MA 21: Skyrmions II

Time: Tuesday 14:00–15:30 Location: HSZ/0004

MA 21.1 Tue 14:00 HSZ/0004

Real-Time Modeling of Skyrmion Dynamics in Arbitrary 2D Spatially Dependent Pinning Potential Landscapes — •Simon M. Fröhlich, Tobias Sparmann, Maarten A. Brems, Jan Rothörl, Fabian Kammerbauer, Klaus Raab, Sachin Krishnia, Mathias Kläui, and Peter Virnau — Institute of Physics, Johannes Gutenberg University Mainz

We investigate how non-flat pinning landscapes influence skyrmion dynamics and develop a quantitative framework that links experimental measurements to predictive simulations. Using real-time magneto-optical Kerr microscopy, we track skyrmion hopping and dynamics in a magnetic thin-film system and extract dwell times and transition statistics across pinning sites. This data is used to construct parameters for a coarse-grained Thiele model, for which we introduce a two-stage parameter identification procedure that directly maps experimental observables onto simulation units. This calibration resolves a key barrier to quantitative quasiparticle-level modeling by enabling reconstruction of pinning energies not directly accessible on experimental timescales. We validate the resulting simulation framework by predicting the density dependence of skyrmion diffusion and confirming it through long-time measurements. The approach provides a robust, simulation-ready description of the pinning landscape and establishes a pathway for predictive in-silico exploration of skyrmion dynamics and device concepts on experimentally relevant time and length scales.

MA 21.2 Tue 14:15 HSZ/0004

Theoretical study on excitation in anti-Skyrmion lattice — •László Udvardi, Mátyás Török, and László Szunyogh — Department of Theoretical Physics, Budapest University of Technology and Economic

Magnetic Skyrmions exhibit intriguing and novel phenomena due to their topologically non-trivial spin textures. Their exceptional stability makes them possible candidates for information carriers for future spintronic devices.

We have determined the parameters appearing in a classical spin model from first principle for $Pt_{95}Ir_{05}$/Pd(111) overlayer. Optimizing the energy of the spin model several local minima have been identified as a Skyrmion with various topological charges. We demonstrate that the frustration of the isotropic exchange interactions is responsible for the creation of these various types of skyrmionic structures. Our study is focused on objects with topological charge of Q=1 anti-Skyrmion. Anti-skyrmions exhibit attractive inter-particle interaction and they have tendency to form clusters or skyrmionic lattice. The excitation spectrum of an anti-skyrmon lattice with various external magnetic field has been calculated. The low energy excitation responsible for the low temperature behavior of the system shows similarities to nematic liquid crystals.

MA 21.3 Tue 14:30 HSZ/0004

Skyrmion topological Hall effect in Ta/CoFeB/MgO at room temperature detected with Kerr microscopy — •Hauke Lars Heyen[1], Michael Vogel[2], Florian Gossing[2], Jakob Walowski[1], Jeffrey McCord[2], and Markus Münzenberg[1] — [1]Institute of Physics, University Greifswald, Germany — [2]Institute of Materials Science, Nanoscale Magnetic Materials and Magnetic Domains, CAU Kiel, Germany

The topological Hall effect is interesting for characterizing materials and their non-trivial spin structures. It arises from spin textures with a finite topological charge, such as skyrmions. In this work, we measured the topological Hall effect originating from topologically protected skyrmions in Ta/CoFeB/MgO single-layer films. Since the small topological Hall contribution appears on top of the dominating anomalous Hall effect, its direct detection in this material system is challenging. Electrical Hall effect measurements contain both effects and to separate these, Kerr-microscopy (MOKE) measurements are carried out simultaneously to Hall effect measurements. We further verify the results with thermal and electrical transport measurements to calculate a topological quantity that contains the topological Nernst and Hall effect respectively. Those measurements are conducted using the experimental scheme introduced in [1].

[1] R. Schlitz et al. All Electrical Access to Topological Transport Features in Mn1.8PtSn Films. Nano Letters, 19(4):2366-2370, March 2019.

MA 21.4 Tue 14:45 HSZ/0004

Optimization of magnetic skyrmion diffusion in thin films — •Alen John[1,2], Maria Andromachi Syskaki[1], Jürgen Langer[1], Gerhard Jakob[2], and Mathias Kläui[2] — [1]Singulus Technologies AG, 63796 Kahl am Main, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany

Topological magnetic solitons, particularly skyrmions, have garnered significant interest for their potential in unconventional computing and sensing applications. In this work, we outline an optimized fabrication strategy for generating and stabilizing low-pinning magnetic skyrmions in magnetic thin films using magnetron sputtering. We focus on Ta/CoFeB/MgO heterostructures with perpendicular magnetic anisotropy and systematically vary key deposition parameters including sputter power and Ar pressure to optimize skyrmion formation. Furthermore, we incorporate an ultrathin Ta dusting layer at the CoFeB/MgO interface to precisely tune the interfacial anisotropy. This combined approach enables the realization of ultralow-pinning thin-film systems that reliably host room-temperature, thermally diffusing skyrmions. Such samples represent a promising platform for emerging applications in unconventional computing paradigms, including reservoir computing[1].

[1] J. Zázvorka et al., Nat. Nanotechnol. 14, 658 (2019)

MA 21.5 Tue 15:00 HSZ/0004

Impact of higher-order exchange on the lifetime of skyrmions and antiskyrmions — Hendrik Schrautzer[1], Moritz Goerzen[2,3], •Bjarne Beyer[3], Pavel Bessarab[1,4], Soumyajyoti Haldar[3], and Stefan Heinze[3,5] — [1]Science Institute and Faculty of Physical Sciences, University of Iceland, Reykjavik, Iceland — [2]CEMES, Université de Toulouse, CNRS, Toulouse, France — [3]Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany — [4]Department of Physics and Electrical Engineering, Linnaeus University, Kalmar, Sweden — [5]Kiel Nano, Surface, and Interface Science (KiNSIS), University of Kiel, Germany

Reliable control of skyrmion lifetime is essential for realizing spintronic devices, yet the role of higher-order interactions (HOI) – which can lead to skyrmion stabilization – remains largely unexplored. Here we calculate lifetimes of isolated skyrmions and antiskyrmions at transition-metal interfaces based on an atomistic spin model that includes fourth-order exchange [1]. Within harmonic transition-state theory, we evaluate both energetic and entropic contributions and find substantially enhanced lifetimes when HOI are included. The four-spin four-site interaction raises the energy barrier and lowers the curvature of the energy landscape in the vicinity of the collapse saddle point, increasing the pre-exponential factor of the arrhenius Law. Further HOI allow thermally stable skyrmions and antiskyrmions even in absence of Dzyaloshinskii-Moriya interaction, interesting in the context of 2D van der Waals magnets lacking inversion symmetry.

[1] H. Schrautzer *et al.*, arxiv:2511.05278 (2025).

MA 21.6 Tue 15:15 HSZ/0004

Real-time observation of topological defect dynamics mediating two-dimensional skyrmion lattice melting — Raphael Gruber[1], •Edoardo Mangini[1], Maria-Andromachi Syskaki[1], Elizabeth Jefremovas[1], Sachin Krishnia[1], Asle Sudbø[2], Peter Virnau[2], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University, Staudingerweg 7, Mainz, Germany — [2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway

Magnetic skyrmions, topologically non-trivial chiral magnetic quasiparticles, can be stabilized in magnetic thin-film stacks [1]. By precisely controlling the externally applied in-plane and out-of-plane magnetic fields, two-dimensional dense arrays of skyrmions—so-called skyrmion lattices—can be formed [2]. Through suitable geometrical confinement, both orientational and translational order can be induced in these lattices. Such systems provide experimental insight into the dynamics of phase transitions in two-dimensional particle systems.

In this work, we show a two-step topological lattice-melting experiment, in which phase transitions are triggered in a skyrmion lattice by tuning the skyrmion size. The Kerr microscopy setup, in conjunction with machine learning approaches, enables real-time tracking of skyrmions, allowing us to investigate the emergence and dynamics of topological lattice defects throughout the phase transitions [3].

[1] K. Everschor-Sitte et al., J. Appl. Phys. 124, 24, 2018
[2] J. Zázvorka et al., Adv. Funct. Mater. 30, 46, 2020
[3] R. Gruber et al., Nat. Nanotechnol. 20, 10, 2025