MA 6: Skyrmions I

Time: Monday 15:00–18:30 Location: H16

Invited Talk MA 6.1 Mon 15:00 H16

Magnetization dynamics of chiral helimagnetic insulators — •Aisha Aqeel — University of Augsburg, Augsburg, Germany — Technical University of Munich, Munich, Germany — Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Nature reveals fascinating patterns, often arising from intricate interactions among individual components. In magnets, remarkable patterns can emerge even in the absence of inversion symmetry. Chiral helimagnets, characterized by their twisted magnetic structures, whether topologically trivial or non-trivial, exhibit collective magnetic excitations ranging from GHz to THz. These exceptional properties make helimagnets highly attractive for spintronic technologies and unconventional computing [1]. However, realizing their full potential demands ultraclean magnetic systems with minimal dissipation and a deep understanding of their magnetization dynamics. In this talk, I will delve into the fundamental properties of chiral helimagnets and their dynamic magnetization behavior, focusing on the insulating material Cu2OSeO3. Our studies reveal evidence for a rare magnetic state in Cu2OSeO3 crystals - elongated skyrmions - observed through magnetic resonance experiments [2]. Additionally, utilizing a surface-sensitive electrical probe - spin Hall magnetoresistance - we discovered that the magnetic configurations at the surfaces of chiral magnets deviate significantly from those in the bulk [3].

[1] O. Lee, et al., Nat. Mater. 23(1), 79-87 (2024). [2] A. Aqeel, et al., Phys. Rev. Lett. 126(1), 017202 (2021). [3] A. Aqeel, et al., Phys. Rev. B 103(10), L100410 (2021).

MA 6.2 Mon 15:30 H16

Skyrmion dynamics in Ta/CoFeB/MgO at room temperature — •Hauke Lars Heyen[1], Malte Römer-Stumm[2], Michael Vogel[2], Florian Gossing[2], Jakob Walowski[1], Ethan Andrew Mullen[3], Christian Denker[1], Karin Dahmen[3], 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 — [3]Department of Physics, The Grainger College of Engineering, University of Illinois Urbana-Champaign, USA

Applications in future storage devices, like the conceptual skyrmion race-track memory, require fundamental control over the skyrmion dynamics. We use Ta/CoFeB/MgO layer stacks to generate skyrmions at room temperature. The skyrmions are moved by applying nanosecond electric current pulses with current densities of around $5 \cdot 10^{10} A/m^2$ and are imaged with the magneto optical Kerr effect (MOKE). With a tracking algorithm the trajectories are determined and they hint at two diffusion types and the skyrmion-Hall effect. The latter occurs simultaneously with the topological Hall-effect that can be measured electrically. Combining the electrical measurements with MOKE allows us to separate the anomalous and the weak topological Hall effect. This allows for a differentiation between topological and non-topological stabilized magnetic structures.

MA 6.3 Mon 15:45 H16

Skyrmion Screws: A Novel 3D Topological Spin Texture — •Thorsten Hesjedal[1,2], Gerrit van der Laan[2], Haonan Jin[3,4], Jingyi Chen[3,4], and Shilei Zhang[3,4] — [1]Department of Physics, Clarendon Laboratory, University of Oxford, Oxford OX1 3PU, UK — [2]Diamond Light Source, Harwell Science and Innovation Campus, Didcot OX11 0DE, UK — [3]School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China — [4]ShanghaiTech Laboratory for Topological Physics, ShanghaiTech University, Shanghai 201210, China

Three-dimensional (3D) magnetic skyrmions have attracted increasing interest as topological spin textures capable of hosting emergent electromagnetic properties and unique spin dynamics. In this study, we present the first direct experimental observation of skyrmion screws — a 3D spin crystal featuring modulations along the z-axis. Using state-of-the-art soft x-ray ptycho-tomography, we fully visualize the skyrmion screw lattice in a $Co_8Zn_{10}Mn_2$ thin lamella, fabricated to induce boundary confinement effects. Ferromagnetic resonance spectroscopy and micromagnetic simulations reveal a distinct low-frequency resonance mode, establishing skyrmion screws as a fundamentally new phase. These findings open avenues for studying 3D topological magnetism and its applications in magnonics and spintronics.

MA 6.4 Mon 16:00 H16

Skyrmion bags embedded in the skyrmion lattice — •Nikolai S. Kiselev — Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany

The micromagnetic model of 2D chiral magnets predicts the existence of skyrmion bags – solitons with arbitrary topological charge [1]. Recent experiments have confirmed the stability of skyrmion bags with positive topological charges [2,3]. Using Lorentz TEM on thin plates of B20-type FeGe, we demonstrate the remarkable stability of skyrmion bags with negative charges embedded within a skyrmion lattice [4]. We outline a robust protocol for nucleating these embedded skyrmion bags, which remain stable even in zero or inverted external magnetic fields. Our findings are in excellent agreement with micromagnetic simulations.

[1] F.N. Rybakov, N.S. Kiselev Phys. Rev. B, 99, 064437 (2019). [2] J. Tang et al., Nature Nanotechnol. 16, 1086 (2021). [3] Y. Zhang et al., Nature Commun. 15, 3391 (2024). [4] L. Yang et al., Adv. Mater. 36, 2403274 (2024).

MA 6.5 Mon 16:15 H16

Skyrmion at finite temperature — •Thorben Pürling[1,2] and Stefan Blügel[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Physics Department, RWTH Aachen University, 52062 Aachen, Germany

In the past decade magnetic skyrmions have been under intense scientific scrutiny. Key properties of magnetic skyrmions such as the radius have been shown to exhibit highly nonlinear behavior as a function of the microscopic interaction parameters representing Heisenberg exchange, Dyzaloshinskii-Moriya interaction (DMI) and magnetic anisotropy [1]. Due to thermal fluctuations in both spin and lattice degrees of freedom, these interaction strengths carry an effective temperature dependence. Hence, temperature should demonstrate a strong effect on quantities like the skyrmion radius. Surprisingly little work has been done in this direction, particularly when it comes to taking lattice vibrations into account. Here we present our first attempts at investigating the role of the lattice dynamics on relevant interaction parameters.

We acknowledge funding from the ERC grant 856538 (project "3D MAGIC") and DFG through SFB-1238 (project C1).

[1] H. Jia *et al.*, Phys. Rev. Materials **4**, 094407 (2020).

MA 6.6 Mon 16:30 H16

Skyrmion lattices emerging from magnetic dipolar interactions — Elizabeth M Jefremovas[1], •Kilian Leutner[1], Miriam G. Fischer[1], Jorge Marqués-Marchán[2], Thomas B. Winkler[1], Agustina Asenjo[2], Jairo Sinova[1,3], Robert Frömter[1], and Mathias Kläui[1,4] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Institute of Material Science of Madrid – CSIC, 28049 Madrid, Spain — [3]Department of Physics, Texas A&M University, College Station, Texas, USA — [4]Center for Quantum Spintronics, Norwegian University of Science and Technology, 7491 Trondheim, Norway

Magnetic skyrmions are well-studied two-dimensional topological spin textures. Surprisingly, little is known about the mutual interactions of dipolar-stabilized skyrmions. By engineering a magnetic multilayer stack, we stabilize for 1 to 30 repetitions skyrmion lattices at room temperature and zero field. Using Kerr microscopy and Magnetic Force Microscopy we observe a drastic decrease in skyrmion size as the number of repetitions is increased. We present an analytical model to describe the skyrmion radius and periodicity from the single-layer to the thick-film limit and complement this with micromagnetic simulations. Additionally, we identify the critical role of the nucleation process in forming the skyrmion lattice. Our work provides a comprehensive understanding of skyrmion-skyrmion interactions, which are driven by dipolar interactions as the multi-layer stack thickness increases.

[1] E. M. Jefremovas et al., arXiv:2407.00539 (2024)

15 min. break

MA 6.7 Mon 17:00 H16

Skyrmion size manipulation by external force — Klaus Raab, Kilian Leutner, •Leonie-Charlotte Dany, Simon Fröhlich, Grischa Beneke, Duc Minh Tranh, Sachin Krishnia, Robert Frömter, Peter Virnau, and Mathias Kläui — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Magnetic skyrmions, spin textures with quasi-particle like properties, exhibit highly promising potential as information carriers in applications like storage or non-conventional computing.[1,2]

We experimentally investigate how the size of skyrmions is influenced by a combination of spin-orbit torques and repulsion from a structural barrier in a Ta/CoFeB/MgO based magnetic thin film. By employing Ga^+ ion implantation to modify the effective anisotropy of the magnetic layer, we create artificial barriers that serve as additional tools for manipulating skyrmions. Furthermore, the resulting changes in the formation of skyrmions lattice is characterized.

Based on the experimental finding, we then develop a new theoretical model within the framework of Thiele equation approach to describe the change in the skyrmions' size and their trajectories. Thiele equation accounts for the skyrmion size and skyrmion-skyrmion distance of an ensemble of skyrmions to an external stimulus, such as spin-orbit torques.

1. Raab, K. *et al., Nat. Commun.* **13**, 6982 (2022).
2. Beneke, G. *et al., Nat. Commun.* **15**, 8103 (2024).

MA 6.8 Mon 17:15 H16

Eigenmode following for direct entropy calculation — •Stephan von Malottki[4], Moritz A. Goerzen[1], Hendrik Schrautzer[1,2], Pavel F. Bessarab[2,3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstrasse 15, 24098 Kiel, Germany — [2]cience Institute, University of Iceland, 107 Reykjavík, Iceland — [3]Department of Physics and Electrical Engineering, Linnaeus University, SE-39231 Kalmar, Sweden — [4]MODL, Insititute of Condensed Matter and Nanosciences, UC Louvain, Belgium

We present an eigenmode following method (EMF) to numerically calculate entropy contributions beyond harmonic approximation. In the framework of transition state theory, this increases the accuracy and applicability of transition rate calculations. In EMF, the potential energy landscape is explored along the investigated eigenvectors by iteratively updating a partial Hessian matrix along the way. Numerical integration of the Boltzmann factor over the obtained energy curve yields the contribution of the eigenmode to the partition function and entropy of the analysed state. The EMF method can be combined with other methods such as the harmonic approximation, making it a feasible method to improve the description of individual eigenmodes. The application of the method will be shown on the example of the Chimera skyrmion collapse mechanism and antiskyrmion rotation modes.

MA 6.9 Mon 17:30 H16

Topological magnetism in diluted artificial adatom lattices — •Amal Aldarawsheh[1,2] and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulations, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]aculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

The ability to control matter at the atomic scale has revolutionized our understanding of the physical world, opening doors to unprecedented technological advancements. Quantum technology, which harnesses the unique principles of quantum mechanics, enables us to construct and manipulate atomic structures with extraordinary precision. Here[1], we propose a bottom-up approach to create topological magnetic textures in diluted adatom lattices on the Nb(110) surface. By fine-tuning adatom spacing, previously inaccessible magnetic phases can emerge. Our findings reveal that interactions between magnetic adatoms, mediated by the Nb substrate, foster the formation of unique topological spin textures, such as skyrmions and anti-skyrmions, both ferromagnetic and antiferromagnetic. Since Nb can be superconducting, our findings present a novel platform with valuable insights into the interplay between topological magnetism and superconductivity, paving the way for broader exploration of topological superconductivity in conjunction with spintronics applications.

[1] A. Aldarawsheh et al., In preparation. Work funded by the PGSB (BMBF-01DH16027)and DFG (SPP 2137; LO 1659/8-1)

MA 6.10 Mon 17:45 H16

The impact of magnetic anisotropy on the stability of antiskyrmions in schreibersite magnets — •Mamoun Hemmida[1], Jan Masell[2,3], Kosuke Karube[3], Dieter Ehlers[1], Hans-Albrecht Krug von Nidda[1], Vladimir Tsurkan[1,4], Yoshinori Tokura[3,5,6], Yasujiro Taguchi[3], and Istvan Kezsmarki[1] — [1]Experimental Physics V, Center for Electronic Correlations and Magnetism, Institute for Physics, University of Augsburg, Germany — [2]Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, Germany — [3]RIKEN Center for Emergent Matter Science, Japan — [4]Institute of Applied Physics, Academy of Sciences of Moldova, Republic of Moldova — [5]Department of Applied Physics and Quantum-Phase Electronics Center, University of Tokyo, Japan — [6]Tokyo College, University of Tokyo, Japan

Magnetic anisotropy is a fundamental property of magnetic materials that plays an essential role in the stability of magnetic domains and skyrmions. In this ferromagnetic resonance (FMR) study we report the evolution of magnetic anisotropy by substituting various 4*d* metals in the easy-plane schreibersite magnet $(Fe,Ni)_3P$ with S_4 tetragonal symmetry,Hemmida2024. Starting from easy-plane anisotropy, Pd doping turns $(Fe,Ni)_3P$ to an easy-axis-type magnet. As a consequence, antiskyrmions are created. FMR study of the planar anisotropy proofs a fourfold symmetry as expected for the tetragonal crystal structure. The corresponding planar anisotropy parameter is an order of magnitude smaller than the uniaxial one. Hemmida2024 M. Hemmida, *et al.*, Phys. Rev. B 110, 054416 (2024).

MA 6.11 Mon 18:00 H16

The impact of the non-chiral magnetic fan state on the transformation of chiral textures in $Mn_{1.4}PtSn$ — M. Winter[1,2], A. Pignedoli[3], M.C. Rahn[4], A.S. Sukuhanov[4], A. Tahn[2], S. Schneider[2], D. Pohl[2], M. Azhar[3], K. Everschor-Sitte[3], J. Geck[4], G. van der Laan[5], T. Hesjedal[5,6], P. Vir[1], C. Felser[1], and •B. Rellinghaus[2] — [1]MPI CPfS, Dresden, Germany — [2]DCN, TU Dresden, Germany — [3]Univ. Duisburg-Essen, Germany — [4]IFMP, TU Dresden, Germany — [5]Diamond Light Source, UK — [6]Univ. Oxford, UK

The Heusler compound $Mn_{1.4}PtSn$ is a chiral magnet that exhibits a rich of variety non-topological and topologically protected chiral magnetic textures at room temperature. We have used Lorentz transmission electron microscopy (LTEM) supported by resonant elastic x-ray scattering (REXS) and micromagnetic simulations to characterize the emerging magnetic structures as function of the magnitude and orientation of an external magnetic field. We find that in out-of-plane fields, chiral soliton lattices emerge, while in-plane fields promote the formation of non-chiral magnetic fan domains. At fields in the stability range of the latter, the nucleation of non-topological bubbles (ntB's) occurs. Intriguingly, ntB's show combined characteristics of chiral solitons and the fan-type structure and may consequently be interpreted as hybrid structures of the latter. Following a distinct field protocol, ordered lattices of these ntB's then successively transform into anti-skyrmion lattices. Financial support by DFG through SPP 2137, project no. 403503416, is gratefully acknowledged.

MA 6.12 Mon 18:15 H16

Emergence of polar skyrmions in 2D Janus CrInX3 (X=Se, Te) magnets — •Duo Wang[1], Fengyi Zhou[1], Monirul Shaikh[2], and Biplab Sanyal[3] — [1]Macao Polytechnic University — [2]University of Nebraska, Kearney — [3]Uppsala University

In the realm of multiferroicity in 2D magnets, whether magnetic and polar skyrmions can coexist within a single topological entity has emerged as an important question. Here, we study Janus 2D magnets CrInX3 (X=Se, Te) for a comprehensive investigation of the magnetic ground state, magnetic excited state, and corresponding ferroelectric polarization by first-principles electronic structure calculations and Monte Carlo simulations. Specifically, we have thoroughly elucidated the magnetic exchange mechanisms, and have fully exemplified the magnetic field dependence of the magnon spectrum. More importantly, our study reveals a previously unrecognized, remarkably large spin-spiral-induced ferroelectric polarization (up to 194.9 μC/m2) in both compounds. We propose an approach to identify polar skyrmions within magnetic skyrmions, based on the observed direct correlation between spin texture and polarization density. Elucidating this correlation not only deepens our understanding of magnetic skyrmions but also paves the way for innovative research in the realm of multiferroic skyrmions.