Micromagnetic Simulation of Three-Dimensional Skyrmion Structures

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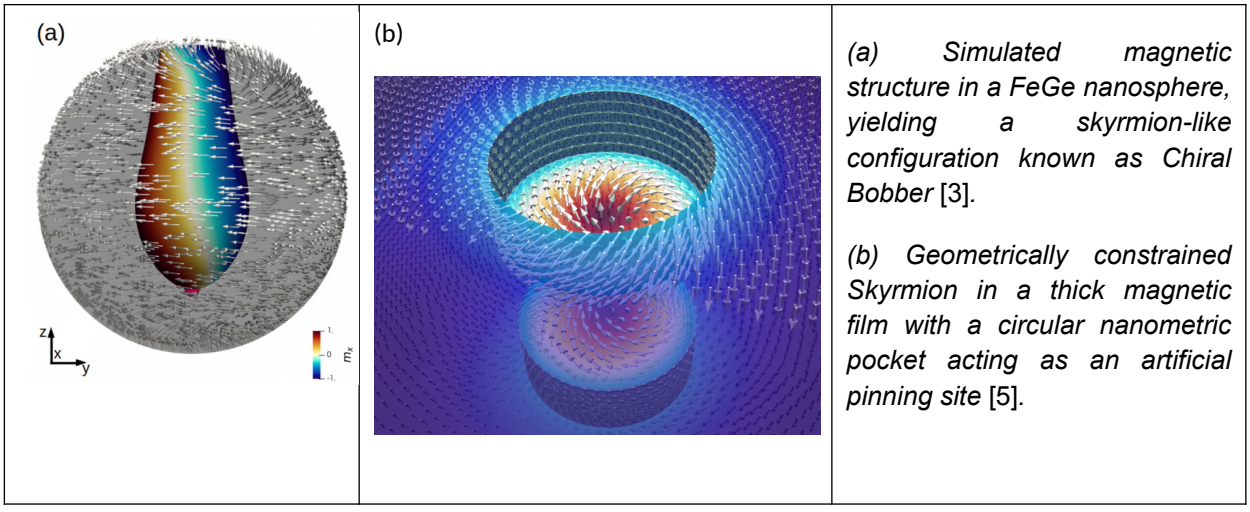
Magnetic skyrmions - swirling nanoscale structures of the magnetization with unique dynamic and topological properties - have attracted massive scientific interest over the past years. These magnetic structures can develop in exotic magnetic materials with properties that break the chiral symmetry. Due to their high stability and their particle-like behavior, these chiral magnetic nanostructures have promising applications in future spintronic devices [1].

While most of the research on the subject has been restricted to two-dimensional skyrmions in flat thin-film geometries, recent studies have shifted towards three-dimensional nanomagnetism [2]. In three-dimensional geometries, skyrmionic structures can take more complex forms, such as Chiral Bobbers [3] or Hopfions [4]. Understanding the formation, the structure, and the dynamic properties of these exotic structures is a challenging task in an emerging field of research.

The goal of this Ph.D. project is to explore, by means of micromagnetic finite-element simulations, the structure and the dynamics of such three-dimensional chiral magnetic nanostructures. This includes investigations on the conditions that are required for their stability, the impact of variations of the sample geometry on these structures [5], their current-driven dynamics, and their intrinsic high-frequency properties.



(a) Simulated magnetic structure in a FeGe nanosphere, yielding a skyrmion-like configuration known as Chiral Bobber [3].

(b) Geometrically constrained Skyrmion in a thick magnetic film with a circular nanometric pocket acting as an artificial pinning site [5].

[1] A. Fert et al., Nature Nanotechnology, 8, 152 (2013) *Skyrmions on the track*
[2] A. Fernández-Pacheco, et al., Nature Comm. 8, 1575 (2017) *Three-dimensional nanomagnetism*
[3] S. Pathak and R. Hertel, Phys. Rev. B 103, 104414 (2021) *Three-dimensional chiral magnetization structures in FeGe nanospheres*
[4] N. Kent et al., Nature Comm. 12, 1562 (2021) *Creation and observation of Hopfions in magnetic multilayer systems*
[5] S. Pathak and R. Hertel, Magnetochemistry 7, 26 (2021) *Geometrically constrained Skyrmions*