MA 43: Skyrmions III / Non-Skyrmionic Magnetic Textures II

Time: Friday 9:30–13:15 Location: H16

MA 43.1 Fri 9:30 H16

All-Optical Control of Bubble and Skyrmion Breathing — •Tim Titze[1], Sabri Koraltan[2], Timo Schmidt[3], Dieter Suess[2], Manfred Albrecht[3], Stefan Mathias[1], and Daniel Steil[1] — [1]I. Physikalisches Insitut, University of Göttingen — [2]Physics of Functional Materials, Faculty of Physics, University of Vienna — [3]Institute of Physics, University of Augsburg

Topologically protected magnetic skyrmions promise tremendous potential for innovative applications, such as unconventional computing schemes. Deterministic control of the dynamics of such spin objects is one key ingredient for future data processing devices. Using ultrafast Kerr spectroscopy, we investigate the spin dynamics of ferrimagnetic $[\mathrm{Fe}(0.35\,\mathrm{nm})/\mathrm{Gd}(0.40\,\mathrm{nm})]_{160}$ multilayers hosting a dense bubble/skyrmion (BSK) lattice at ambient temperature [1, 2]. Ultrafast laser excitation of the BSK lattice leads to coherent spin dynamics in the form of BSK breathing [3]. By tuning the time delay between excitations in a dual pulse excitation scheme we demonstrate optical control of the breathing dynamics of the BSK lattice in amplitude and phase [4]. This fast and reversible technique presents a promising pathway towards future BSK-based spintronic and magnonic devices.

[1] S. A. Montoya *et al.*, Phys. Rev. B **95**, 2024415 (2017)
[2] M. Heigl *et al.*, Nat. Commun. **12**, 261 (2021)
[3] T. Titze *et al.*, Adv. Funct. Mater. **34**, 2313619 (2024)
[4] T. Titze *et al.*, Phys. Rev. Lett. **133**, 156701 (2024)

MA 43.2 Fri 9:45 H16

Spiral multiferroics as a natural skyrmion racetrack — •Luca Maranzana[1,2], Maxim Mostovoy[3], Naoto Nagaosa[4], and Sergey Artyukhin[1] — [1]Quantum Materials Theory, Italian Institute of Technology, Via Morego 30, Genoa, Italy — [2]Department of Physics, University of Genoa, Via Dodecaneso 33, Genoa, Italy — [3]Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 3, 9747 AG Groningen, Netherlands — [4]RIKEN Center for Emergent Matter Science (CEMS), Wako, Saitama 351-0198, Japan

Magnetic skyrmions are localized spin textures with a nontrivial topology. This property ensures excellent stability even at nanometer length scales, establishing skyrmions as promising information carriers in magnetic storage and processing devices. Still, their fate in a wide variety of magnetic backgrounds is poorly understood. Here, we show that spiral multiferroics, some of the most basic non-collinear magnets, host bimerons, a particular type of skyrmion. Multiferroic properties of a spin spiral endow the bimeron with magnetic and ferroelectric dipole moments that, surprisingly, depend on its position relative to the spiral. This enables precise positioning of the bimeron by a rotating magnetic field (e.g. of a circularly polarized electromagnetic wave). At low frequencies, the bimeron magnetic moment rotates in sync with the field, and this topological spin texture is pumped in the Archimedean screw fashion. The results establish spiral multiferroics as a natural racetrack, where one full rotation of the field moves the bimeron by one spiral period.

MA 43.3 Fri 10:00 H16

Pathways to Bubble and Skyrmion Lattice Formation in Fe/Gd Multilayers — Tim Titze[1], Sabri Koraltan[2], Timo Schmidt[3], Dieter Suess[2], Manfred Albrecht[3], Stefan Mathias[1], and •Daniel Steil[1] — [1]University of Goettingen — [2]University of Vienna — [3]University of Augsburg

Fe/Gd multilayers host a rich variety of magnetic textures, including topologically trivial bubbles and topologically protected skyrmions [1-4]. Using time-resolved Kerr spectroscopy, we highlight how different control strategies including temperature T, out-of-plane magnetic fields H and femtosecond light excitation can be used to create such textures via different pathways. We find that varying the magnetic field at constant temperature leads to a different (H,T) phase diagram of magnetic textures than moving along a temperature trajectory at constant magnetic field, which is corroborated by micromagnetic simulations. We furthermore show that bubble and skyrmion (BSK) creation by impulsive light excitation is at least partially a non-adiabatic process, as the creation occurs in parts of the (H,T) phase diagram, where neither the constant T nor the constant H trajectory predict their existence. We discuss a possible scenario for the creation of BSKs in this material system involving the inhomogeneity of the excitation process.

[1] S. A. Montoya *et al.*, Phys. Rev. B **95**, 2024415 (2017)
[2] M. Heigl *et al.*, Nat. Commun. **12**, 261 (2021)
[3] T. Titze *et al.*, Adv. Funct. Mater. **34**, 2313619 (2024)
[4] T. Titze *et al.*, Phys. Rev. Lett. **133**, 156701 (2024)

MA 43.4 Fri 10:15 H16

Nitrogen-vacancy scanning imaging of a room-temperature skyrmion lattice in a van der Waals ferromagnet Fe3-xGaTe2 — •Young-Gwan Choi[1], Hayden Binger[1], Luke Turnbull[1], Yejin Lee[1], Lotte Boer[1], Chenhui Zhang[2], Haneul Kim[3], Claire Donnelly[1], Hyunsoo Yang[2], and Uri Vool[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Department of Electrical and Computer Engineering, National University of Singapore, 117583 Singapore, Singapore — [3]Department of Physics, University of Ulsan, 44610 Ulsan, Korea

We report the visualization of the magnetic stray field from a room-temperature skyrmion lattice in the van der Waals ferromagnet Fe3-xGaTe2(FGaT) by nitrogen-vacancy (NV) scanning. By employing a field-cooled process, we observed the transition from labyrinth domain structures to a stable skyrmion lattice state, demonstrating the formation of a stable skyrmion lattice phase. The experiments were conducted on FGaT flakes with an approximate thickness of 100 nm, revealing detailed insights into the stable formation of the skyrmion phase even at room temperature. These results highlight the capability of NV scanning for direct and quantitative imaging of room-temperature skyrmions, offering valuable insights into their properties and advancing the understanding of skyrmion lattices. This study provides a basis for further exploration of skyrmion-based spintronic applications.

MA 43.5 Fri 10:30 H16

Controlling topolopogical spin textures in Heusler magnetic nanowires — •Rikako Yamamoto[1,2], Luke Turnbull[1,2], Marisel Di Petro Martinez[1,2], Jeffrey Neethirajan[1], José Claudio Corsaletti Filho[1], Simone Finizio[3], Tim Butcher[3,4], Igor Beinik[5], Claas Abert[6], Dieter Suess[6], Praveen Vir[1], Chandra Shekar[1], Claudia Felser[1], and Claire Donnelly[1,2] — [1]MPI-CPfS, Dresden, Germany — [2]WPI-SKCM2, Higashi-Hiroshima, Japan — [3]PSI, Villigen, Switzerland — [4]MBI, Berlin, Germany — [5]MAX-IV, Lund, Sweden — [6]University of Vienna, Vienna, Austria

Nontrivial topological spin textures, such as magnetic skyrmions and antiskyrmions, have been attracting considerable interest due to their fundamental properties and potential applications. Antiskyrmions, commonly found in materials with anisotropic Dzyaloshinskii-Moriya interactions, are of particular interest due to their complex winding, and prospect for unidirectional motion. However, such textures are energetically degenerate, and their formation remains open to exploration. Here we gain control over the formation and stability of anti-skyrmions by nanopatterning anti-skyrmion-hosting Heusler magnets. By patterning nanowires oriented at different angles to the crystallographic unit cell, we combine intrinsic and geometrical anisotropies. Using x-ray dichroic ptychography to image the magnetic configuration of these nanowires, we observe that the competition between geometrical and intrinsic anisotropy can lead to preferential formation of topological objects in the nanostructure. This approach provides new opportunities for enhanced control of topological spin textures.

MA 43.6 Fri 10:45 H16

Confinement-Induced Magnetoresistances in Skyrmion-based Magnetic Tunnel Junctions — •Moritz Winterott[1,2] and Samir Lounis[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Innovations are essential to address the rapidly growing demand for data. One of the most promising solution are magnetic tunnel junctions [1] (MTJs) which utilize spin-dependent tunnelling between two ferromagnetic layers separated by an insulating barrier and present a high-speed, non-volatile, and energy-efficient memory solution. Combining MTJs with skyrmions offers great potential [2] due to the nanoscale size and topological protection of the later ones. However creation and efficient electrical detection of skyrmions in MTJs remains

challenging. We demonstrate that a strong splitting of spin-channels leads to confined states inside the skyrmion, complementary to Friedel oscillations reaching far outside the skyrmion. These non-trivial signatures in the electronic structure induce new magnetoresistances augmenting the efficiency of those enabled by spin-orbit coupling and magnetic non-collinearity [3], which could facilitate electrical detection of skyrmions in MTJs. We employ a tight-binding scheme to explore the impact of the skyrmion size, Fermi energy and splitting of the spin-channels.
– [1] Parkin et al., Nat. Mater. 3, 862 (2004); [2] Chen et al., Nature 627, 522-527 (2024); [4] Fernandes et al., Nat. Com. 13, 1576 (2022).

MA 43.7 Fri 11:00 H16

Field-induced Reversal of Magnetic Anisotropy in Skyrmion Hosts — •Hans-Albrecht Krug von Nidda, Bertalan Szigeti, Mamoun Hemmida, Dieter Ehlers, and István Kézsmárki — Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, D-86135 Augsburg, Germany

Skyrmions show up in non-centrosymmetric magnets due to the complex interplay of anisotropic Dzyaloshinskii-Moriya interaction, uniaxial magnetic anisotropy, and magnetic dipolar interactions. A magnet is commonly classified as either easy-axis or easy-plane, when the magnetic anisotropy forces the magnetization to align parallel or perpendicular to the high-symmetry axis, respectively. We show that this simple classification fails for systems with competing anisotropy terms. Our multi-frequency electron spin resonance spectroscopy study on the skyrmion hosts GaMo4S8 and GaV4Se8 reveals counteracting exchange and g-factor anisotropies. Consequently, the total aniotropy changes sign in moderate magnetic fields: GaMo4S8 turns from an easy- to a hard-axis magnet, while GaV4Se8 does the opposite. These findings underscore the significance of precisely quantifying all anisotropy components, because a single effective value, when encompassing conflicting terms, proves to be insufficient for an accurate description of magnetic states.

MA 43.8 Fri 11:15 H16

Short-pitch skyrmions in layered rare-earth frustrated magnets — •Vladislav Borisov[1], Rohit Pathak[1], Sagar Sarkar[1], Anna Delin[2,3,4], and Olle Eriksson[1,3] — [1]Uppsala University, Sweden — [2]KTH Royal Institute of Technology, Stockholm, Sweden — [3]Wallenberg Initiative Materials Science for Sustainability (WISE) — [4]SeRC (Swedish e-Science Research Center), KTH Stockholm, Sweden

While most skyrmionic systems rely on the presence of Dzyaloshinskii-Moriya interaction (DMI), there are a few known compounds, such as $GdRu_2Si_2$ with 122-type structure, where extremely compact skyrmions around 2 nm are stabilized without DMI, as discovered in recent experiments [1]. Several theory studies, including our recent work [2], suggest the importance of magnetic frustration and local anisotropy for the skyrmion stability. The present work explores further the variety of magnetic phases in other compounds with the 122-type crystal structure using density functional theory and atomistic spin dynamics at finite temperature and applied magnetic field. Various chemical compositions, included those from [3], are considered here and interesting trends for RKKY-like Heisenberg interactions between the rare-earth moments, calculated using magnetic force theorem, and real-space textures are analyzed.

1. N. D. Khanh et al., Nature Nanotech. 15, 444-449 (2020).
2. S. Sarkar et al., arXiv:2409.06736.
3. T. Nomoto, R. Arita, J. Appl. Phys. 133, 150901 (2023).

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15 min. break

MA 43.9 Fri 11:45 H16

Tunable magnetic skyrmion bubbles in centrosymmetric magnets — Dola Chakrabartty[1], István Kézsmárki[1], and •Ajaya Kumar Nayak[2] — [1]Experimentalphysik V, Center for Electronic Correlations and Magnetism, Institute for Physics, Augsburg University, D-86135 Augsburg, Germany — [2]School of Physical Sciences, National Institute of Science Education and Research, HBNI, Jatni, 752050, Bhubaneswar, India

Magnetic skyrmions are topologically protected spin textures that can avoid defects and be mobilized by low current densities, making them potential candidates for high-density and low-power consuming logic and memory devices. Skyrmion-like spin textures with different helicities and vorticities have recently been found also in centrosymmetric magnets, stabilized by competing dipolar interaction and out-of-plane magnetic anisotropy. The primary motivation of this study is to explore the extensive tunability of magnetic skyrmion bubbles in centrosymmetric magnets with internal and external parameters. We have demonstrated that in the centrosymmetric system by applying external magnetic field and tuning magnetic anisotropy one can transform skyrmions (topological number -1) to type-II bubble (topological number 0) through Bloch line formation. We found that the skyrmions are stable when there is only out-of-plane uniaxial anisotropy, whereas the introduction of small in-plane anisotropy turns them to type-II bubbles. Presently, we are in the process of exploring the tunability of skyrmions in such systems with other external stimuli, such as uniaxial strain and laser irradiation.

MA 43.10 Fri 12:00 H16

Gate-Voltage-Induced Changes of the Magnetic Properties of Skyrmion-Hosting Gd/Fe Multilayers — •Sebastian Hofmann[1], Steffen Wittrock[2], Tamer Karaman[1], Sascha Petz[2], Daniel Metternich[2], Krishnanjana Puzhekadavil Joy[2], Kai Litzius[1], and Felix Büttner[1,2] — [1]Universität Augsburg Institut für Physik, Universitätsstraße 1, 86159 Augsburg — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin

Ionic gating has recently emerged as a versatile method to induce large and controllable changes of the local magnetic properties of thin films. This allows, for example, to manipulate the existence [1] and chirality [2] of magnetic skyrmions. However, existing gating experiments have focused on ultrathin films, where skyrmions are usually micron sized. Here, we show that ionic gating with oxygen and hydrogen can be used to control ferrimagnetic Gd/Fe multilayer materials with thicknesses of more than 40 nm, in which sub-100 nm skyrmion can be observed. We find that ionic gating can shift the compensation temperature by more than 100 K, i.e., by a similar magnitude as in sub-10 nm thick films [3]. However, unlike ultrathin films, our thicker materials exhibit vertical variation of magnetic properties, suggesting a pathway toward gate-control of spin textures in 3D. [1] Yang, S. et al. Adv. Mat. 2208881 (2022). [2] Fillion, C.-E. et al. Nat. Comm. 13, 5257 (2022). [3] Huang, M. et al. Nat. Nanotechnol. 16, 981 (2021).

MA 43.11 Fri 12:15 H16

Shape anisotropy in helimagnets — •Jan Masell[1], Maurice Colling[2], Mariia Stepanova[2], Mario Hentschel[3], and Dennis Meier[2] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]NTNU Norwegian University of Science and Technology, Trondheim, Norway — [3]University of Stuttgart, Stuttgart, Germany

In chiral magnets, the competition between ferromagnetic exchange and Dzyaloshinskii-Moriya interaction (DMI) stabilizes a long-ranged helical state as the ground state. The orientation and pitch of the helix is described by the q-vector. For isotropic model systems, the q-vector can point in any direction while in real materials its orientation is pinned by anisotropies, such as exchange or single ion anisotropy.

In this talk, I will discuss the impact of the shape of the magnet on the orientation of the helical phase. While shape anisotropy is a well-established phenomenon in ferromagnets, its role in chiral magnets remains less explored. I will present our theoretical results for a new type of DMI-shape-anisotropy for non-trivial magnetic textures, caused by the competition between standard shape anisotropy and the chiral surface twist inherent to systems with DMI. Our experimental data on FeGe confirm the existence of such non-trivial anisotropy, challenging present models for magnetic textures in nanostructures with DMI.

MA 43.12 Fri 12:30 H16

Extraordinary return point memory of Pt/Co/Dy ferrimagnetic multilayers — •Tamer Karaman[1], Kai Litzius[1], Sebastain Wintz[2], Aladin Ullrich[1], Daniel Metternich[1,2], Steffen Wittrock[2], Krishnanjana Joy[1,2], Sebastian Hoffman[1], Timo Schmidt[1], Manfred Albrecht[1], and Felix Büttner[1,2] — [1]Institute of Physics, University of Augsburg, 86159 Augsburg, Germany — [2]Helmholtz-Zentrum Berlin, 14109 Berlin, Germany

Chiral magnetic spin textures are promising candidates for various spintronics applications [1]. These applications rely fundamentally on the controlled motion of spin textures under external stimuli. In this study, we report on the contrary and unique behaviour of Pt/Co/Dy rare-earth transition metal (RE-TM) ferrimagnetic multilayers, particularly their demonstration of full return-point memory. By studying the domain and domain wall response with field cycling using real-space imaging techniques, we observe deterministic behaviour where domains completely return to their original positions, even after exposure to high applied fields. Such observation is rarely documented in the literature and invites a variety of interpretations [2, 3]. This study emphasizes the significance of unexplored aspects of RE-TM ferrimagnets, advancing deeper exploration and broader utilization of these materials.

1. Fert, A. et al. Nat. Rev. Mater. 2, 17031 (2017). 2. Kappenberger, P. et al. Phys. Rev. Lett. 91, 267202 (2003). 3. Seu, K. A. et al. New J. Phys. 12, 035009 (2010).

MA 43.13 Fri 12:45 H16

Fascinating mesoscale magnetic textures in the topological Kagome system $TbMn_6Sn_6$ — •Ralph Rajamathi[1], Manuel Zahn[1,2], Kai Litzius[1], István Kézsmárki[1], and Sándor Bordács[3] — [1]Center for Electronic Correlations and Magnetism, University of Augsburg — [2]Department of Materials Science and Engineering, Norwegian University of Science and Technology — [3]Department of Physics, Budapest University of Technology and Economics

In recent years, the Kagome ferrimagnet $TbMn_6Sn_6$ has garnered significant interest due to its unconventional band topology, which realizes exotic quantum states like a Chern insulating phase. It exhibits a spin-reorientation transition (SRT) from easy-axis to easy-plane at 310 K, where skyrmion bubbles have been observed in lamellae. However, magnetic textures in bulk crystals have been unexplored so far. Here, we used magnetic force microscopy (MFM) to image the magnetic pattern on the surface of bulk crystals, and magnetometry to study the role of second order magnetic anisotropy. Two types of textures were observed, namely long-ranged stripes that invert contrast on reversing the tip's magnetization, decorated by star-shaped structures whose contrast is independent from the the tip's magnetization. Reorientation of the stripes and creation/elimination of the "stars" in an external magnetic field indicate low magnetic pinning. Analyzing the in-plane magnetometry data, a metastable magnetization state was observed below the SRT temperature, indicating the possibility of an intermediate in-plane state, which was observed by MFM in the vicinity of SRT.

MA 43.14 Fri 13:00 H16

Domain walls with 90° magnetization rotation in the topological kagome magnet $TbMn_6Sn_6$ — •Manuel Zahn[1,2], Ralph Rajamathi[1], Kai Litzius[1], Dennis Meier[2], Sándor Bordács[3], and István Kézsmárki[1] — [1]Center for Electronic Correlations and Magnetism, University of Augsburg — [2]Department of Materials Science and Engineering, Norwegian University of Science and Technology (NTNU) — [3]Department of Physics, Budapest University of Technology and Economics

The layered Kagome ferrimagnet, $TbMn_6Sn_6$, attracts much attention due to its topologically non-trivial features. The bulk electronic band structure realizes a Chern insulating state and in the real space, skyrmion bubbles have been observed in thin lamellae of this compound. $TbMn_6Sn_6$ exhibits a zero-field first-order spin reorientation transition at $T_{SR} = 315$ K, below/above which the magnetic moment points perpendicular/parallel to the Kagome plane. Here, using magnetic force microscopy, we reveal peculiar domain textures in the vicinity of T_{SR} on the surface of bulk $TbMn_6Sn_6$ crystals. Upon approaching T_{SR} from lower temperatures, we observed a broadening of the domain walls separating regions oppositely magnetized perpendicular to the Kagome plane, and the emergence of a strictly in-plane magnetized region at the center of the walls. We compared these results with analytical calculations based on a continuum magnetic model and found that the $\pi/2$ stepwise rotation of the magnetization is a universal effect at the spin reorientation transition.