Skyrmions in Easy-Plane Anisotropy Materials

M. Vousden[1], M. Albert[1], M. Beg[1], M. A. Bisotti[1], R. Carey[1], D. Chernyshenko[1], D. Cortés-Ortuño[1], W. Wang[2], C. Marrows[3], O. Hovorka[1], and H. Fangohr[1].

[1]*Faculty of Engineering and the Environment, University of Southampton, Southampton, U.K.*
[2]*Department of Physics, Ningbo University, Ningbo 315211, China.*
[3]*School of Physics and Astronomy, University of Leeds, Leeds, U.K.*

Contact: mark.vousden@soton.ac.uk

Overview

Skyrmions are topological defects that can be observed in the magnetization texture of materials that lack inversion symmetry. They demonstrate promise in data storage applications due to their small size, and the low current required to drive them. However, analytical work suggests that skyrmions are not ground states in thin films with easy-plane anisotropy,[1] though recent experiments detect skyrmions in easy-plane anisotropic helimagnetic thin films.[2] In this work, prior analyses are extended by considering three-dimensional thin films, since magnetization variance in the out-of-plane direction is known to radically affect skyrmion energetics.[3] Demagnetizing effects are also modelled. In addition, the effect of anisotropy strength on metastable skyrmion size is investigated.

Methodology

To model a large thin film, a cuboidal simulation cell is considered with periodic boundary conditions imposed on the magnetization in the lateral directions. To identify stable magnetization configurations in this cell, the energy must be minimized. The micromagnetic energy model used here accounts for isotropic exchange, the Dzyaloshinskii-Moriya interaction, the effect of an applied magnetic field, magnetocrystalline anisotropy, and demagnetizing effects. The macrogeometry approach is implemented to model the periodicity of the demagnetizing field. The minimum energy state is found by relaxing each initial magnetization configuration shown in Fig. 1 using damped Landau-Lifshitz-Gilbert dynamics in a finite-element framework. Fig. 2 shows how the relaxed state with the lowest energy varies with applied field and anisotropy strength.

Discussion

Skyrmionic states shown in Fig. 2 (snapshots D, E, and F) are minimum energy states for both easy-axis and easy-plane anisotropy cases. The upper limit of anisotropy strength for ground state skyrmions is similar to analytical findings,[1] but the considerable easy-plane skyrmion presence results from the extensions applied in this work. Skyrmions are also found as metastable states in a greater parameter space. Large magnetic fields suppress skyrmions as stable and metastable configurations.

Fig. 3 shows that skyrmion size increases with decreasing magnetic field magnitude (snapshots J, K, and L), and increasing easy-plane anisotropy (snapshots G, H, and I). This is because the magnetization component in the plane is more favorable energetically, which increases the length over which the magnetization will twist to form the skyrmion.

To conclude, skyrmions are minimum energy states in magnetic systems with easy-plane anisotropy, which is in agreement with experimental observations.[2] This could encourage research into a broader range of materials for skyrmion applications.

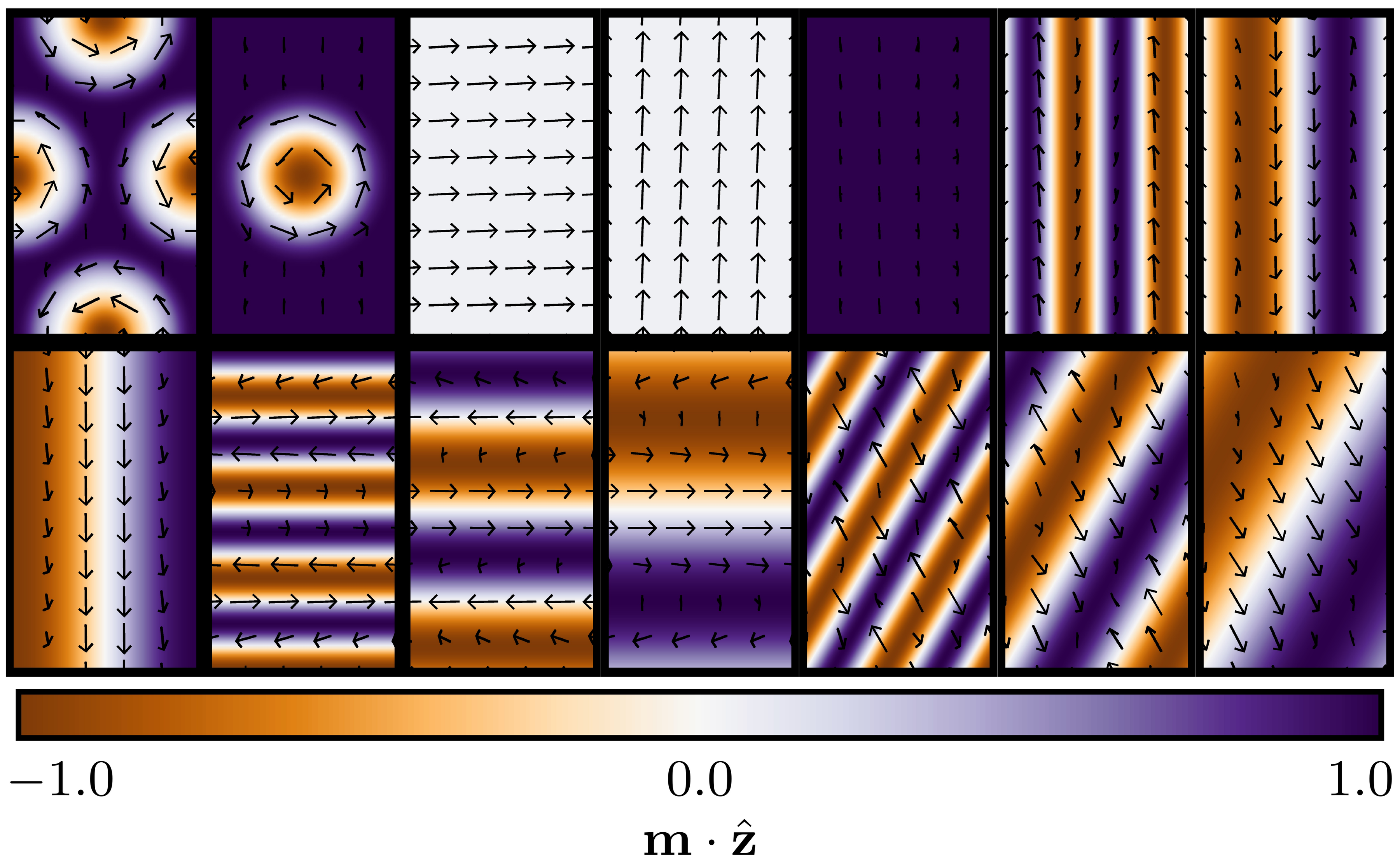

Fig. 1: Initial magnetization configurations to be relaxed using Landau-Lifshitz-Gilbert (LLG) dynamics.

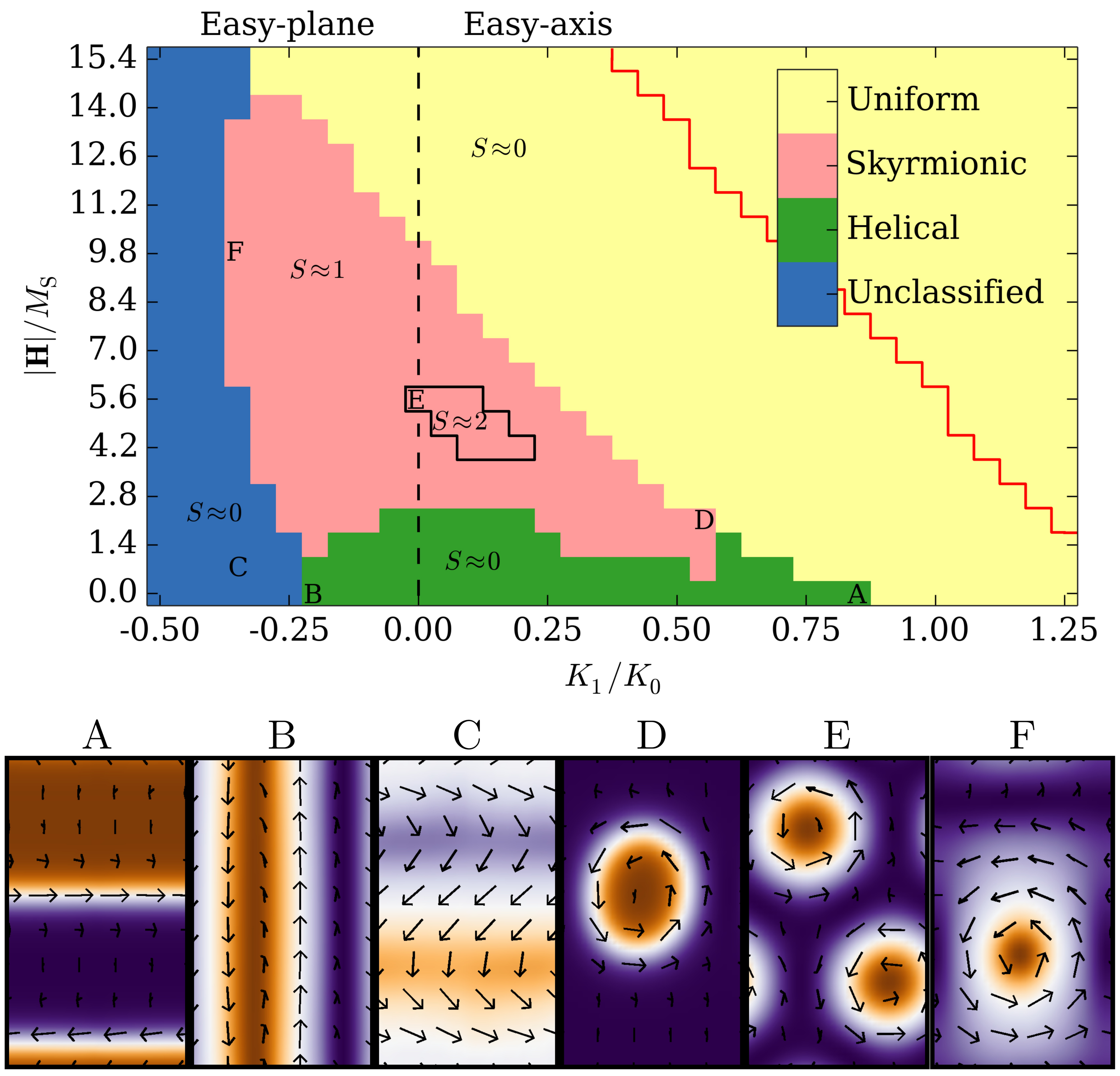

Fig. 2: Top: Minimum-energy state variation with anisotropy strength (horizontal axis) and external field strength (vertical axis). Parameters below the red line support metastable skyrmion configurations. Bottom: Selected magnetization configurations, including skyrmions (D, E, F).

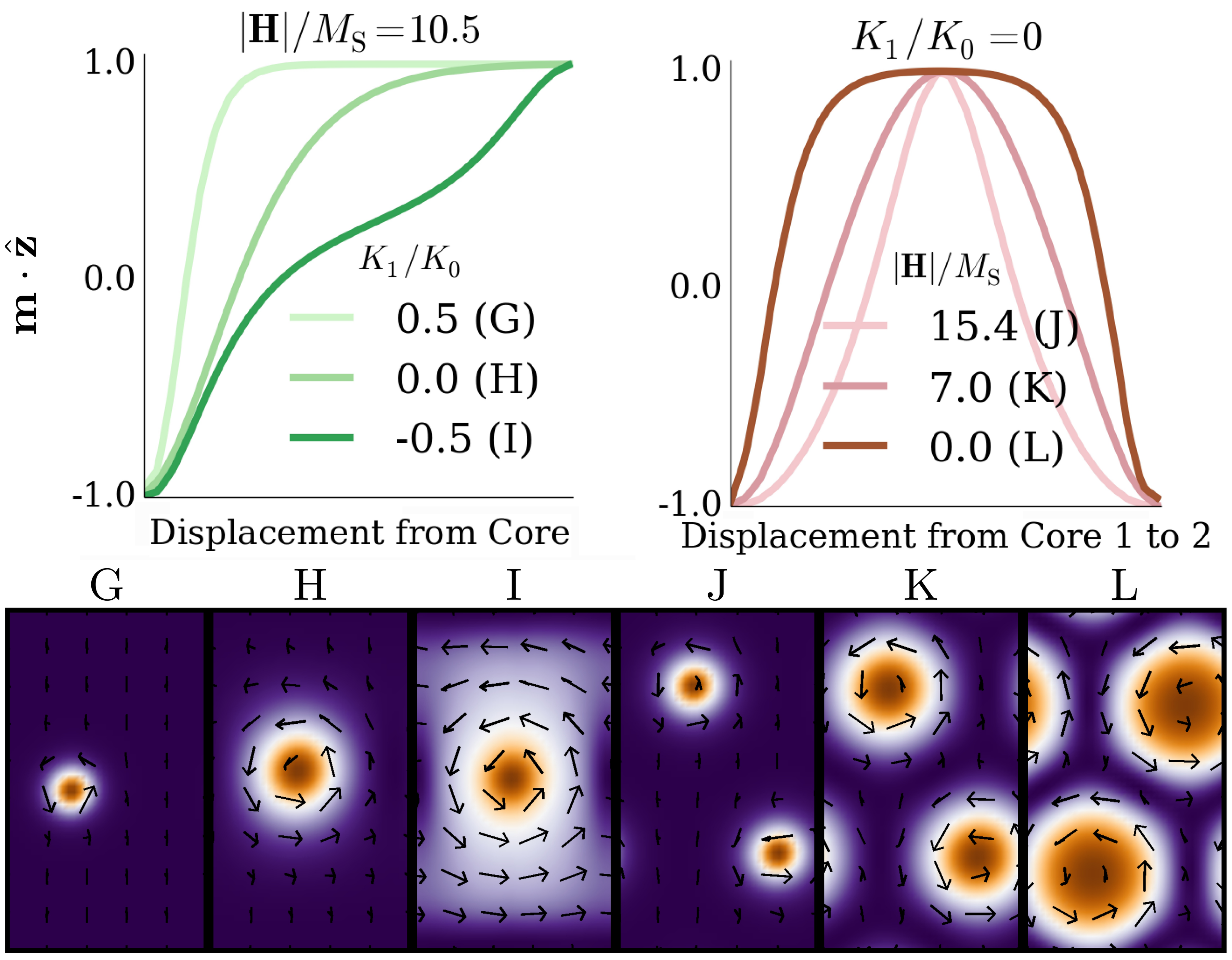

Fig. 3: Metastable skyrmion profile variation with anisotropy strength (left) and external field strength (right). Skyrmions enlarge with strong easy-plane anisotropy to fill the simulation cell.

References and Acknowledgments

[1]: M. N. Wilson, A. B. Butenko, A. N. Bogdanov, and T. L. Monchesky. Phys. Rev. B 89 (2014).
[2]: S. Huang and C. Chien. Phys. Rev. Lett. 108 (2012).
[3]: F. Rybakov, A. Borisov, and A. N. Bogdanov. Phys. Rev. B 87 (2013).
We acknowledge financial support from EPSRC's DTC grant EP/G03690X/1.