MA 17: Skyrmions II (joint session MA/KFM)

Time: Friday 10:00–13:15 Location: H5

Invited Talk MA 17.1 Fri 10:00 H5

Emergent electromagnetic response of nanometer-sized spin textures — •Max Hirschberger[1,2], Takashi Kurumaji[2], and Leonie Spitz[2] — [1]Quantum-Phase Electronics Center, The University of Tokyo, Bunkyo-ku 113-8656, Tokyo, Japan — [2]RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Saitama, Japan

Recently, we have worked to reduce the size of topological spin textures in bulk magnets towards the scale of several nanometers, exploiting new material platforms which are centrosymmetric and thus fundamentally different from previously explored non-centrosymmetric (chiral or polar) systems. Nanometer-sized skyrmions reported here are not stabilized by the Dzyaloshinskii-Moriya interaction, but rather by frustrated exchange or Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions. A wide array of experimental techniques in condensed matter was incorporated to establish the presence of skyrmion lattices in the new materials Gd_2PdSi_3 and $Gd_3Ru_4Al_{12}$, with Heisenberg Gd^{3+} magnetic moments.

When a conduction electron moves through such a topological spin texture, it acquires a quantum mechanical phase (Berry phase), sometimes modeled by a (virtual) emergent magnetic field B_{em} acting on the electron. Nanometric skyrmions give rise to B_{em} of order 500 Tesla, and we have recently found quantitative evidence for this giant B_{em} using electrical Hall measurements and thermoelectric properties such as the topological Nernst effect. Ongoing work is focused on the control of magnetic interactions and electromagnetic responses via chemical composition tuning.

MA 17.2 Fri 10:30 H5

Current-induced H-shaped-skyrmion creation and their dynamics in the helical phase — •Ross Knapman[1], Davi R Rodrigues[2], Jan Masell[3], and Karin Everschor-Sitte[2,4] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [3]RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Japan — [4]Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, 47057 Duisburg, Germany

A promising application of magnetic skyrmions is in racetrack memory devices. [1] While efforts focussing on this have often been concentrated on the use of ferromagnetic racetracks, previous work has suggested that the use of helimagnets could be more effective. [2] Here, the helices provide a means to naturally confine the skyrmions to quasi-1D channels, mitigating the skyrmion Hall effect. They additionally allow for high-speed skyrmion motion. Inspired by previous works in which it is suggested that skyrmions can be created through the interplay of spin-polarized currents and magnetic impurities, [3] we propose a method of creating skyrmions in a helical background. [4]

[1] Fert, A et. al., Nat. Nanotechnol. 8(3), 152-156 (2013).
[2] Müller, J. et.al., Phys. Rev. Lett. 119(13), 137201 (2017).
[3] Everschor-Sitte, K. et. al., New J. Phys. 19(9), 092001 (2017).
[4] Knapman, R. et. al., J. Phys. D: Appl. Phys. 54(40). 404003 (2021).

MA 17.3 Fri 10:45 H5

Magnetic skyrmions probed by SP-STM: topology imprinted on the charge current and spin transfer torque — •Krisztian Palotas[1,2], Levente Rozsa[3], and Laszlo Szunyogh[2] — [1]Wigner Research Center for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Hungary — [3]University of Konstanz, Germany

The controlled creation/annihilation of individual magnetic skyrmions have been demonstrated by using spin-polarized scanning tunneling microscopy (SP-STM) [Science 341, 636], where the spin-polarized current exerts a torque on the spin moments of the sample. However, the detailed microscopic mechanism of this process is presently unknown. Our work contributes to this understanding by a theoretical investigation of the tunneling electron charge and spin transport probing magnetic skyrmions. The spin-polarized charge current (I) and tunneling spin transport vector quantities, the longitudinal spin current and the spin transfer torque (STT), are consistently calculated within a simple electron transport theory [PRB 94, 064434]. The electron tunneling model is extended to SP-STM in high spatial resolution, and applied to magnetic skyrmions [PRB 97, 174402; PRB 98, 094409]. Besides the vector spin transport characteristics, the relationships among conventional charge current SP-STM images [PRB 96, 024410], the magnitudes of the spin transport quantities [PRB 97, 174402], and the topology of various skyrmionic objects are analyzed [J. Magn. Magn. Mater. 519, 167440]. It is also shown that at specific SP-STM tip positions the STT efficiency (STT/I) can reach very large values ~h/e.

MA 17.4 Fri 11:00 H5

Alternative to Dzyaloshinskii-Moriya interaction for monolayer Fe_3GeTe_2 and other two-dimensional ferromagnets with trigonal prismatic symmetry — •Ivan Ado[1,2], Gulnaz Rakhmanova[3], Dmitry Zezyulin[3], Ivan Iorsh[3], and Misha Titov[1] — [1]Radboud University, Institute for Molecules and Materials, 6525 AJ Nijmegen, The Netherlands — [2]Institute for Theoretical Physics, Utrecht University, 3584 CC Utrecht, The Netherlands — [3]ITMO University, Faculty of Physics, Saint-Petersburg, Russia

Our work reveals a new potential source of noncollinear magnetic textures in a certain class of two-dimensional ferromagnets. Namely, in those that are described by the trigonal prismatic symmetry (point group D_{3h}): monolayer Fe_3GeTe_2, some transition metal dichalcogenides, and others. It is known that the Dzyaloshinskii-Moriya interaction does not contribute to the free energy density in such systems. We find that there exists a single (!) fourth order "chiral" contribution beyond the Dzyaloshinskii-Moriya interaction compatible with D_{3h} (if boundary effects are neglected). We study whether it is consistent with recent experiments on Fe_3GeTe_2. We also find that this contribution might stabilize bimerons – the in-plane analog of skyrmions. Surprisingly, we were even able to estimate the radius of such bimerons analytically.

[1] I. A. Ado, Gulnaz Rakhmanova, Dmitry A. Zezyulin, Ivan Iorsh, and M. Titov, arXiv:2105.14495

MA 17.5 Fri 11:15 H5

Skyrmions as quasiparticles: Free energy and entropy — •Daniel Schick, Markus Weissenhofer, Levente Rózsa, and Ulrich Nowak — Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany

Magnetic skyrmions are quasiparticles primarily investigated due to their exceptional stability enabling data storage [1] and magnetic logic applications[2]. While at low temperatures they are robust against thermal fluctuations, they are rapidly created and annihilated at high temperatures[3]. In our paper[4], we calculated the free energy and entropy of magnetic skyrmions for a (Pt0.95Ir0.05)/Fe bilayer on Pd(111), using atomistic spin simulations at different temperatures. At low temperatures, skyrmions possess a higher entropy than the topologically trivial state, reducing the free-energy difference between skyrmions and collinear states with increasing temperature. At elevated temperatures we find the free energy of skyrmions to be lower than that of topologically trivial states, meaning that they are energetically preferred due to entropic stabilization. While this result is qualitatively in line with linear spin-wave theory, going beyond this approximation reveals deviations and even sign changes in both the energy difference and the entropy difference at increased temperatures.

[1] G. Yu et al., Nano Lett. 17, 1, 261-268, 2017
[2] S. Luo et al., Nano Lett. 18, 2, 1180-1184, 2018
[3] S. von Malottki et al., Phys. Rev. B 99, 060409(R), 2019
[4] D. Schick et al., Phys. Rev. B 103, 214417, 2021

MA 17.6 Fri 11:30 H5

Non-linear Magnetic Response of Topological Spin Textures in Helimagnetic FeGe — •Mariia Stepanova[1,2], Jan Masell[3], Erik Lysne[1,2], Peggy Schoenherr[4], Laura Köhler[5], Michael Paulsen[6], Alireza Qaiumzadeh[2], Naoya Kanazawa[7], Achim Rosch[8], Yoshinori Tokura[3,7], Arne Brataas[2], Markus Garst[5], and Dennis Meier[1,2] — [1]NTNU, Trondheim, Norway — [2]Center for Quantum Spintronics, NTNU, Trondheim, Norway — [3]RIKEN, Wako, Japan — [4]UNSW, Sydney, Australia — [5]KIT, Karlsruhe, Germany — [6]PTB, Berlin, Germany — [7]University of Tokyo, Tokyo, Japan — [8]Universität zu Köln, Köln, Germany

Chiral magnets possess a periodic layered structure which is similar to cholesteric liquid crystals, forming a wide variety of non-trivial topological defects. Using magnetic force microscopy (MFM), we resolve 1D and 2D topological defects in the near-room temperature helimagnet FeGe, including disclinations and dislocations with nonzero topological winding number, as well as three fundamental types of helimagnetic domain walls. Interestingly, in addition to their non-trivial structure, all topological defects in FeGe exhibit a pronounced non-linear magnetic response in MFM, which is not observed in regions with perfect lamellar-like order. This magnetic signature is reminiscent of the "lines of flare" that arise in cholesteric liquid crystals, suggesting local variations in magnetic susceptibility. By combining MFM and micromagnetic simulations, we investigate the origin of the magnetic signature of the topological defects and discuss possibilities to utilize the anomalous local response as read-out signal in spintronics devices.

MA 17.7 Fri 11:45 H5

Lifetimes of skyrmions and antiskyrmions in exchange frustrated films — •Moritz A. Goerzen[1], Stephan von Malottki[1,2], Sebastian Meyer[1,4], Pavel F. Bessarab[2,3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel — [2]University of Iceland, Reykjavík, Iceland — [3]ITMO University, St. Petersburg, Russia — [4]Université de Liège, Sart Tilman, Belgium

Recently, it has been shown that isolated skyrmions can be stabilized in zero magnetic field in a Rh/Co bilayer on the Ir(111) surface due to frustration of exchange interactions [1]. Here, we predict that antiskyrmions are also metastable at zero field in this film system and can co-exist with skyrmions. Based on an atomistic spin model parametrized from density functional theory [1], we calculate the lifetime of these co-existing topological states using the geodesic nudged elastic band method as well as transition state theory in harmonic approximation [2,3]. We find significant differences between the lifetimes of skyrmions and antiskyrmions due to the effect of the Dzyaloshinskii-Moriya interaction.

[1] Meyer, Perini *et al.*, Nature Comm. **10**, 3823 (2019)
[2] Bessarab *et al.*, Sci. Rep. **8**, 3433 (2018)
[3] von Malottki *et al.*, Phys. Rev. B **99**, 060409 (2019)

MA 17.8 Fri 12:00 H5

Identification of skyrmion transition mechanisms by sub-10 nm maps of the transition rate — •Stephan von Malottki[1,2], Florian Muckel[3], Christian Holl[3], Benjamin Pestka[3], Marco Pratzer[3], Pavel F. Bessarab[1,4], Stefan Heinze[2], and Markus Morgenstern[3] — [1]Science Institute, University of Iceland — [2]ITAP, University of Kiel — [3]Institute of Physics B and JARA-FIT, RWTH Aachen University — [4]ITMO University, St. Petersburg

In addition to the conventional radial symmetric collapse of magnetic skyrmions, recent studies predicted the occurrence of skyrmion annihilation processes via the chimera skyrmion state [1-3]. Here, we demonstrate the realization of both the radial symmetric and the chimera transition mechanism in the ultra-thin film system fcc-Pd/Fe/Ir(111) [4]. Scanning tunneling microscopy is used to create transition rate maps of magnetic switching events induced by single electron events. In combination with energy density maps of the transition states obtained by atomistic spin simulations parametrized from first principles, they allow for the identification of both annihilation mechanisms. It is further shown, that a transition between both mechanisms can be achieved by the application of external in- and out-of-plane magnetic fields, yielding a sound agreement between experiment and theory.

[1] Meyer et al., Nat. Commun. **10**, 3823 (2019)
[2] Heil et al., Phys. Rev. B **100**, 134424 (2019)
[3] Desplat et al., Phys. Rev. B **99**, 174409 (2019)
[4] Muckel et al., Nat. Phys. **17**, 395-402 (2021)

MA 17.9 Fri 12:15 H5

Kinetic small-angle neutron scattering of skyrmion lattice order in chiral magnets — •Denis Mettus[1], Alfonso Chacon[1], Andreas Bauer[1], Sebastian Mühlbauer[2], Alla Bezvershenko[3], Lukas Heinen[3], Achim Rosch[3], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany — [3]Institute for Theoretical Physics, Universität zu Köln, D-50937 Köln, Germany

Skyrmions are topologically non-trivial spin textures that attract great interest, offering a possible avenue towards novel spintronics applications, e.g. in skyrmion-based racetrack memory. A key feature that motivates this interest is related to the exceptionally efficient coupling of skyrmion lattice order to spin currents, notably spin-polarized charge currents and magnon currents as observed in MnSi, FeGe, and Cu_2OSeO_3. This raises the question of the microscopic mechanisms that control the pinning and the elasticity modulus of the skyrmion lattice, and how they depend on the topology, electronic structure, and disorder. In the following contribution, we report kinetic studies of skyrmion lattice order by means of Time-resolved Small Angle Neutron Scattering (TISANE). We compare the unpinning processes in different systems, such as $Mn_{1-x}Fe_xSi$ where spin-transfer torques are dominated by spin-polarized charge currents and insulating material Cu_2OSeO_3 with the spin transfer torques being due to magnon currents.

MA 17.10 Fri 12:30 H5

Decoding of complex magnetic structures from Hall-effect measurements — •Juba Bouaziz[1], Hiroshi Ishida[2], Samir Lounis[1,3], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — [2]College of Humanities and Sciences, Nihon University, Sakura-josui, Tokyo 156-8550, Japan — [3]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

It is generally accepted that the Hall response of complex spin-textures is given in terms of the linear superposition of the ordinary (OHE), the anomalous (AHE) and the topological Hall effect (THE). This addition is not questioned and is experimentally used to relate Hall responses to magnetic textures. Here, using a simple and transparent multiple scattering approach, we show that this relation is incomplete [1]. We introduce a missing contribution, the non-collinear Hall effect (NHE). The angular form of this term depends on the underlying crystal structure. The presence of the NHE may results in a substantial Hall response in non-collinear magnets without invoking the presence of non-coplanar spin textures or magnetic skyrmions and enables the decoding of exotic non-collinear magnetic textures that have been observed in itinerant magnets. [1] J. Bouaziz et al. PRL 126, 147203 (2021).

This work was supported by DFG through SPP 2137 "Skyrmionics" (Project BL444/16-1), SFB 1238 (project C01) and SFB/TRR 173 (project MO 1731/5-1), DARPA TEE program, through grant MIPR# HR0011831554 from DOI, and ERC- consolidator grant 681405-DYNASORE.

MA 17.11 Fri 12:45 H5

Spin-orbit enabled all-electrical readout of chiral spin-textures — •Imara Lima Fernandes[1], Stefan Blügel[1], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Non-collinear magnetic states are promising candidates for future information technology. However, their implementation in conventional memories is hindered by the inability of the electrical readout of their chiral nature based on current perpendicular to-plane (CPP) geometries [1,2,3]. In this work, we investigate the emergence of a rich family of new spin-mixing magnetoresistances enabling highly efficient all-electrical readout of the chirality and helicity of spin-swirling textures. Such transport effects are systematised at various non-collinear magnetic states and compared with the revealed spin-orbit-independent multi-site magnetoresistances. Owing to their simple implementation in readily available reading devices, the proposed magnetoresistances offer exciting and decisive ingredients to explore with all-electrical means the rich physics of topological and chiral magnetic objects.
– Funding is provided by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 – DYNASORE and grant 856538 – 3D MAGiC). [1] Crum et al., Nat. Commun. 6, 8541 (2015); [2] Hanneken et al., Nat. Nano. 10, 1039 (2015); [3] Fernandes et al., Nat. Commun. 11, 1602 (2020).

MA 17.12 Fri 13:00 H5

Skyrmion Dynamics at Finite Temperatures: Beyond Thiele's Equation — •Markus Weissenhofer, Levente Rózsa, and Ulrich Nowak — Fachbereich Physik, Universität Konstanz, Universitätsstraße 10, DE-78457 Konstanz, Germany

Magnetic textures are often treated as quasiparticles following Thiele's equation of motion [1]. We use atomistic spin simulations based on the stochastic Landau-Lifshitz-Gilbert equation to simulate the

Brownian and current-driven motion of ferromagnetic skyrmions in a (Pt0.95Ir0.05)/Fe-bilayer on a Pd(111) surface.

Our results reveal that the existing theory based on Thiele's equation is insufficient to describe the dynamics of skyrmions at finite temperatures. We propose an extended equation of motion that goes beyond Thiele's equation by taking into account the coupling of the skyrmion to the magnonic heat bath leading to an additional dissipative term that is linear in temperature. Our results indicate that this so-far-neglected magnon-induced friction even dominates for elevated temperatures and lower Gilbert damping values, typical for thin films and multilayers [2].

[1] A. A. Thiele, Phys. Rev. Lett. 30, 230, (1973)
[2] Weißenhofer et al. , Phys. Rev. Lett., (in press 2021)