MA 12: Skyrmions I

Time: Monday 15:00–18:30 Location: EB 301

MA 12.1 Mon 15:00 EB 301

Reversible and Multidirectional Laser-Driven Motion of Chiral Domain Walls and Skyrmion Bubbles — •Kai Litzius[1], Jason Bartell[2], Lisa-Marie Kern[3], Shiyu Zhou[4], Daniel Suzuki[2], Pooja Reddy[2], Felix Steinbach[3], Bastian Pfau[3], Clemens von Korff Schmising[3], Stefan Eisebitt[3,5], Geoffrey Beach[2], Felix Büttner[1,6], and Lucas Caretta[4] — [1]University of Augsburg, Augsburg, Germany — [2]Massachusetts Institute of Technology, Cambridge, USA — [3]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany — [4]Brown University, Providence, USA — [5]Technische Universität Berlin, Berlin, Germany — [6]Helmholtz-Zentrum Berlin, Berlin, Germany

Noncolinear spin textures, including domain walls and skyrmions, are pivotal for advancing memory and logic applications. Current-driven devices, however, often face challenges in multidimensional motion, demanding intricate fabrication and a comprehensive understanding of spin texture dynamics in multidimensional space. In this study, we investigate the displacement of chiral solitons in ferrimagnetic Pt/GdCo/Ta films using ultrafast laser pulses, allowing for motion over arbitrary distances and directions. We highlight the critical role of the DMI in ensuring reproducible domain wall motion, preventing a destabilization and domain randomization due to precessional dynamics. Furthermore, we find that a negative temperature derivative of the domain wall energy caused by a laser-induced transient thermal gradient can explain the observation. This stresses the importance of the compensation point for light-induced effects in ferrimagnets.

MA 12.2 Mon 15:15 EB 301

3D Skyrmions in frustrated magnets — •Steven Schoenmaker, Ricardo Zarzuela, and Jairo Sinova — Johannes Gutenberg-University, Mainz, Germany

Three-dimensional magnetic solitons have received growing interest in the last few years driven by their intrinsic complexity and their potential use in topological computing and high-density memory storage. Noteworthy advancements have led to the experimental observation of hopfions [1] and skyrmion strings [2] in collinear magnets. Shankar skyrmions [3], the condensed matter realization of skyrmions present in baryonic matter and of which magnetic skyrmions are a two-dimensional analog, can emerge in spin systems described by a SO(3)-order parameter, such as frustrated magnets [4]. Motivated by this possibility, we discuss minimal phenomenological models for Shankar skyrmions in magnetically frustrated spintronic platforms, with an eye on their crystal phases.

[1] F. Zheng et al., Nature 623, 718-723 (2023).
[2] T. Yokouchi et al., Sci. Adv. 4, eaat1115 (2018); S. Seki et al., Nat. Comms. 11, 256 (2020).
[3] R. Shankar, J. Physique 38, 1405 (1977).
[4] R. Zarzuela, H. Ochoa and Y. Tserkovnyak, Phys. Rev. B 100, 054426 (2019).

MA 12.3 Mon 15:30 EB 301

Current induced dynamics of skyrmions in synthetic antiferromagnets — •Venkata Krishna Bharadwaj, Ricardo Zarzuela, and Jairo Sinova — 1Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, D-55099 Mainz, Germany

Magnetic skyrmions, distinctive for their topological magnetic whirls and a trivial magnetization configuration at their boundary, exhibit a non-zero skyrmion Hall angle during current-driven dynamics, owing to their inherent topological nature in ferromagnets [1]. This characteristic poses a challenge for practical applications. However, this effect is suppressed for skyrmions in synthetic antiferromagnets (SAFs), due to the overall zero topological charge in SAFs [2]. Recent experimental observations of skyrmions at room temperature in SAFs [3] have opened up promising avenues for realizing extremely small and mobile skyrmions, crucial for various spintronic applications. This work investigates the current-driven dynamics of skyrmions in compensated SAFs, evaluating the impact of interlayer coupling and current strengths on the Hall angle. Additionally, the model is expanded to include ferrimagnets.

[1] K. Litzius et al., Nat. Phys. 13, 170 (2017). [2] X. Zhang et al, Nat. Commun. 7, 10293(2016) [3] T. Dohi et al, Nat. Commun. 10, 5153 (2019)

MA 12.4 Mon 15:45 EB 301

Walking Skyrmions: directed movement in oscillating magnetic fields — •Alla Bezvershenko, Hannah Dürschmidt, Leon-Sascha Gernert, and Achim Rosch — Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany

Magnetic skyrmions are topologically non-trivial spin textures that attract great interest, offering a possible avenue towards novel spintronics applications. One of the reasons for it are small critical current densities needed to depin the skyrmion lattice. Pinning by disorder remains arguably one of the most important obstacles for all skyrmion-based non-equilibrium experiments and the creation of useful skyrmion devices. In this work, we introduce an elastic model for skyrmion strings in the bulk MnSi in the presence of pinning forces under oscillating magnetic fields. We discuss a remarkably rich non-equilibrium phase diagram of this model and find periodic magnetic driving schemes, under which a directed motion of skyrmion strings becomes possible.

MA 12.5 Mon 16:00 EB 301

Meron-antimeron lattice in Gd_2PdSi_3 and its topological Hall effect — •Leonie Spitz[1,2], Sebastian Esser[3], Fehmi Sami Yasin[2], Kamil Kolincio[2], Takashi Kurumaji[2], Sonia Francoual[4], Pablo Bereciartua[4], Akiko Kikkawa[2], Yasujiro Taguchi[2], Xiuzhen Yu[2], Taka-hisa Arima[2,5], Yoshinori Tokura[2,3,6], and Max Hirschberger[2,3] — [1]Paul-Scherrer-Institut, Switzerland — [2]RIKEN Center for Emergent Matter Science, Japan — [3]Dept. of Applied Phys., The University of Tokyo, Japan — [4]PETRA-III Synchrotron, DESY, Germany — [5]Dept. of Adv. Materials Science, The University of Tokyo, Japan — [6]Tokyo College, The University of Tokyo, Japan

Merons and antimerons are triple-**q** spin textures with winding number $n = \pm 1/2$. Apart from the winding number, meron/antimeron lattices differ from a skyrmion lattice in the phase between their constituent helical spin-density waves [1]. A skyrmion lattice accompanied by a large topological Hall effect was found in the centrosymmetric frustrated triangular lattice magnet Gd_2PdSi_3 in a magnetic field [2]. We focused on the zero-field ground state of Gd_2PdSi_3 and identified its triple-**q** magnetic structure as a meron-antimeron lattice. We studied the characteristics of the transition between the meron-antimeron phase and the skyrmion phase in Gd_2PdSi_3 to elucidate which degree of freedom is driving the transition in this case [3].

[1] S. Hayami *et al.*, Nat. Commun. **12**, 6927 (2021) [2] T. Kurumaji *et al.*, Science **365**, 914-918 (2019) [3] L. Spitz *et al.*, manuscript in preparation

MA 12.6 Mon 16:15 EB 301

The mechanism and timescale of skyrmion localization during all-optical topological switching — •Daniel Metternich[1,2], Michael Schneider[3], Torstein Hegstad[4], Giuseppe Mercurio[5], Riccardo Battistelli[1,2], Christopher Klose[3], Victor Deinhardt[1,2], Krishnanjana Puzhekadavil Joy[2], Manas Patra[1,2], Steffen Wittrock[1], Marcel Möller[6], Sergey Zayko[6], Claus Ropers[6], Johan Mentink[4], Bastian Pfau[3], and Felix Büttner[1,2] — [1]Helmholtz-Zentrum Berlin, Germany — [2]Universität Augsburg, Germany — [3]Max-Born-Institut, Germany — [4]Radboud Universiteit, Netherlands — [5]EuXFEL, Hamburg, Germany — [6]Max-Planck-Institut, Göttingen, Germany

Heating a Co/Pt-multilayer with an optical laser pulse can create skyrmions at picosecond timescales. While the nucleation of these features is understood as being facilitated by transient fluctuations, the mechanisms of localization during this process has remained a puzzle.

Here, we present a real-time study of the skyrmion localization dynamics, conducted via time resolved SAXS at the EuXFEL. Using a periodic grid of ion irradiated areas (where the magnetic anisotropy is reduced), we can distinguish in the Fourier-space scattering signal between the time evolution at localization centers and evolution of homogeneous fluctuations. We observe that the localization process sets in only after a phase of homogeneous, fluctuation-driven nucleation events. Atomistic simulations and analytical modeling show that the localization is driven by a larger annihilation energy barrier and hence a lower skyrmion decay rate in the ion-irradiated areas.

MA 12.7 Mon 16:30 EB 301

Quantum Skyrmion Operator in Chiral Magnets — •Andreas Haller[1], Sebastián A. Díaz[2], Wolfgang Belzig[2], and Thomas L. Schmidt[1] — [1]University of Luxembourg, Luxembourg — [2]University of Konstanz, Germany

In this talk, we discuss a variational Ansatz to represent quantum skyrmions as bosonic operators. The Ansatz contains and treats independently two fundamentally different terms: the classical magnetic order, and a "quantum cloud" of local spin-flip excitations. Interestingly, we find two distinct regions in the single-skyrmion state diagram of the model: one where leading quantum corrections around the classical magnetic order are targeted by standard linear spin-wave (SW) theory and one that demands an interacting SW theory. Using matrix product state simulations, we verify that a two-skyrmion quantum ground state indeed satisfies bosonic exchange statistics on large distances, which paves the way toward a coarse-grained bosonic description of intriguing many-body quantum phases such as skyrmion superfluids.

15 min. break

MA 12.8 Mon 17:00 EB 301

Pressure tuning of the anomalous Hall effect in the antiskyrmion compound Mn1.4Pt0.9Ir0.1Sn — •Parul Devi[1,2], Krishna Kant Dubey[3], Moaz Elghazali[1], Praveen Vir[4], Marc Uhlarz[1], Boby Joseph[5], Chandra Shekhar[4], Sanjay Singh[3], Claudia Felser[4], and Toni Helm[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [3]Indian Institute of Technology (Banaras Hindu University), Varanasi 221005, India — [4]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [5]Elettra-Sincrotrone Trieste Strade Statale 14, Km 163.5 in Area Science Park, Basovizza 34149, Italy

We report on the pressure evolution of the anomalous Hall effect (AHE) in the antiskyrmion compound Mn1.4Pt0.9Ir0.1Sn. Herein, the observation of the isostructural phase transition in an antiskyrmion host tetragonal compound Mn1.4Pt0.9Ir0.1Sn at pressure * 20 GPa is presented. The magnetotransport and Hall-effect response of a single crystalline can be continuously tuned by the application of hydrostatic pressure * 30 GPa. We uncover a pressure-induced evolution at the low-temperature state of Mn1.4Pt0.9Ir0.1Sn into a distinct phase reminiscent of long-range ferromagnetism. This state is characterized by a steep negative magnetoresistance and an enhanced AHE with hysteretic behavior depending on the external magnetic field.

MA 12.9 Mon 17:15 EB 301

In-situ correlation of the Hall effect with the occurrence of topological magnetic phases — •S. Schneider[1,2], V. Bhatia[2], A. Yadav[2], S. Waddy[2], D. A. Mayoh[3], G. Balakrishnan[3], T. Sato[2], Y. Pivak[4], D. Pohl[1], A. Thomas[5], D. J. Reilly[2], B. Rellinghaus[1], J. M. Cairney[2], and M. Garbrecht[2] — [1]Dresden Center for Nanoanalysis (DCN), TU Dresden, Germany — [2]The University of Sydney, Australia — [3]University of Warwick, United Kingdom — [4]DENSsolutions, Netherlands — [5]IFW Dresden, Germany

Skyrmions are potential future nanoscale information carriers since they can be electrically manipulated and detected. Magnetic imaging in a transmission electron microscope (TEM) has proven extremely valuable for unveiling the details of these magnetic solitons. Hall effect measurements on such spin textures are usually conducted on samples that differ substantially in size and morphology from those investigated in a TEM. Since the stability of skyrmions is highly sensitive to the sample geometry, the correlation of magneto-transport and TEM data is problematic if not conducted on identical samples. We have therefore devised an in-situ measurement platform that bridges this gap and allows for magneto-transport measurements in-situ in a TEM. We correlate the Hall effect in a $Co_8Zn_9Mn_3$ lamella with the occurrence of topologically protected magnetic phases such as the helical phase and skyrmions. Our new setup provides the field dependence of the Hall voltage while simultaneously monitoring the magnetic phases in detail, thereby providing valuable insights into the existence and nature of the intensely debated electrical signature of skyrmionic structures.

MA 12.10 Mon 17:30 EB 301

Exploring the variety of chiral magnetic textures in $Mn_{1.4}PtSn$ — •M. Winter[1,2,3], M.C. Rahn[4], A.S. Sukhanov[4], S. Schneider[2], A. Tahn[2], D. Pohl[2], P. Vir[1], T. Helm[6], A. Thomas[4], A. Pignedoli[8], M. Azhar[8], K. Everschor-Sitte[8], J. Geck[4], G. van der Laan[7], T. Hesjedal[5,7], C. Felser[1], and B. Rellinghaus[2] — [1]MPI CPfS, Dresden, Germany — [2]DCN, TU Dresden, Germany — [3]IFW Dresden, Germany — [4]IFMP, TU Dresden, Germany — [5]Univ. Oxford, UK — [6]HZDR, Dresden, Germany — [7]Diamond Light Source, UK — [8]Univ. Duisburg-Essen, Germany

Combining in-situ Lorentz transmission electron microscopy (LTEM) and resonant elastic x-ray scattering (REXS) allows for an unambiguous correlation of magnetic scattering patterns with their underlying real space magnetic textures. We have applied this approach to explore the rich variety of magnetic textures emanating from basic chiral motifs in $Mn_{1.4}PtSn$. Supported by theoretical calculations and micromagnetic simulations, our experiments show that stripe domains, which are stabilized by the uniaxial magnetic anisotropy, rather than the so far assumed helical phase constitute the magnetic ground state of the material. Upon applying an external magnetic field, the stripe domains transform into a magnetic fan state or a chiral soliton lattice, depending on whether the field is applied within the plane of the anisotropic DMI or perpendicular to it, respectively. The findings allow to understand the kinetic pathways towards the formation of both non-topological bubbles and antiskyrmion lattices in $Mn_{1.4}PtSn$. The work is supported by DFG (SPP2137) and by MPG (IMPRS-CPQM).

MA 12.11 Mon 17:45 EB 301

Skyrmonic device for three dimensional magnetic field sensing enabled by spin-orbit torques — •Sabri Koraltan and Dieter Suess — Physics of Functional Materials, Faculty of Physics, University of Vienna, Vienna, Austria

Magnetic skyrmions are topologically protected magnetic solitons that are promising for storage or computing applications. In this work, we demonstrate that we can use a skyrmion device based on [W/CoFeB/MgO]xN multilayers for three-dimensional field sensing enabled by spin-orbit torques (SOT). We stabilize isolated chiral skyrmions and stripe domains in the multilayers, as shown by magnetic-force microscopy images and micromagnetic simulations. We perform magnetic transport measurements to show that we can sense both in and out-of-plane magnetic fields by a differential measurement scheme in which the symmetry of the SOT leads to cancellation of the DC offset. With the magnetic parameters obtained with vibrating sample magnetometry and ferromagnetic resonance measurements, we perform micromagnetic simulations where we investigate the fundamental origin of the sensing signal. That is, the topological transformation between skyrmions and stripes leading to an increase in the transverse voltage due to the anomalous and topological Hall effects.

MA 12.12 Mon 18:00 EB 301

Novel effects in S4/D2d-symmetric magnets: hybrid antiskyrmions and helix-switches — •Jan Masell[1,2] and Fehmi S. Yasin[2] — [1]Karlsruhe Institute of Technology (KIT), Germany — [2]RIKEN CEMS, Japan

Magnetic materials which obey only an S4 symmetry, i.e., whose only symmetry is one 4-fold roto-inversion axis, were recently identified as hosting a number of new competing interactions, stabilizing various novel magnetic textures. I will present our recent works where we identified the complex three-dimensional structure of antiskyrmions in an S4-symmetric material. Combining micromagnetic modelling and tomographic vector field electron holography, we could show that antiskyrmions in soft magnets terminate via Néel type skyrmion caps on the surfaces, which topologically requires the stabilization of a pairs of (anti-)Bloch points underneath each surface.[1] This novel texture is a natural consequence of the competition between bulk type S4-symmetric DMI and dipolar interaction, thus, can be expected as a ground state in many more materials of S4 or D2d symmetry. The same competition of energies causes pinning of the helices in these materials. I will discuss our recent experiments which showed that the direction of the q-vector of these phases can be controlled by temperature gradients [2], and I will outline how the competition with in-plane anisotropy may give arise to much more complex orientation transitions of the stripy phase of these materials.

[1] F.S.Yasin, J.Masell, et al., arXiv:2308.14219
[2] F.S.Yasin, J.Masell, et al., Nat Comm 14, 7094 (2023)

MA 12.13 Mon 18:15 EB 301

Tunable topological magnetism in superlattices of nonmagnetic B20 systems — •Vladislav Borisov[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

Using atomistic spin dynamics simulations, we predict topological magnetism in hitherto uninvestigated multilayers of B20 compounds. We address up to $2 \cdot 10^6$ spins in the simulations, with magnetic interactions calculated from density functional theory [1,2]. We assume atomically sharp interfaces. Our main focus is on FeSi/CoSi and FeSi/FeGe superlattices with varying number of layers and interface types. First, we show that finite magnetism appears near the FeSi/CoSi interfaces. B20 layers further away from the interface are non-magnetic, similarly to bulk FeSi and CoSi compounds. Our simulations [3] predict stable antiskyrmions in [001]-oriented FeSi/CoSi, intermediate skyrmions in [111]-oriented FeSi/CoSi, and Bloch skyrmions in the FeSi/FeGe(001) multilayer. The skyrmion sizes vary between 7 and 37 nm. The unusual characters of the topological textures can be attributed to the complex structure of the Dzyaloshinskii-Moriya matrix, which is quite different compared to known magnets. Importantly, we also show that it is possible to stabilize AFM skyrmions as well, which can be interesting for applications due to their zero skyrmion Hall effect.

1. A. Szilva *et al.*, Rev. Mod. Phys. 95, 035004 (2023).
2. arXiv:2310.08628. 3. arXiv:2309.14421.