MA 37: Skyrmions III

Time: Thursday 9:30–13:00 Location: EB 301

MA 37.1 Thu 9:30 EB 301

Classical and quantum skyrmions in monoaxial chiral magnets — •Vladyslav Kuchkin[1,2], Stefan Liscak[1], Andreas Haller[1], Thomas Schmidt[1], and Nikolai Kiselev[3] — [1]University of Luxembourg — [2]University of Iceland — [3]Forschungszentrum Jülich

Chiral magnets represent a special type of magnetic materials with non-zero Dzyaloshinskii-Moriya interactions (DMI). The interplay between DMI and Heisenberg exchange interaction can stabilize a wide variety of magnetic textures: spin spirals, skyrmion lattices, isolated solitons, etc. In ordinary magnets, the DMI is isotropic, which fixes the chirality type of all such textures. However, if the DMI vanishes in certain spatial directions, magnetic solitons of different chiralities might be stable. In our theoretical work, we have demonstrated the existence of skyrmions and antiskyrmions in such monoaxial chiral magnets and studied the static and dynamic properties of these solitons. In particular, we showed that applying a rotating magnetic field of frequency ω leads to a motion of solitons with a velocity $v \sim \omega$. From the point of view of quantum skyrmions, monoaxial chiral magnets are a unique system in which skyrmion and antiskyrmion states are energetically degenerate. The latter makes these materials promising for skyrmion-based quantum computation, in which skyrmions of different topological charges play the role of qubits.

MA 37.2 Thu 9:45 EB 301

Topological Magnon-Plasmon-Polaritons in Ferromagnets, Antiferromagnets and Skyrmion Crystals — Tomoki Hirosawa[1], Pieter Gunnink[2], and •Alexander Mook[2] — [1]Aoyama Gakuin University, Japan — [2]Johannes Gutenberg University Mainz

The strong coupling of magnetic excitations with electromagnetic waves and other collective modes in the solid state offers exciting possibilities for magnonic quantum hybrid systems and cavity control of material properties. The recent advent of two-dimensional materials has sparked interest in the hybridization of magnons with plasmons [1-3], which can support topologically non-trivial properties [4,5].

Here, we explore the topological properties of magnon(-plasmon) polaritons with a strong focus on effectively two-dimensional ferromagnets, antiferromagnets, and skyrmion crystals. We show that the anticrossing can give rise to a finite quasiparticle Berry curvature and a topological gap. We discuss the possibility of chiral edge states and cavity-engineered thermal Hall and spin Nernst transport.

[1] Ghosh et al., Phys. Rev. B 107, 195302 (2023), [2] Dyrdał et al., Phys. Rev. B 108, 045414 (2023), [3] Costa et al., Nano Lett. 23, 10, 4510-4515 (2023), [4] Okamoto et al., Phys. Rev. B 102, 064419 (2020), [5] Efimkin, Kargarian, Phys. Rev. B 104, 075413 (2021),

MA 37.3 Thu 10:00 EB 301

Laser-Controlled Real- and Reciprocal-Space Topology in Multiferroic Insulators — Tomoki Hirosawa[3], Jelena Klinovaja[2], Daniel Loss[2], and •Sebastián A. Díaz[1] — [1]University of Konstanz, Konstanz, Germany — [2]Univesity of Basel, Basel, Switzerland — [3]Aoyama Gakuin University, Tokyo, Japan

Magnetic materials in which it is possible to control the topology of their magnetic order in real space or the topology of their magnetic excitations in reciprocal space are highly sought-after as platforms for alternative data storage and computing architectures. Here we show that multiferroic insulators, owing to their magneto-electric coupling, offer a natural and advantageous way to address these two different topologies using laser fields. We demonstrate that via a delicate balance between the energy injection from a high-frequency laser and dissipation, single skyrmions—archetypical topological magnetic textures—can be set into motion with a velocity and propagation direction that can be tuned respectively by the laser field amplitude and polarization. Moreover, we uncover an ultrafast Floquet magnonic topological phase transition in a laser-driven skyrmion crystal and we propose a new diagnostic tool to reveal it using the magnonic thermal Hall conductivity.

[1] T. Hirosawa, J. Klinovaja, D. Loss, and S. A. Díaz, Phys. Rev. Lett. 128, 037201 (2022)

MA 37.4 Thu 10:15 EB 301

Intrinsic and extrinsic skyrmion Hall deflections of intrinsic AFM skyrmions — •Amal aldarawsheh[1,2], Moritz Salermann[1,3,4], Muayad Abusaa[5], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulations, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany — [3]RWTH Aachen University, 52056 Aachen, Germany — [4]Science Institute and Faculty of Physical Sciences, University of Iceland, VR-III, 107 Reykjavík, Iceland — [5]Arab American University, Jenin, Palestine

Antiferromagnetic (AFM) skyrmions, comprised of two antiferromagnetically coupled ferromagnetic (FM) solitons, are promising for spintronic racetrack memories due to their predicted zero skyrmion Hall effect. Our ab-initio study explores the dynamic behavior of intrinsic single and interchained AFM skyrmions in the CrPdFe/Ir(111) system [1,2] driven by a spin torque, all based on atomistic spin dynamics simulations. Surprisingly, we unveil an intrinsic and extrinsic skyrmion Hall and uncover that FM skyrmions in the underlying Fe layer act as effective traps for AFM skyrmions, confining and reducing their velocity. These findings hold significant promise for spintronic applications, advancing our understanding of AFM and FM skyrmion interactions in heterostructures. [1] A. Aldarawsheh et al., Nat. Commun.**13**, 7369 (2022). [2] A. Aldarawsheh et al., Front. Physics. **11**, 335 (2023). Work funded by the PGSB (BMBF-01DH16027)and DFG (SPP 2137; LO 1659/8-1)

MA 37.5 Thu 10:30 EB 301

Dipolar-stabilized skyrmions transparent for TEM — •Andrii Savchenko[1], Vladyslav Kuchkin[2], Filipp Rybakov[3], and Nikolai Kiselev[1] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Science Institute, University of Iceland, 101 Reykjavík, Iceland — [3]Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden

In magnetic multilayers with asymmetric interfaces between magnetic and nonmagnetic layers, the interfacial Dzyaloshinskii-Moriya interaction (iDMI) can give rise to dipolar-stabilized skyrmions (magnetic bubbles) with Neel-type domain walls (DWs). For these DWs, the Lorentz Transmission Electron Microscopy (LTEM) contrast is absent when the electron beam is incident normal to the film surface and occurs only when the sample is tilted with respect to the beam. Such behavior in LTEM is often used to confirm the presence of iDMI. We have found another type of DW that exhibits the same behavior in LTEM. These Bloch-type DWs possess alternating chirality in adjacent layers. The skyrmions with these DWs can be observed in multilayers with weak interlayer exchange coupling (IEC) and without iDMI. The LTEM contrast for these skyrmions becomes visible only when the sample is tilted relative to the electron beam. In multilayers without IEC, dipolar skyrmions with alternating chirality and fixed chirality in the DWs have nearly identical energies and can coexist in the whole range of magnetic fields. Thus, the binary data can be efficiently encoded by the sequence of skyrmions of those two types.

MA 37.6 Thu 10:45 EB 301

Multipole magnons in topological skyrmion lattices resolved by cryogenic Brillouin light scattering microscopy — •Riccardo Ciola[1], Ping Che[2], Markus Garst[1], Volodymyr Kravchuk[1], Arnaud Magrez[2], Helmuth Berger[2], Thomas Schönenberger[2], Henrik Rønnow[2], and Dirk Grundler[2] — [1]Karlsruhe Institute of Technology, Germany — [2]École Polytechnique Fédérale de Lausanne, Switzerland

Chiral magnets provide an innovative framework to study non-collinear spin textures and their associated magnetization dynamics. They include helical and conical magnetic textures that are spatially modulated with a wavevector k_h as well as the topologically non-trivial skyrmion lattice (SkL) phase. Their spin waves have been explored in the long-wavelength regime using resonance and spin wave spectroscopy, and in the short wavelength regime using inelastic neutron scattering. Here, we show that Brillouin light scattering (BLS) is ideally suited to probe the complementary range of wavevectors $k \leq k_h$. We analysed bulk spin waves in the SkL phase of Cu_2OSeO_3. We provide parameter-free predictions for the corresponding resonances and their spectral weights. The theoretical results are compared to a BLS experiment in the backscattering geometry that probe magnons with a wavevector $k = 48 rad/\mu m < k_h = 105 rad/\mu m$. The clockwise, counterclockwise and breathing modes are resolved. Due to the finite wavevector of the magnon excitations, finite spectral weight is theoretically predicted also for other resonances. Experimentally, at least one additional resonance with quadrupole character is identified.

MA 37.7 Thu 11:00 EB 301

Skyrmion lattice and helical spin waves in the B20 chiral magnet $Cr_{0.82}Mn_{0.18}Ge$ — •Victor Ukleev[1], Priyaranjan Baral[2], Jonathan White[2], Chen Luo[1], Florin Radu[1], and Luana Caron[1,3] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [2]Paul Scherrer Institute, Villigen, Switzerland — [3]Faculty of Physics, Bielefeld University, Bielefeld, Germany

In our comprehensive investigation, we delve into the intriguing magnetic properties of the solid solution $Cr_{0.82}Mn_{0.18}Ge$, which emerges from the chiral cubic B20-type compounds CrGe and MnGe. While CrGe remains a metallic paramagnet devoid of long-range magnetic order, MnGe is a helimagnet with a short spiral pitch of a few nm. Our study reveals a striking difference from the behaviors of the parent compounds and $Cr_{0.82}Mn_{0.18}Ge$. Bulk measurements, coupled with small-angle neutron scattering, unambiguously establish the helimagnetic ground state below the critical temperature (T_C) of 13 K, wherein the spiral pitch undergoes a notable variation from 40 to 35 nm upon cooling to 2 K. We identify a low-field induced skyrmion state in the A-phase, extending over an unusually wide temperature range, 6 K below T_C. Remarkably, these field-cooled skyrmions persist as a metastable state at the base temperature and zero field, demonstrating the unique and robust nature of this magnetic configuration. This study not only contributes to the understanding of the magnetic phase diagram of $Cr_{0.82}Mn_{0.18}Ge$ but also highlights the emergence and stability of exotic magnetic states in this solid solution, paving the way for further exploration of its unique magnetic properties.

15 min. break

MA 37.8 Thu 11:30 EB 301

Nonlinear dynamics and stability of skyrmion strings — •Volodymyr Kravchuk — Leibniz Institute for Solid State and Materials Research, , Helmholtzstraße 20, 01069 Dresden

Here we analyze the nonlinear dynamics of a skyrmion string in a low-energy regime by means of the collective variables approach. Using the perturbative method of multiple scales (both in space and time), we show that the weakly nonlinear dynamics of the translational mode propagating along the string is captured by the focusing-type nonlinear Schroedinger equation [1]. As a result, the basic planar-wave solution, which has the form of a helix-shaped wave, experiences modulational instability. The latter leads to the formation of cnoidal waves. Both types of cnoidal waves, dn- and cn-waves, as well as the separatrix soliton solution, are confirmed by micromagnetic simulations. Beyond the class of traveling-wave solutions, we found Ma-breather propagating along the string. Finally, we proposed a generalized approach that enables one to describe the nonlinear dynamics of the modes of different symmetries, e.g., radially symmetrical or elliptical.

By computing the spectrum of the magnons propagating along the string in the presence of the longitudinal spin current, we found the current-induced Goldstone spin wave instability. A longitudinal current is thus able to melt the skyrmion string lattice via a nonequilibrium phase transition [2].

[1] V.P. Kravchuk, Phys. Rev. B 108, 144412 (2023).

[2] S. Okumura, V.P. Kravchuk, M. Garst, Phys. Rev. Lett. 131, 066702 (2023).

MA 37.9 Thu 11:45 EB 301

Unravelling the significance of higher-order exchange interactions for skyrmion stability in monolayer MnSeTe — •Megha Arya[1], Lionel Calmels[1], Rémi Arras[1], Soumyajyoti Haldar[2], Stefan Heinze[2], and Dongzhe Li[1] — [1]CEMES, Université de Toulouse, CNRS, 29 rue Jeanne Marvig, F-31055 Toulouse, France — [2]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstrasse 15, 24098 Kiel, Germany

Magnetic skyrmions in atomically thin van der Waals (vdW) materials provide an ideal playground to push skyrmion technology to the single-layer limit. Here, we investigate the intrinsic magnetic skyrmions in a monolayer Janus vdW magnet, MnSeTe, by first-principles calculations combined with atomistic spin simulations. A very large Dzyaloshinskii-Moriya interaction (DMI) is observed due to the intrinsic broken inversion symmetry and strong spin-orbit coupling for monolayer MnSeTe, which is in agreement with the literature. We will show that the interplay between the large DMI, the exchange coupling, and the magnetic anisotropy energy allows stabilizing zero-field nanoscale skyrmions in monolayer MnSeTe, becoming technologically competitive. We further show that the nanoscale skyrmions have moderate energy barriers protecting skyrmions against annihilation. Finally, we unravel the role of higher-order exchange interactions - which have so far been overlooked - as they can play an intriguing role in the stability of skyrmions.

MA 37.10 Thu 12:00 EB 301

Enhanced thermally-activated skyrmion diffusion with tuneable effective gyro tropic force — Takkaki Dohi[1], Markus Weissenhofer[2], Nico Kerber[1], Fabian Kammerbauer[1], Yuqing Ge[1], •Klaus Raab[1], Jakub Zázvorka[3], Maria-Andromachi Syskaki[1,4], Aga Shahee[1], Moritz Ruhwedel[5], Tobias Böttcher[5], Philip Pirro[5], Gerhard Jakob[1], Ulrich Nowak[2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany — [3]Institute of Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, Prague 12116, Czech Republic — [4]Singulus Technologies AG, 63796 Kahl am Main, Germany — [5]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Gottlieb-Daimler-Straße 46, 67663 Kaiserslautern, Germany

The topology of magnetic skyrmions lets them respond distinctly to electromagnetic stimuli and should have a substantial effect on stochastic diffusive motion. We present enhanced thermally activated diffusive motion of skyrmions within a specially designed synthetic antiferromagnet1, in which the topology can be precisely tuned2. By suppressing the effective topological charge, we achieve a diffusion coefficient more than ten times higher compared to ferromagnetic skyrmions and demonstrate the topology-dependence of the diffusive dynamics. 1.*Dohi, T. et al. Nat. Commun. 10, 5153 (2019). 2.*Dohi, T. et al. Nat. Commun. 14 (2023).

MA 37.11 Thu 12:15 EB 301

Enhancing Skyrmion Diffusion by Alternating Excitations — •Maarten A. Brems, Raphael Gruber, Tobias Sparmann, Jan Rothörl, Peter Virnau, and Mathias Kläui — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Magnetic skyrmions in thin films have been shown to exhibit thermal diffusion in a pinning-induced inhomogeneous energy landscape [1]. As a consequence, the targeted manipulation of the skyrmions' interaction with the pinning sites allows us to drastically enhance skyrmion diffusivity even at constant temperature. Recently, we have experimentally demonstrated an increase of the skyrmion diffusion coefficient by over two orders of magnitude [2]. Therein, we leverage the systems' intrinsic stochasticity directly as we employ fully deterministic excitations only. Constant-temperature tunability of stochastic motion is key to dynamically adjusting the speed-efficiency-balance of skyrmion-based Brownian computers [3] and thereby greatly enhances their application scenarios [4].

[1] R. Gruber et al., Nat Commun 13, 3144 (2022). [2] R. Gruber, M. A. Brems et al., Adv. Mater. 35, 2208922 (2023). [3] K. Raab, M. A. Brems et al., Nat. Commun. 13, 6982 (2022). [4] M. A. Brems et al., Appl. Phys. Lett. 119, 132405 (2021).

MA 37.12 Thu 12:30 EB 301

Simulation of a realistic skyrmion-based multiturn counter-sensor device at finite temperatures — •Kilian Leutner[1], Thomas Brian Winkler[1], Robert Frömter[1], Raphael Gruber[1], Johannes Güttinger[2], Hans Fangohr[3], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [2]Infineon Technologies AG, Villach, Austria — [3]Max-Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, 22761 Hamburg, Germany

Magnetic skyrmions, as topologically stabilized quasi particles, hold great promise for energy-efficient applications encompassing storage, logic, and sensing devices. In this work, we introduce an innovative, realistic, and feasible concept for a multi-turn counter-sensor device utilizing skyrmions, a step towards applied skyrmionics. In the sensor the encoded number of sensed rotations corresponds to the number of nucleated skyrmions [1]. The sensor only consumes energy at the readout. Our simulation study reveals a robust design and protocol for reading out a skyrmion storage, facilitating accurate quantification of skyrmion numbers, even in the presence of thermal fluctuations and thermal diffusion. Emphasizing the fundamental principles underlying reliable and realistic readout mechanisms, our findings extend applicability to a broader class of skyrmion-based devices. Additionally, we provide insights into the detection of skyrmions through their strayfield via magnetic tunnel junctions (MTJ).

[1] K. Leutner, et al., Phys. Rev. Appl., accepted (2023), arXiv:2211.05711 (2022)

MA 37.13 Thu 12:45 EB 301

Antiferromagnetic (anti)merons and bimerons in synthetic antiferromagnets — •Mona Bhukta[1], Takaaki Dohi[1,2], Venkata Krishna Bharadwaj[1], Ricardo Zarzuela[1], Maria-Andromachi Syskaki[1], Jairo Sinova[1], Robert Frömter[1], and Mona Bhukta[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba, Sendai 980-8577, Japan

In recent years, topological defects stabilized by the Dzyaloshinskii-Moriya interaction, such as skyrmions, bimerons, etc, have caught increasing interest due to their small size, topologically enhanced stability and low threshold-current density required for their motion under the application of spin-orbit torques [1]. In this work, we investigate the conditions to stabilize antiferromagnetic meronic spin textures at room temperature to observe them experimentally in synthetic antiferromagnets [2]. By combining different magnetic imaging techniques such as magnetic force microscopy (MFM), scanning electron microscopy with polarization analysis (SEMPA), and X-ray magnetic circular dichroism photoemission electron microscopy (XMCD-PEEM) we image the three-dimensional Néel order parameter, revealing the of merons and antimerons in the Pt/CoFeB/Ir based SyAFM stacks [3].

[1] K. Litzius et al., Nat. Phys. 13, 170 (2017) [2] T. Dohi et al, Nat. Commun. 10, 5153 (2019) [3] M. Bhukta et al, arXiv:2303.14853 (2023)