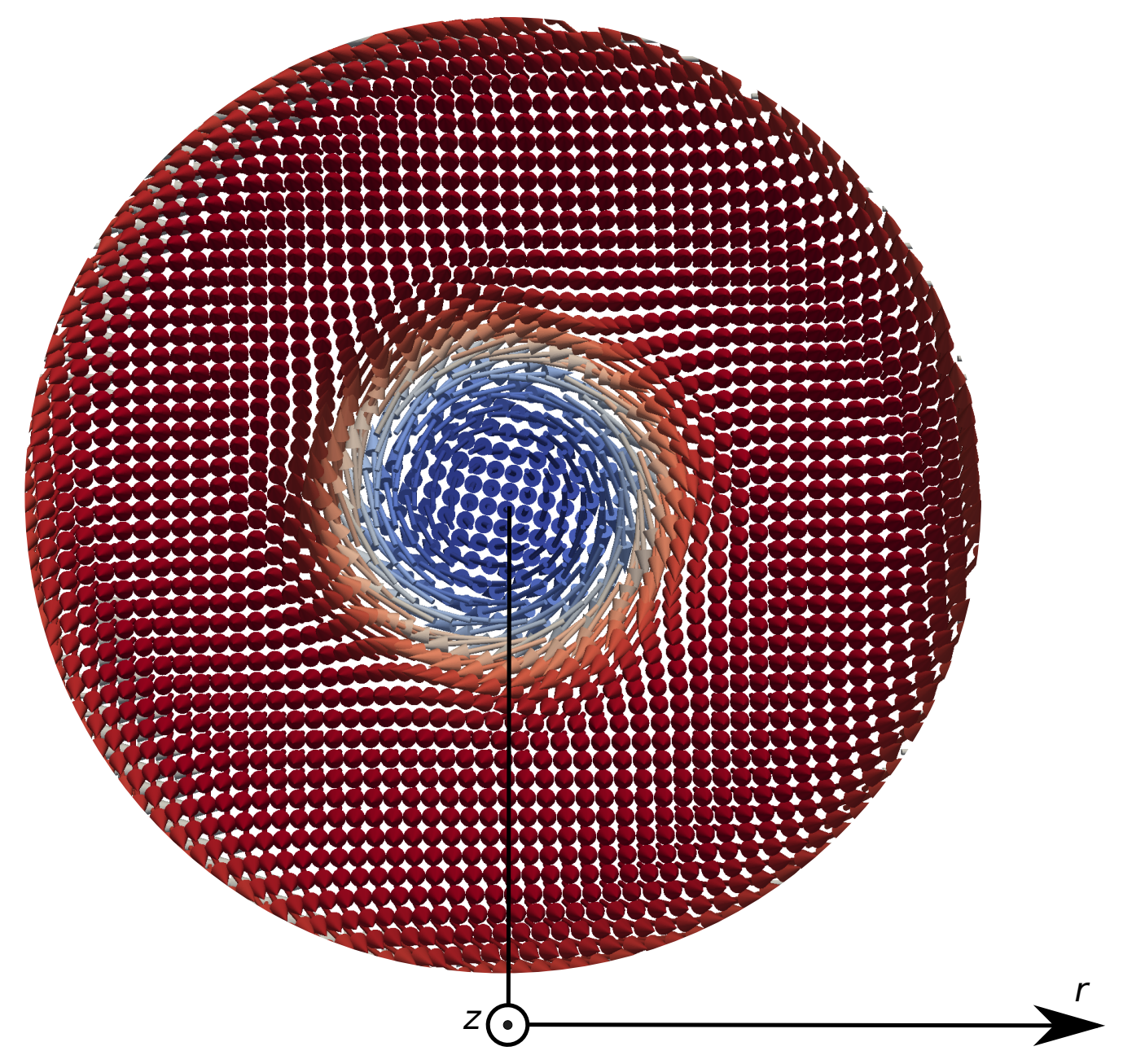
- We have only symmetric exchange, DMI, and uniaxial anisotropy energy terms in the Hamiltonian.
- In a two-dimensional disk sample with 50 nm radius, an isolated skyrmion is formed.
- We solve the boundary value problem [9] using the shooting method:

$$\frac{\mathrm{d}^2\theta}{\mathrm{d}r^2} = -\frac{1}{r}\frac{\mathrm{d}\theta}{\mathrm{d}r} + \left(\frac{1}{r^2} + \frac{1}{\Delta^2}\right)\frac{\sin 2\theta}{2} - \frac{2\sin^2\theta}{\xi r}$$

$$\frac{\mathrm{d}\theta}{\mathrm{d}r} = -\frac{D}{2A}$$

- We perform shooting at m_z=-1 and R=0 because we assume the skyrmion orientation to point down in core.
- The magnetisation at the core points in the negative z direction and then rotates in a Bloch-type wall configuration to the periphery.
- There is additional tilting of magnetisation at the boundary due to the specific boundary conditions.





Summary

- We implemented the OOMMF extension module for simulating bulk Dzyaloshinskii-Moriya interactions [8].
- We collect a set of simple problems that can be used to test new and existing micomagnetic simulation tools with DMI tools effectively.
- We provide the full calculation of the semi-analytical solution and the numerical solution (computed with OOMMF) in public Jupyter Notebooks [10].