TT 45: Skyrmions III (joint session MA/TT)

Time: Wednesday 15:00–18:30 Location: POT 6

TT 45.1 Wed 15:00 POT 6

Noncommutative geometry and the anomalous Hall effect in chiral spin textures — •Fabian R. Lux[1], Frank Freimuth[1], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

We demonstrate that the anomalous Hall effect (AHE) in chiral magnetic textures can naturally be described in the language of Alain Connes' noncommutative geometry which provides it with a deep geometrical interpretation. For periodic magnetic structures, the formalism reduces to the well-known Kubo-Bastin equations, but its applicability extends to all aperiodic cases in general. Under the assumption of a slowly varying texture, we derive the first order correction to the conventional AHE which is linear in the gradients of the magnetization texture [1]. This chiral Hall effect is neither proportional to the net magnetization nor to the emergent magnetic field that is responsible for the topological Hall effect and thus introduces an interesting twist in the interpretation of experimental data.

We acknowledge funding from Deutsche Forschungsgemeinschaft (DFG) through SPP 2137 "Skyrmionics".

[1] F. R. Lux *et al.*, arXiv:1910.06147 (2019)

TT 45.2 Wed 15:15 POT 6

Magnetic force microscopy investigation of spin textures in the ferromagnetic semimetal Fe_2Sn_3 — •Markus Altthaler[1,2], Erik Lysne[2], Erik Roede[2], Mohamed Kassem[1], Vladimir Tsurkan[1], Lilian Prodan[1], Stephan Krohns[1], Dennis Meier[2], and István Kézsmárki[1] — [1]Universität Augsburg, Germany — [2]Norwegian University of Science and Technology (NTNU)

Recently, Fe_3Sn_2 has been reported to exhibit a giant anomalous Hall effect [1] as well as a topological electronic structure [2] and to host magnetic skyrmions [3]. Unlike common skyrmion hosts, this material has inversion symmetry, therefore, the skyrmions do not emerge due to the Dzyalohinskii-Moriya interaction. Z. Hou et al. [3] suggested that both uniaxial magnetic anisotropy competing with long-range dipolar forces and exchange frustration due to the Kagome lattice play a significant role in the formation of skyrmions at room temperature in this compound. Our goal was to specify in more detail the driving force of skyrmion formation. In MFM studies performed on the surface of bulk Fe_3Sn_2 crystals we did not find stripe domains, instead a dendrite pattern, which indicates the lack of magnetic spirals in bulk samples. On the other hand, we found stripe domains in thin lamellae in zero magnetic field which transform to a bubble (skyrmion) lattice in modest magnetic fields. This together with the thickness dependence of the spiral wavelength implies that the uniaxial anisotropy competing with dipolar interactions is the origin of modulated magnetic states in Fe_3Sn_2. [1] L. Ye et al., Nature **555** (2018), 638; [2] J.-X. Yin et al., Nature **562** (2018), 91; [3] Z. Hou et al., Adv. Mater. (2017), 1701144

TT 45.3 Wed 15:30 POT 6

Stability and dynamics of in-plane Skyrmions — •Venkata Krishna Bharadwaj[1], Ricardo Zarzuela[1], Kyoung-Whan Kim[2], Jairo Sinova[1,3], and Karin Everschor-Sitte[1] — [1]Johannes Gutenberg-University, Mainz — [2]Center for Spintronics, Korea Institute of Science and Technology, South Korea — [3]Institute of Physics Academy of Sciences of the Czech Republic, Cukrovarnická 10, 162 00 Praha 6, Czech Republic

In this work [1] we analyze skyrmions in in-plane magnets. Through symmetry analysis, we offer possible material candidates to observe these skyrmions and also provide the phase diagram of such crystal systems. In addition, we determine their stability and properties, taking into account the crystal symmetries of the materials. Using micromagnetic simulations we show that in-plane skyrmions can be produced via two mechanisms, namely: i) the 'blowing bubbles' technique, i.e the creation of skyrmions due to current flow through constricted geometries and ii) shedding of skyrmions from a magnetic impurity driven by spin-transfer torques, analogues to their out-of-plane counterparts. Furthermore, we study the spin-orbit torques driven skyrmion dynamics both analytically and through micromagnetic simulations. Our results also indicate the possibility of designing the racetrack for in-plane skyrmions, which are promising candidates for memory applications.
[1]R. Zarzuela, V.K. Bharadwaj, K-W. Kim, J. Sinova, K. Everschor-Sitte, arXiv:1910.00987 (2019)

TT 45.4 Wed 15:45 POT 6

First-principles prediction of in-plane magnetic skyrmions: a topological spin-texture for high-storage density — •Flaviano José dos Santos, Markus Hoffmann, Manuel dos Santos Dias, Stefan Blügel, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany

Magnetic skyrmions competitive in information technology should be small to allow a high storage density. However, the dipole-dipole interaction (DDI) effectively impedes the miniaturization of skyrmions embedded in thin films and multilayers with typically out-of-plane magnetization. We predict from first-principles the existence of in-plane magnetic skyrmions in a Co monolayer on W(110). The magnetization of Co exhibits an in-plane easy axis, a geometry in which the DDI contributes to reducing the size of such topological spin textures. We discuss the various properties of these particles and list the mechanisms causing their stabilization. Due to the in-plane easy axis of the magnetization, mirror symmetry is preserved enabling the existence of antiskyrmions being degenerate in energy with skyrmions. This makes Co/W(110) a strong candidate for prospective devices, such as skyrmion/antiskyrmion racetracks [3].
We acknowledge funding from EU Horizon 2020 via ERC-consolidator Grant No. 681405-DYNASORE and DARPA TEE program through grant MIPR (#HR0011831554) from DOI. — Refs.: [1] Vidal-Silva *et al.*, J. Magn. Magn. Mater. **443**, 116 (2017); [2] Büttner *et al.*, Sci. Rep. **8**, 4464 (2018); [3] Moon *et al.*, arXiv:1811.12552 (2018).

TT 45.5 Wed 16:00 POT 6

Skyrmion lattice formation — •Thomas Winkler, Jakub Zázvorka, Nico Kerber, Klaus Raab, Florian Dittrich, Yuqingh Ge, Peter Virnau, and Mathias Kläui — Johannes Gutenberg Universität Mainz, Staudinger Weg 7, 55128 Mainz

Magnetic skyrmions are highly interesting magnetic spin structures and potential candidates for next generation computing devices due to their topology based stability [1,2]. There has been much work on the individual static and dynamic properties of skyrmions. However, their collective behavior is not yet well explored in particular in multilayer stacks with interfacial DMI. We have stabilized a skyrmion lattice in a single stack of Ta(5)/Co20Fe60B20(0.9)/Ta(0.08)/MgO(2)/Ta(5), and found that statistical order parameters can be varied by a change of the In-plane field and the temperature. The 2d skyrmion ensemble typically forms a liquid phase, but we also observe the emergence of hexagonal order for high densities. Using experimentally obtained parameters, coarse-grained numerical simulations are performed by modelling skyrmions as repulsive soft disks [3] to explain the results.

[1] Finocchio, G., Büttner, F., Tomasello, R., Carpentieri, M. & Kläui, M. Magnetic skyrmions: from fundamental to applications. J. Phys. D. Appl. Phys. 49, 423001 (2016). [2] Fert, A., Reyren, N. & Cros, V. Magnetic skyrmions: advances in physics and potential applications. Nat. Rev. Mater. 2, 17031 (2017). [3] S. Kapfer, S., Krauth, W. Soft-disk melting: From liquid-hexatic coexistence to continuous transitions. Physical Review Letters 114, 035702 (2015)

TT 45.6 Wed 16:15 POT 6

The effects of disorder on hysteresis loops in chiral magnets — David Cortes[1], Marijan Beg[1], Hans Fangohr[1,2], Tom Lancaster[3], Peter Hatton[3], Thorsten Hesjedal[4], and •Ondrej Hovorka[1] — [1]University of Southampton, UK — [2]European XFEL GmbH, Schenefeld, Germany — [3]Durham University, UK — [4]Oxford University, UK

In this talk we investigate the effect of random pinning sites on magnetization behaviour in systems with Dzyaloshinskii-Moriya interaction (DMI). We consider a standard classical spin Hamiltonian with Heisenberg exchange and DMI energy terms, and model the disorder through statistical Gaussian distribution of anisotropy. We first develop a mean-field model which allows to compute systematically and efficiently the magnetisation versus field hysteresis loops for variable temperature, and can be used for computing qualitative thermodynamic phase diagrams to guide computationally costly Monte-Carlo simulations. We show that as the standard deviation of the anisotropy distribution increases, relative to the strength of exchange interaction and DMI, the nature of the reversal modes observed along a typical hysteresis loop changes in a certain temperature window. Namely, in 'clean' systems with narrow anisotropy distribution, the reversal proceeds through the appearance of skyrmion lattices at low external fields, while in 'dirty' systems with broad anisotropy distribution, the reversal is through the nucleation of individual or small groups of skyrmions. We systematically quantify this effect and discuss its broader implications for applications.

TT 45.7 Wed 16:30 POT 6

Tuning the topology flip of magnetic skyrmions by an in-plane magnetic field — Florian Muckel[1], Stephan von Malottki[2], Christian Holl[1], Benjamin Pestka[1], Marco Pratzer[1], Pavel F. Bessarab[3], Stefan Heinze[2], and •Markus Morgenstern[1] — [1]II. Institute of Physics B, RWTH Aachen University and JARA-FIT, Germany — [2]Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany — [3]University of Iceland, Reykjavík, Iceland and ITMO University, St. Petersburg, Russia

Topological protection of magnetic skyrmions on a discrete lattice manifests itself in an energy barrier that can be overcome by local heating, for example by a tunneling electron. Here we use spin polarized scanning tunneling microscopy at 7 K to probe the current induced collapse of magnetic skyrmions in the Pd/Fe bilayer on Ir(111) as a function of the in-plane magnetic field $B_{\|}$ .The collapse rate caused by single hot electrons is tuned by four orders of magnitude via $B_{\|}$. We aim a more detailed understanding of the skyrmion collapse mechanism by locally mapping the collapse rate and deduce a change from a radially symmetric shrinkage of the skyrmion [1] towards a zipper-like Chimera collapse mechanism predicted by theory [2].

[1] Bessarab et. al. Comp. Phys. Comm. 196, (2015). [2] Meyer et. al. Nat. Commun. 10, (2019)

15 min. break.

TT 45.8 Wed 17:00 POT 6

Observation of unusual magnetic response at topological defects in FeGe — •Mariia Stepanova[1,2], Erik Lysne[1,2], Peggy Schoenherr[3], Jan Masell[4], Laura Köhler[5], Achim Rosch[6], Naoya Kanazawa[7], Yoshinori Tokura[4,7], Markus Garst[5,8], Alireza Qaiumzadeh[2], Arne Brataas[2], and Dennis Meier[1,2] — [1]NTNU, Trondheim, Norway — [2]QuSpin, NTNU, Trondheim, Norway — [3]ETH Zurich, Zürich, Switzerland — [4]RIKEN, Wako, Japan — [5]Technische Universität Dresden, Dresden, Germany — [6]Universität zu Köln, Köln, Germany — [7]University of Tokyo, Tokyo, Japan — [8]Karlsruhe Institute of Technology, Karlsruhe, Germany

Lamellar textures do not just arise in liquid crystals and biological systems, they are also observed in helimagnets. Analogous to cholesteric liquid crystals, chiral magnets possess a periodic layered structure and form different types of non-trivial topological defects. Using magnetic force microscopy (MFM) on the near-room temperature helimagnet FeGe, we resolve 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 an unusual MFM response, which is not observed in regions with perfect lamellar-like order. This magnetic signature is similar to the so-called "lines of flare" in cholesteric liquid crystals, suggesting local variations in magnetic susceptibility. We investigate the origin of the magnetic signature of the topological defects and discuss the possibility to use the local MFM response as a read-out signal in device applications.

TT 45.9 Wed 17:15 POT 6

Band structure tuning of a skyrmion lattice with giant topological Hall effect — •Leonie Spitz[2], Max Hirschberger[1], Shang Gao[1], Taro Nakajima[1], Christian Pfleiderer[2], Takahisa Arima[1,3], and Yoshinori Tokura[1] — [1]RIKEN Center for Emergent Matter Science, 2-1 Hirosawa, Wakoshi, Saitama 351-0198, Japan — [2]Physik-Department, Technical University of Munich, 85748 Garching, Germany — [3]Department of Advanced Materials Science, University of Tokyo, Kashiwa, Chiba 277-8561, Japan

A skyrmion lattice accompanied by a large topological Hall effect was found for the centrosymmetric frustrated triangular lattice magnet Gd_2PdSi_3 [1]. In contrast to non-centrosymmetric compounds, the skyrmion spin-vortices reported for Gd_2PdSi_3 can not be stabilized by the Dzyaloshinskii-Moriya interaction, but rather by frustration and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction [2-4]. The nanometer-scale size of the skyrmions in Gd_2PdSi_3 is a further novelty and may give rise to a very large emergent magnetic field B_{em}.

The project to be presented aims at a deeper understanding of the emergence of the giant topological Hall effect in Gd_2PdSi_3. In an extensive study we investigated the effect of isoelectronic doping on the topological Hall effect, the magnetic structure, and the band structure of the system.

[1] T. Kurumaji, et al., Science 365, 914-918 (2019) [2] T. Okubo, et al., Phys. Rev. Lett. 108, 017206 (2012) [3] A. O. Leonov, et al., Nat. Commun. 6, 8275 (2015) [4] S. Hayami, et al., Phys. Rev. B 95, 224424 (2017)

TT 45.10 Wed 17:30 POT 6

Nanoscale magnetic resonance imaging at room temperature using single spins in diamond — •Tetyana Shalomayeva[1], Jianpei Geng[1], Qi-Chao Sun[1], Rainer Stöhr[1], Stuart Parkin[2], and Jörg Wrachtrup[1,3] — [1]3rd Institute of Physics, University of Stuttgart — [2]Max Planck Institute of Microstructure Physics — [3]Max Planck Institute for Solid State Research

Due to the significant development of compounds hosting skyrmions at ambient conditions [1] the need of the quantitative real-space imaging of the magnetic textures is high nowadays. As an atomic-sized magnetic field sensor we use the point lattice defect in diamond, which consists of carbon vacancy and substitutional nitrogen atom (NV centre). For the scanning probe experiments single NV centre is integrated into the monolithic nanopillar, which plays the role of the sharp end of the AFM tip.

In this contribution we demonstrate the scanning probe measurement of the magnetic helical structure on the surface of thin Mn1.4Pt0.9Pd0.1Sn lamella via off-axial fluorescence quenching at room temperature and further numerical extraction of B-field.

[1] A.K. Nayak et al. Nature 548, 561-566 (2017)

TT 45.11 Wed 17:45 POT 6

Real-Space Imaging of the low-temperature Skyrmion phase in Cu2OSeO3 by Magnetic-Force-Microscopy — •Gerald Malsch[1], Peter Milde[1,2], Dmytro Ivaneiko[1], Christian Pfleiderer[3], Helmuth Berger[4], and Lukas Eng[1,2] — [1]Institute of Applied Physic, TU Dresden, 01187 Dresden, Germany — [2]ct.qmat: Würzburg-Dresden Cluster of Excellence - EXC 2147, TU Dresden, Germany — [3]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [4]Institut de Physique de la Matière Complexe, EPFL, 1015 Lausanne, Switzerland

Both small-angle neutron scattering measurements (SANS) and theoretical calculations indicate that there might exist additional skyrmion phases in Cu2OSeO3 in addition to its high-temperature phase, found at very low temperatures (LT) and only for magnetic fields applied along the <100> direction. These phases are usually hidden beneath a metastable tilted conical phase, but can be revealed by modulating the applied magnetic field.

Here we present a Magnetic-Force-Microscopy (MFM) analysis monitoring this LT skyrmion phase in real space. We find the LT skyrmion lattice to nucleate in micrometer-sized domains that coexist with tilted conical domains during the annealing process. Moreover, individual skyrmion domains are rotated relative to each other, resulting exactly in the ring-shaped halo as measured by SANS or REXS on a multidomain Cu2OSeO3 crystal.

TT 45.12 Wed 18:00 POT 6

Magnetic anisotropy in the itinerant helimagnet MnSi — •Schorsch Michael Sauther[1], Michelle Hollricher[1], Vivek Kumar[1], Andreas Bauer[1], Markus Garst[2], Dirk Grundler[3], Christian Pfleiderer[1], and Marc Andreas Wilde[1] — [1]Phys.-Dept. E51, TU München — [2]TFP, KIT, Karlsruhe — [3]LMGN, IMX, STI, EPF Lausanne

We report torque magnetometry in Manganese silicide (MnSi). In our experiments, we employ different implementations of cantilever magnetometry to measure the torque τ resulting from the anisotropic magnetization $\vec{M}_{\perp}$ of a high-quality, single-crystalline bulk sample of MnSi. The angular dependence of τ displays distinct oscillations with differently pronounced extrema im compliance with an effective Landau potential for the magnetization. This minimal model allows us to extract the anisotropy constant directly from the $\tau(\phi)$ curve. We study its dependence on field magnitude and temperature in the vicinity of the material's modulated phases and discuss our results in the context of complementary experiments [1,2].

[1] A. Bauer *et al.*, Phys. Rev. B **95**, 024429 (2017)
[2] T. Adams *et al.*, Phys. Rev. Lett. **121**, 187205 (2018)

TT 45.13 Wed 18:15 POT 6

Quantitative magnetic force microscopy investigation of magnetic features in the biskyrmion hosting hexagonal Mn33Ni33Ga33 magnet — •N. Puwenberg[1,2], C. F. Reiche[3], P. Devi[4], U. Burkhardt[4], C. Felser[4], M. Sharma[1,2], T. Mühl[1], and B. Büchner[1,2] — [1]IFW Dresden, Dresden, Germany — [2]Technische Universität Dresden, Dresden, Germany — [3]University of Utah, Salt Lake City, USA — [4]MPI CPfS, Dresden, Germany

We present quantitative magnetic force microscopy maps and distance dependent force spectroscopy measurements of the potentially biskyrmion hosting compound Mn33Ni33Ga33 employing an in-house fabricated custom-designed force sensor. Our magnetic sensing element is based on an iron-filled carbon nanotube attached to the free end of a super-flexible cantilever. Using a high aspect ratio magnetic nanowire offers a well-defined magnetic moment with a monopole-like magnetic stray-field characteristics at the nanowire's end, enabling the opportunity to easily quantify the magnetic stray-field on the sample surface. Our measurements were conducted in a single pass non-contact hybrid imaging mode. It features a direct sensing of the perpendicular magnetic stray-field component by measuring the normal cantilever deflection whilst a tip-sample distance control is realized by exploiting an AC bias driven flexural cantilever oscillation. Furthermore, the distance-dependency of the magnetic field and field gradient measured in the vicinity of individual magnetic features is fitted to simple magnetic models to make predictions about feature type, size and extension into the bulk's perpendicular third dimension.