MA 55: Skyrmions III

Time: Friday 9:30–12:45 Location: HSZ/0004

MA 55.1 Fri 9:30 HSZ/0004

RC circuit based on magnetic skyrmions — •Ismael Ribeiro de Assis, Ingrid Mertig, and Börge Göbel — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

Skyrmions are nanosized magnetic whirls attractive for spintronic applications due to their innate stability. They can emulate the characteristic behavior of various spintronic and electronic devices such as spin-torque nano-oscillators, artificial neurons and synapses, logic devices, diodes, and ratchets. Here, we show that skyrmions can emulate the physics of an RC circuit-the fundamental electric circuit composed of a resistor and a capacitor-on the nanosecond time scale. The equation of motion of a current-driven skyrmion in a quadratic energy landscape is mathematically equivalent to the differential equation characterizing an RC circuit: the applied current resembles the applied input voltage and the skyrmion position resembles the output voltage at the capacitor. These predictions are confirmed via micromagnetic simulations. We show that such a skyrmion system reproduces the characteristic exponential voltage decay upon charging and discharging the capacitor under constant input. Furthermore, it mimics the low-pass filter behavior of RC circuits by filtering high frequencies in periodic input signals. Since RC circuits are mathematically equivalent to the leaky-integrate-fire (LIF) model widely used to describe biological neurons, our device concept can also be regarded as a perfect artificial LIF neuron.

MA 55.2 Fri 9:45 HSZ/0004

Accelerating Skyrmion-Based Computing via Oscillating Magnetic Fields — •Yuean Zhou[1], Thomas B. Winkler[2], Grischa Beneke[1], Fabian Kammerbauer[1], Robert Frömter[1], Giovanni Finocchio[3], Johan H. Mentink[2], Davi R. Rodrigues[4], and Mathias Kläui[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [2]Radboud University, Institute for Molecules and Materials, Netherlands — [3]Department of Mathematical and Computer Sciences, Physical Sciences and Earth Sciences, University of Messina, Italy — [4]Department of Electrical and Information Engineering, Politecnico di Bari, Italy

Skyrmion-based unconventional computing architectures, including stochastic, reservoir, and probabilistic computing [1], rely on stochasticity and dynamical transitions. However, pinning effects restrict mobility in realistic device geometries. To stably enhance the dynamics, we apply an additional oscillating out-of-plane magnetic field [2], and quantify the skyrmion motion in confined geometries using Markov State Models constructed from skyrmion trajectories recorded by Kerr microscopy. The diffusion enhancement shows a distinct maximum around 25 Hz and tapers off on either side, suggesting a stochastic-resonance-driven mechanism. Micromagnetic simulations qualitatively reproduce the resonance peak, supporting this interpretation. Controlled periodic driving thus provides an effective route to boost skyrmion dynamics for unconventional computing. [1] T.B. Winkler et al., arXiv:2508.19623 (2025) [2] R. Gruber et al., Adv. Mater. 2208922 (2023)

MA 55.3 Fri 10:00 HSZ/0004

Dipolar Skyrmion Continuum Mechanics — •Kilian Leutner[1], Klaus Raab[1], Grischa Beneke[1], Duc M. Tran[1], Sachin Krishnia[1], Robert Frömter[1], and Mathias Kläui[1,2] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [2]Center for Quantum Spintronics, Norwegian University of Science and Technology, 7491 Trondheim, Norway

Magnetic skyrmions–topological quasiparticle spin textures–offer a platform for both fundamental physics and applications [1]. In multilayer films, micrometer-scale skyrmions can emerge from dipolar interactions, and describing the long-timescale behavior of an ensemble requires multiscale modeling. We extend the Thiele equation by treating the skyrmion radius as a dynamic variable and derive the forces governing changes in both position and size from micromagnetic theory. As a novel approach to describe ensemble dynamics, we develop a continuum-mechanics framework in which individual skyrmions are replaced by macroscopic fields such as density, velocity, and radius. The equation of state required for this description–relating pressure and density in the basic case–is calculated using dipolar-lattice theory [2]. We validate these two theoretical frameworks by examining how a spin-orbit torque compresses a skyrmion lattice in a Ta/CoFeB/MgO wire in an experiment. The continuum-mechanics model provides deeper insight into dipolar skyrmion ensembles as a hyperelastic medium composed of interacting particles of variable size.

[1] C. Back et al. J. Phys. D: Appl. Phys., 53, 363001 (2020).
[2] E. M. Jefremovas, K. Leutner et al. Newton, 1, 100036 (2025).

MA 55.4 Fri 10:15 HSZ/0004

Magnetoresistance and Planar Hall Effect in Noncollinear Magnets — •Juba Bouaziz[1,2], Hiroshi Ishida[3], Hiroshi Katsumoto[1], and Stefan Blügel[1,4] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich — [2]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg — [3]College of Humanities and Sciences, Nihon University, Tokyo — [4]Institute for Theoretical Physics, RWTH Aachen University, 52062 Aachen

Magnetotransport measurements are widely used to probe magnetic structures. We study how noncollinear magnetism modifies magnetoresistance (MR) and the planar Hall effect (PHE). In the weak-coupling limit, and using a multiple-scattering expansion of the electron current for Rashba-mediated conduction electrons [1], we show that noncollinearity introduces additional contributions to both MR and PHE. These arise from tilted magnetic moments and include a chiral MR term determined by the chirality of the magnetic structure. We also identify a noncollinear magnetoresistance (NCMR) contribution that persists even without Rashba spin-orbit interaction. Finally, we analyze the form and magnitude of these effects for different nanostructures, including magnetic trimers and topological spin textures such as skyrmions.

[1] J. Bouaziz et al., Phys. Rev. Lett. 126, 147203 (2021).

MA 55.5 Fri 10:30 HSZ/0004

Reorientation of skyrmion lattice with local magnetic field gradients — •Duc Tran[1], Edoardo Mangini[1], Elizabeth Jefremovas[1], Dennis Meier[2,3], Robert Frömter[1], and Mathias Kläui[1,2] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Centre for Quantum Spintronics, NTNU, 7491 Trondheim, Norway — [3]Faculty of Physics, University of Duisburg-Essen, 45057 Duisburg, Germany

We present a minimally invasive approach for nucleating and manipulating skyrmion lattices in soft CoFeB multilayers using single-pass MFM. By matching the scan-line spacing to the domain periodicity, we drive reversible transitions from stripe domains to isolated skyrmions and locally ordered lattices using the field gradient generated by the magnetic tip. Skyrmion positions are used to calculate the local orientational order parameter ψ_6, allowing quantitative assessment of lattice order[1]. Repeated scanning leads to a systematic increase in $\langle|\psi_6|\rangle$, revealing a progression from a disordered configuration toward a well-ordered hexagonal lattice. We show that the lattice orientation can be directly controlled by altering the scanning direction, as verified through both real-space analysis and fast Fourier transforms. This technique enables on-demand creation, rearrangement, and deletion of metastable skyrmions, offering unprecedented control over lattice symmetry, ordering, and orientation[2].

[1] R. Gruber et al., Nat. Nanotechnol. 20, 1405–1411 (2025).
[2] D. Tran et al., Appl. Phys. Lett. (in press 2025), arXiv:2508.14771.

MA 55.6 Fri 10:45 HSZ/0004

Static and dynamic spin texture manipulation in Fe/Gd multilayers — Tim Titze[1], Sabri Koraltan[2,4], Timo Schmidt[3], Mailin Matthies[1], Florian Bruckner[2], Claas Abert[2], Amalio Fernández-Pacheco[4], Dieter Suess[2], Claus Ropers[5], Manfred Albrecht[3], Stefan Mathias[1], and •Daniel Steil[1] — [1]Georg-August-Universität Göttingen — [2]University of Vienna — [3]University of Augsburg — [4]Technical University of Vienna — [5]Max-Planck Institute for Multidisciplinary Sciences, Göttingen

Topological spin textures can be created, annihilated and manipulated in Fe/Gd multilayers using adiabatic and non-adiabatic external stimuli like temperature, magnetic fields and ultrashort light pulses. In this talk, I will show various ways to control magnetic spin textures statically and dynamically in $[Fe(0.35\text{ nm})/Gd(0.40\text{ nm})]_{160}$ multilayers, combining time-resolved magneto-optical Kerr spectroscopy with micromagnetic simulations and static magnetic imaging techniques. In particular, I will discuss different pathways for skyrmion creation [1,3], the use of in-plane fields as an additional control knob [4], as well as tailoring the skyrmion breathing mode using a two pulse excitation sequence [2].

[1] Adv. Funct. Mater. **34**, 2313619 (2024)
[2] Phys. Rev. Lett. **133**, 156701 (2024)
[3] Phys. Rev. B **112**, 064413 (2025)
[4] arXiv:2510.21320 (2025)

15 min break

MA 55.7 Fri 11:15 HSZ/0004

Effects of interlayer Dzyaloshinskii-Moriya interaction on the shape and dynamics of magnetic twin-skyrmions — •Tim Matthies[1], Levente Rózsa[2,3], Roland Wiesendanger[1], and Elena Vedmedenko[1] — [1]University of Hamburg, Hamburg, Germany — [2]Wigner Research Centre for Physics, Budapest, Hungary — [3]Budapest University of Technology and Economics, Budapest, Hungary

Magnetic skyrmions have been proposed as promising candidates for storing information due to their high stability and easy manipulation by spin-polarized currents. Here, we study how these properties are influenced by the interlayer Dzyaloshinskii-Moriya interaction (IL-DMI), which stabilizes twin-skyrmions in magnetic bilayers. We find that the spin configuration of the twin-skyrmion adapts to the direction of the IL-DMI by elongating or changing the helicities in the two layers. Driving the skyrmions by spin-polarized currents in the current-perpendicular-to-plane configuration, we observe significant changes either in the skyrmion velocity or in the skyrmion Hall angle depending on the current polarization. These findings unravel further prospects for skyrmion manipulation enabled by the IL-DMI.

MA 55.8 Fri 11:30 HSZ/0004

Current-Induced Skyrmion Dynamics and Diffusion — •Leonie-Charlotte Dany, Maarten Brems, Simon Fröhlich, Tobias Sparmann, Fabian Kammerbauer, Sachin Krishnia, Peter Virnau, and Mathias Kläui — Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany

Magnetic skyrmions, nanoscale chiral spin textures with particle-like behavior, are promising candidates for information storage and unconventional computing due to their robustness and efficient current-driven motion [1-3]. In Ta/CoFeB/MgO multilayers, we investigate the transition of current-driven skyrmion motion from creep, through depinning, to the viscous flow regime driven by a unipolar, pulsed current. By varying current density, pulse width, and frequency, we demonstrate how external stimulation overcomes pinning potentials and enables skyrmions to enter into a regime characterized by linear velocity-current relations, i.e., the viscous flow regime. Additional studies with an alternating, net-zero current drive reveal an exponential increase of the diffusion coefficient with current density, while higher frequencies suppress diffusion following a power-law dependence. These findings provide quantitative insight into controlling skyrmion mobility and diffusion, essential for spintronic device design [4].

[1] G. Beneke *et al.*, *Nat. Commun.*, **15**, 8103 (2024).
[2] K. Raab *et al.*, *Nat. Commun.*, **13**, 6982 (2022).
[3] K. Everschor-Sitte *et al.*, *J. Appl. Phys.*, **124**, 24, 240901 (2018).
[4] L. Dany *et al.*, under preparation.

MA 55.9 Fri 11:45 HSZ/0004

Correlating on-the-fly Electrical and Optical Skyrmion Readout — •Grischa Beneke[1], Kilian Leutner[1], Nikhil Vijayan[1,2], Fabian Kammerbauer[1], Duc Minh Tran[1], Sachin Krishnia[1], Johannes Güttinger[2], Armin Satz[2], Robert Frömter[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Germany — [2]Infineon Technologies Austria AG, Austria

Magnetic skyrmions, topologically stabilized spin textures, are promising candidates for memory devices and non-conventional computing due to their stability, non-linear interactions, and low-power manipulation. However, reliable electrical readout of individual skyrmions remains a fundamental challenge, as current magnetic tunnel junction and anomalous Hall effect techniques fail to reliably detect single moving skyrmions. Our approach leverages thermally activated skyrmions, where a low constant drive current simultaneously drives skyrmion motion and the Hall voltage necessary for detection. We demonstrate reliability through real-time correlation between Hall voltage signals and direct Kerr microscopy imaging. Two consecutive Hall crosses enable skyrmion velocity determination in accordance with Kerr microscopy videos [1]. We present an analytical formula for the skyrmion AHE readout signal, demonstrating scalability from micrometer to nanometer dimensions. These advances establish a robust platform for skyrmion-based sensors, counters, and unconventional computing systems requiring precise individual skyrmion control and detection.

[1] G. Beneke et al., Accepted for publication in Appl. Phys. Lett., arXiv:2508.15519 (2025).

MA 55.10 Fri 12:00 HSZ/0004

CNN-Based Classifier for Automated Identification of Magnetic States in Spin Dynamics Simulations — •Amal Aldarawsheh[1], Ahmed alia[2], and Stefan Blügel[1] — [1]Peter Grünberg Institute Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany — [2]Institute for Advanced Simulation (IAS-7), Forschungszentrum Jülich, 52425 Jülich, Germany

The identification and classification of different magnetic states are essential for understanding the complex behavior of magnetic systems. Traditional approaches that rely on handcrafted features or manual inspection often fall short, particularly when dealing with subtle or topologically complex spin textures. In this study, we present an automated deep learning model that employs an EfficientNetV1B0 Convolutional Neural Network to classify nine distinct magnetic states, including both FM and, for the first time, AFM spin textures such as AFM skyrmions and AFM stripe domains. The spin configurations are generated through atomistic spin dynamics simulations using the *Spirit* code, then visualized with VFRendering to produce RGB images, which serve as inputs to the classification model. To train and evaluate the model, we created a new dataset of manually labeled RGB images. Experimental results show that the proposed model achieves an accuracy and F1-score of 99%, significantly outperforming established deep learning baselines.

MA 55.11 Fri 12:15 HSZ/0004

Exchange striction model calculations for the skyrmion-containing compound $Gd_3Ru_4Al_{12}$ — •Justus Grumbach[1], Martin Rotter[2], and Mathias Doerr[1] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany — [2]McPhase Project, Sestiere Cannaregio 2904, 30121 Venezia, Italy

For the compound $Gd_3Ru_4Al_{12}$, we measured the complete dilatometric tensor, enabling a refinement of the phase diagrams in all crystallographic directions (see also the talk by M. Doerr). The most prominent feature is a lattice effect indicating a coupling of skyrmions to the crystal lattice, as previously evidenced by a docking of the propagation vector onto the crystal lattice. In the simulations, an approach for calculating the exchange striction was implemented that takes volume-influences into account and is particularly suitable for Gd-based compounds. Major aspects supporting our experimental results could be reproduced. The presentation will outline the full simulation process - from modeling, through the calculation of general magnetostrictive effects, to the influence of skyrmions - and conclude with a discussion of the volume effect in the skyrmion phase.

MA 55.12 Fri 12:30 HSZ/0004

Volume effect in Gd-containing skyrmion compounds — •Mathias Doerr[1], Justus Grumbach[1], and Maximilian Hirschberger[2] — [1]Technische Universität Dresden, Germany. — [2]University of Tokyo and RIKEN Center for Emergent Matter Science, Japan.

Skyrmions with a smaller characteristic wavelength are currently investigated in centrosymmetric compounds. The interplay between skyrmion lattices (SkL) and underlying crystallographic structures offers the possibility to determine the stability region of skyrmions by dilatometric measurements (thermal expansion and forced magnetostriction). Magnetostriction measurements on the two hexagonal metallic compounds $Gd_3Ru_4Al_{12}$ with a planar breathing kagome lattice and the triangular lattice magnet Gd_2PdSi_3 show a volume change (plateau phase) in the stability region of the skyrmion lattice, indicating the need for an unstrengthened crystal lattice for the formation of skyrmions. Another important result of our investigations was the refinement of the *H*-*T* phase diagrams for both investigated materials. The key results of the measurements were verified using a mean field calculation (see talk by J. Grumbach).