Nonlinear dynamics of magnetic skyrmions

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Nano-contacted spin-torque skyrmion oscillators (STSOs) are anticipated to find application as nanoscale sources of microwave emission in future technological applications and to show new possibilities as processing memory devices. Presently, the output power and the phase stability of individual skyrmions are not fully understood and not competitive with existing oscillator technologies. Possible synchronization of multiple coupled confined skyrmions has been proposed to enhance the microwave emission. The control of device-to-device variations, such as mode splitting of the microwave emission, is essential for single and multiple STSOs to be successfully synchronized. In this work, we numerically investigate different excitation modes (field pulse driven) of helimagnetic nanodisks to understand the phase stability and the frequency changes of skyrmion structures; see Figure 1. The principle aim of this study is to understand how large the non-equilibrium dynamics is and to lay the foundation to use a combination of electrical measurements and time-resolved scanning Kerr microscopy (TRSKM) to map and directly observe skyrmion dynamics. For the numerical integration of the Landau-Lifshitz-Gilbert, we consider our convergent implicit-explicit finite-element-based tangent plane scheme [1], whose analysis has recently been extended to cover chiral interactions of Dzyaloshinskii-Moriya type [2]. Significant changes in skyrmion stability and dynamics were observed as a function of the applied field pulse strength. This work demonstrates that, based on field pulse shape and strength, skyrmion structures can be excited and even forced in local non-equilibrium structures that are recovered with additional field pulses. Numerical characterization of such dynamics permits a deeper insight into the requirements for optimal excitation and future possible phase-locking of multiple STSOs that share common magnetic layers.

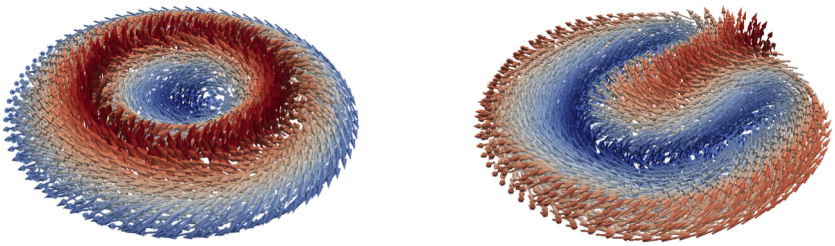

Figure 1. Two stable magnetization configurations in a helimagnetic nanodisk: Skyrmion state (left) and horseshoe state (right).

[1] G. Di Fratta, C.-M Pfeiler, D. Praetorius, M. Ruggeri, B. Stiftner. *Linear second-order IMEX-type integrator for the (eddy current) Landau-Lifshitz-Gilbert equation.* Submitted for publication.

[2] G. Hrkac, C.-M Pfeiler, D. Praetorius, M. Ruggeri, A. Segatti, B. Stiftner. *Convergent tangent plane integrators for the simulation of chiral magnetic skyrmion dynamics.* Submitted for publication.