MA 29: Skyrmions II

Time: Wednesday 15:00–18:45 Location: H20

MA 29.1 Wed 15:00 H20

Emergent electromagnetic inductance of interface skyrmions in $SrRuO_3/SrIrO_3$ bilayers — •Ludwig Scheuchenpflug[1], Sebastian Esser[2], Robert Gruhl[1], Max Hirschberger[2,3], and Philipp Gegenwart[1] — [1]Universität Augsburg, Lehrstuhl für Experimentalphysik VI — [2]Department of Applied Physics, University of Tokyo, Japan — [3]RIKEN Center for Emergent Matter Science, Japan

Emergent electromagnetic induction (EEMI) by current-driven spin dynamics was proposed and observed in the spin helix magnet $Gd_3Ru_4Al_{12}$ [1], where the (current-nonlinear) imaginary impedance at kHz frequency was associated with the motion of helical spin structures. To explore the possibility of EEMI arising from current-driven skyrmion dynamics, we fabricated and microstructured epitaxial thin film bilayers of ferromagnetic $SrRuO_3$ and paramagnetic $SrIrO_3$ on $SrTiO_3$. This bilayer system is known to host DMI-stabilized Néel-skyrmions, indicated by the topological Hall-effect (THE) [2]. We reproduce the THE signatures and observe an accompanying large and current-linear imaginary impedance at low temperatures over broad current density and frequency ranges, signaling the EEMI from the low-energy dynamics of pinned interface skyrmions.

[1] Naoto Nagaosa, Jpn. J. Appl. Phys. 58, 120909 (2019), Yokouchi et al., Nature 586, 232 (2020).
[2] J. Matsuno et al., Science Adv. 2, e1600304 (2016), S. Esser et al., Phys. Rev. B 103, 214430 (2021).

MA 29.2 Wed 15:15 H20

Surface acoustic wave based movement of skyrmions — •Philipp Schwenke, Ephraim Spindler, Vitaliy Vasyuchka, Philipp Pirro, Abbass Hamadeh, and Mathias Weiler — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

Magnetic skyrmions have significant potential for utilization in spintronic devices, primarily due to their stability and the ability to be manipulated by electric currents. However, when a current is applied, the skyrmions do not move in a direction parallel to the current flow due to the skyrmion Hall effect [1]. Consequently, the precise control of their movement is challenging. Recently, it has been demonstrated that a skyrmion can be moved using a surface acoustic wave (SAW) [2]. Here, we propose an alternative scheme for acoustic manipulation of magnetic skyrmions. Our approach is based on exploiting skyrmion pinning and non-sinusoidal SAWs. To demonstrate feasibility of our approach, we performed micromagnetic simulations using Mumax in a realistic pinning energy landscape.

[1] G.Chen *et. al*, Nature Phys. **13**, 112-113 (2017)
[2] Y.Yang *et. al*, Nat. Commun. **15**, 1018 (2024)

MA 29.3 Wed 15:30 H20

Quantum skyrmions and antiskyrmions in monoaxial chiral magnets — •Stefan Liščák, Andreas Haller, Andreas Michels, Thomas L. Schmidt, and Vladyslav Kuchkin — Department of Physics and Materials Science, University of Luxembourg

Classical monoaxial chiral magnets represent a unique magnetic system that allows for the stabilization of both skyrmions and antiskyrmions of equal energy. Unlike a similar situation in frustrated magnets, the energy landscape here is much simpler, consisting of four states: the saturated ferromagnetic state, spin-spiral, skyrmion, and antiskyrmion. This simplicity makes such systems interesting for potential applications that rely on manipulating these states. We study the quantum analog of the already established classical theory by investigating the low-excitation spectra of a spin-1/2 quantum Heisenberg model with monoaxial Dzyaloshinskii-Moriya interaction. We establish that such a model supports the existence of skyrmion and antiskyrmion states of equal energy using the density matrix renormalization group method (DMRG). This degeneracy allows for the existence of a mesoscopic Schrödinger cat state exhibiting properties of both skyrmion and antiskyrmion. To characterize this superposition, we calculate two-point correlation functions, which can be measured in neutron scattering experiments. Finally, we introduce a perturbation in the form of a magnetic field gradient to induce a non-trivial time evolution of the superposition state. We study this time evolution both using a numerical variational approach and the collective coordinates method.

MA 29.4 Wed 15:45 H20

Magnetometry on the low-temperature skyrmion state in Cu_2OSeO_3 — Christian Oberleitner[1], •Lukas Heindl[1], Johannes Friedrich[1], Andreas Bauer[1,2], Denis Mettus[1,3], Helmut Berger[4], and Christian Pfleiderer[1,2,3] — [1]Physik-Dep., TU Munich, D-85748 Garching — [2]ZQE, TU Munich, D-85748 Garching — [3]MLZ, TU Munich, D-85747 Garching — [4]Inst. de Phys., EPFL, CH-1015 Lausanne

In cubic chiral magnets, skyrmion lattice states emerge near the magnetic ordering temperature, stabilized by thermal fluctuations [1]. Recently, a distinct low-temperature skyrmion state (LTS) was observed in Cu_2OSeO_3 for magnetic fields along the $\langle 100 \rangle$ axes, emphasizing the role of cubic anisotropies [2, 3]. Nucleation of this state at low temperatures requires an intermediate phase, the tilted conical phase, and has been studied mainly along major crystallographic axes [4].

Here, we examine the nucleation dynamics of the LTS under field rotation away from high-symmetry directions. Magnetization and ac susceptibility measurements on spherical and cuboid samples reveal key geometry effects. Spherical samples, with uniform internal field distributions, show significant spontaneous LTS nucleation. In contrast, cuboid samples, with inhomogeneous internal fields, need external field pumping to achieve substantial LTS populations[5].

[1]: S. Mühlbauer et al., Science, 323 (2009) 915-919 [2]: S. Seki et al., Phys. Rev. B, 85 (2012) 220406(R) [3]: A. Chacon et al., Nat. Phys., 14 (2018) 936-941 [4]: M. Halder et al., Phys Rev., B 98 (2018) 144429 [5]: A. Aqeel et al., Phys. Rev. Lett., 126 (2021) 017202

MA 29.5 Wed 16:00 H20

Edge dislocations in helimagnets as mobile topological defects — •Maurice Colling[1], Manuel Zahn[1,2], Jan Masell[3], and Dennis Meier[1] — [1]NTNU Norwegian University of Science and Technology, Trondheim, Norway — [2]University of Augsburg (UniA), Augsburg, Germany — [3]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Magnetic topological solitons, such as skyrmions and hopfions, represent fertile ground for emergent physical properties with potential applications in spintronics and unconventional computing. In my talk, I will present magnetic edge dislocations as intriguing nano-sized topological textures, which can serve as mobile information carriers. Edge dislocations naturally arise in the helimagnetic background of the B20-type material FeGe, which we study as a model system. Using micromagnetic simulations, we demonstrate how isolated dislocations can be initialized in a track-like geometry and how their movement can be controlled using spin-polarized currents and magnetic fields. Furthermore, we show how pinning sites can be introduced to achieve 'stop-and-go' motion, allowing to translate events (e.g. magnetic field or current pulses) into positional information. One key difference between dislocations and other topological solitons is their relaxation motion which is driven by the system's intrinsic tendency to revert toward the helimagnetic ground state. This feature makes them interesting candidates for sensing and computing applications and low-energy device technologies in general.

MA 29.6 Wed 16:15 H20

Cubic magnetic anisotropy in $B20$ magnets: Interplay of anisotropy and magnetic order in $Fe_{1-x}Co_xSi$ — •Gilles Gödecke, Julius Grefe, Stefan Süllow, and Dirk Menzel — Insitut für Physik der Kondensierten Materie, TU Braunschweig, D-38106 Braunschweig, Germany

The itinerant systems MnSi and $Fe_{1-x}Co_xSi$ are prominent members among the chiral $B20$ helimagnets. They are known to host chiral spin structures and magnetic skyrmions as a result from the competition of various magnetic interactions, one of which is magnetic anisotropy. Recently, a secondary skyrmion phase governed by cubic anisotropy was identified in the compound Cu_2OSeO_3 [1] raising the question wether such a phase also exists in MnSi and $Fe_{1-x}Co_xSi$. To aid the search for this phase, a better understanding of the cubic anisotropy in these systems would be beneficial.

Here, we report on the quantitative measurement of the cubic magnetocrystalline anisotropy constants in MnSi and $Fe_{1-x}Co_xSi$ ($0.08 \leq$

$x \leq 0.70$) single crystals. Our work presents a systematic study regarding the cubic anisotropy at $T = 5\,\mathrm{K}$ and $T = 10\,\mathrm{K}$ by means of angle-resolved SQUID magnetization measurements. We observe that the cubic anisotropy is generally weaker than in familiar compounds and more pronounced in MnSi than in $Fe_{1-x}Co_xSi$. For $Fe_{1-x}Co_xSi$ the anisotropy gains at low Co-concentrations with increasing x, vanishes for $x = 0.50$, and is then finite for high x.

[1] A. Chacon et al., Nature Physics 14, 936-941 (2018)

MA 29.7 Wed 16:30 H20

Imaging Topological Defect Dynamics Mediating 2D Skyrmion Lattice Melting — •Raphael Gruber[1], Jan Rothörl[1], Simon Fröhlich[1], Maarten Brems[1], Fabian Kammerbauer[1], Maria-Andromachi Syskaki[1], Elizabeth Martín Jefremovas[1], Sachin Krishnia[1], Asle Sudbø[2], Peter Virnau[1], and Msthias Kläui[1] — [1]Institute of Physics, JGU Mainz — [2]QuSpin, NTNU Trondheim

Two-dimensional (2D) phase transitions are mediated by topological defects, as predicted by KTHNY theory. Using real-time Kerr microscopy, we image the two-step melting of a 2D skyrmion lattice with high spatial and temporal resolution. Skyrmions in low-pinning thin-film systems offer tunability of their size and effective temperature [2,3], allowing us to controllably drive the phase transitions.

Our results reveal the emergence of an intermediate hexatic phase and identify topological defects as the key feature of the melting. We provide new insight into 2D melting dynamics and measure a dislocation diffusion coefficient orders of magnitude higher than skyrmion diffusion. This work highlights skyrmions as a versatile platform for studying phase behavior in 2D systems

[1] Kosterlitz & Thouless, J. Phys. C: Solid State Phys. 5, L124 (1972). [2] Zázvorka et al., Nat. Nanotechnol. 14, 658-661 (2019). [3] Gruber et al., Adv. Mater. 35, 2208922 (2023).

15 min. break

MA 29.8 Wed 17:00 H20

Imaging Topological Defect Dynamics Mediating 2D Skyrmion Lattice Melting — Maarten A. Brems[1], Tobias Sparmann[1], •Simon M. Fröhlich[1], Leonie-C. Dany[1], Jan Rothörl[1], Fabian Kammerbauer[1], Elizabeth M. Jefremovas[1], Oded Farago[2], Mathias Kläui[1], and Peter Virnau[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Ger many — [2]Biomedical Engineering Department, Ben Gurion University of the Negev, Be'er Sheva 84105, Israel

We demonstrate fully quantitative Thiele model simulations of magnetic skyrmion dynamics on previously unattainable experimentally relevant large length and time scales by ascertaining the key missing parameters needed to calibrate the experimental and simulation time scales and current-induced forces. Our work allows us to determine complete spatial pinning energy landscapes that enable quantification of experimental studies of diffusion in arbitrary potentials within the Lifson-Jackson framework. Our method enables us to ascertain the time scales, and by isolating the effect of ultra-low current density (order 10^6 A/m^2) generated torques we directly infer the total force acting on the skyrmion for a quantitative modelling. [2]

[1] S. Lifson and J. L. Jackson, J. Chem. Phys. 36, 2410 (1962). [2] M. A. Brems et al., Phys. Rev. Lett., (2024) (accepted for publication)

MA 29.9 Wed 17:15 H20

The dynamics of skyrmion shrinking — •Frederik Austrup[1], Wolfgang Häusler[2], Michael Lau[1], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg — [2]Institut für Physik, Universität Augsburg

When magnetic skyrmions decay, their size in real space decreases in a finite time before they eventually collapse. We derive a continuum model to describe the shrinking behavior of skyrmions before they collapse. Using the Landau-Lifshitz-Gilbert equation and the time derivative of the vectorfield, we find a set of coupled nonlinear ordinary differential equation for the time dependent skyrmion radius and helicity. In particular, we use a triangular-shaped skyrmion profile of its polar angle. Contrary to the commonly expected simple exponential decrease in size, we reveal a more complicated time dependence, where the time-dependent radius crosses over from an exponential decay towards a square root decrease, $\sim (t - t_c)^{1/2}$, near a critical time t_c at which it collapses. This critical time is found to depend logarithmically on the lattice constant. Additionally, we present studies examining the interplay between the shrinking and a transformation through different skyrmion configurations, depending on the various system parameters. The findings are accompanied by numerical studies, supporting the predictions from the theoretical continuum model.

MA 29.10 Wed 17:30 H20

Effects of chiral polypeptides on skyrmion stability and skyrmion diffusion — Fabian Kammerbauer[1], Yael Kapon[2], •Theo Balland[1], Shira Yochelis[2], Sachin Krishnia[1], Yossi Paltiel[2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes-Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Institute of Applied Physics, Faculty of Sciences, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel

CISS, chirality-induced spin selectivity is a phenomenon that has raised significant interest due to the large spin polarizations generated by organic molecules and other effects such as magnetic switching of ferromagnets induced by chiral molecules [1]. In hybrid systems, these chiral molecules have been observed to influence magnetic properties such as changes in the magnetization [2]. In this study, we investigate how chiral molecules of α-helix polyalanine interact with chiral spin structures, namely magnetic skyrmions, which are stabilized in ferromagnetic/heavy metal multilayers due to Dzyaloshinskii-Moriya interaction [3]. Using magneto-optic Kerr effect imaging, we show that chiral polypeptides can influence the stability of skyrmions by modifying the ranges of temperature and applied magnetic field in which they are stable. We also show that the chiral molecules affect the skyrmion dynamics, in particular the thermal diffusion of the skyrmions [4].

[1] R. Naaman et al. Nat. Rev. Chem. 3, 250 (2019)
[2] Y. Kapon et al. J. Chem. Phys. 159, 064701 (2023)
[3] K. Everschor-Sitte et al. J. Appl. Phys. 124, 240901 (2018)
[4] Y. Kapon et al. (under review)

MA 29.11 Wed 17:45 H20

Interactions between Skyrmions with various topological charges — •László Udvardi and Mátyás Török — Department of Theoretical Physics, Budapest University of Technology and Economics, Budapest, Hungary

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 a FePd bilayer on Ir(111) and $Pt_{95}Ir_{05}$/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. We focused on objects with topological charge of Q=-1 (Skyrmion) and Q=1 (anti Skyrmion) and explored the interactions between them. We found that although the interaction between Skyrmions with Q=-1 is always repulsive it has attractive part between anti Skyrmions. The excitation of an isolated Skyrmion and a lattice has been also investigated.

MA 29.12 Wed 18:00 H20

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

Skyrmions are nano-sized 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 29.13 Wed 18:15 H20

Intrinsic non-reciprocity in skyrmion dynamics in synthetic antiferromagnet — •Mona Bhukta[1], Takaaki Dohi[1], Fabian Kammerbauer[1], Maria-Andromachi Syskaki[1,2], Duc Minh Tran[1], Markus Weigand[3], Sebastian Wintz[3], Simone Finizio[4], Jörg Raabe[4], Robert Frömter[1], and Mathias Kläui[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Singulus Technologies AG, 63796 Kahl am Main, Germany. — [3]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 14109 Berlin, Germany — [4]Paul Scherrer Institut, Swiss Light Source, Forschungsstrasse 111 5232 PSI Villigen, Switzerland.

In this work, we investigate the dynamics of isolated AFM skyrmion tubes in synthetic antiferromagnetic (SyAFM) multilayers composed of 30-50 ferromagnetic (FM) layers, antiferromagnetically coupled via the interlayer exchange interaction. Using element-specific time-resolved scanning transmission X-ray microscopy (STXM), we demonstrate the current-induced dynamics of the resulting AFM skyrmions. In uncompensated SyAFM, we observe a current-polarity-dependent, nonreciprocal skyrmion Hall effect of individual AFM skyrmions, arising from the unique intrinsic properties of the hybrid chiral skyrmion tubes in the flow regime. This nonreciprocity can be tuned by the degree of magnetic compensation and vanishes in highly compensated SyAFM [1]. References [1] T. Dohi, M. Bhukta, et al., Observation of a nonreciprocal skyrmion Hall effect of hybrid chiral skyrmion tubes in synthetic antiferromagnetic multilayers,arxiv (2024).

MA 29.14 Wed 18:30 H20

Hybrid magnonic crystal based on skyrmions — •Krzysztof Szulc[1,2], Mateusz Zelent[2], and Maciej Krawczyk[2] — [1]Institute of Molecular Physics, Polish Academy of Sciences, Poznań, Poland — [2]ISQI, Faculty of Physics and Astronomy, Adam Mickiewicz University, Poznań, Poland

We study a hybrid magnonic crystal consisting of a Py waveguide over which the periodic chain of Co/Pt dots is placed [K. Szulc et al. arXiv:2404.10493]. In the dots, the Dzyaloshinskii-Moriya interaction is present, thus it is possible to stabilize the single-domain state and the skyrmion state. We show that the dispersion relation changes with the change of the magnetization configuration of the dot. The sizes of bandgaps significantly differ in these systems. Due to different character of excitation of the both states, the system with skyrmions in dots can interact with the waveguide at lower frequencies or even be excited below the frequencies of the waveguide. Furthermore, I show that one part of the skyrmion modes hybridize with the waveguide modes, sometimes inducing additional band gaps in the spectrum, while the second part does not interact, forming bound states. Such a system of waveguide coupled to the chain of dots forms a reconfigurable spin-wave platform which can be used in spin-wave filtering and artificial neural networks.

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