# MA 34: Skyrmions II (joint session MA/TT)

Time: Wednesday 9:30–13:00 Location: POT 6

**Invited Talk** MA 34.1 Wed 9:30 POT 6

**Anatomy of skyrmion-defect interactions and their impact on detection protocols** — •Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Magnetic skyrmions are topological swirling spin-textures with enormous potential for new technologies that store, transport and read information. However, imperfections are intrinsic to any real device, affecting the detection, nucleation, type of motion and velocity of a skyrmion. I will discuss our first-principles investigations of the electronic, magnetic and transport properties of single skyrmions interacting with 3d and 4d impurities embedded in PdFe/Ir(111). We found that the obtained energy landscape has a universal shape as function of the defect's electron filling, enabling predictions of the repulsive or attractive nature of the impurity [1]. This finding can be used to design complex energy profiles with targeted properties via atom-by-atom manufacturing of multi-atomic defects. Finally, I address how the latter affect the electronic structure and the chiral orbital magnetism, with consequences for the efficiency of skyrmion detection protocols, either all-electrical [2,3] or optical [4]. — Work done with I. L. Fernandes, J. Bouaziz, D. M. Crum, M. dos Santos Dias, M. Bouhassoune, I. Gede Arjana, J. Chico and S. Blügel and supported by the EU Horizon 2020 via ERC-consolidator Grant No. 681405–DYNASORE.

[1] Fernandes *et al.*, Nat. Commun. **9**, 4395 (2018); [2] Fernandes *et al.*, ArXiv:1906.08838; [3] Crum *et al.*, Nat. Commun. **6**, 8541 (2015); [4] dos Santos Dias *et al.*, Nat. Commun. **7**, 13613 (2016)

MA 34.2 Wed 10:00 POT 6

**Electrical and optical manipulation of magnetic skyrmions** — •Felix Büttner[1], Bastian Pfau[2], Lucas Caretta[1], Kai Litzius[1], Michael Schneider[2], Guiseppe Mercurio[3], Marie Böttcher[4], Bertrand Dupé[4], Johan Mentink[5], Stefan Eisebitt[2], and Geoffrey Beach[1] — [1]MIT, Cambridge, MA, USA — [2]MBI, Berlin, Germany — [3]XFEL, Hamburg, Germany — [4]University of Mainz, Germany — [5]RU Nijmegen, The Netherlands

Magnetic skyrmions are nanoscale twisted spin textures with a topology equivalent to the unit sphere. Skyrmions exhibit fascinating quasi-particle physics, including skyrmion gyration [1], inertia [1], the skyrmion Hall effect [2], topological damping [3], sub-ns switching [4], and ultra-fast motion [5]. They are also promising candidates for several data storage and data processing technologies. In this context, fast and energy efficient operation is key. In this talk I will give a brief overview of our latest results of on skyrmion displacement by nanosecond spin-orbit torque current pulses and ultrafast light pulses. The main part of the talk will focus on the physics and speed of optically induced topological switching (skyrmion nucleation) and how this is different from classical bubble behavior. These results will be discussed from a theoretical and experimental perspective.

[1] Büttner et al., Nat Phys 11, 225 (2015). [2] Litzius et al., Nat Phys 13, 170 (2017). [3] Büttner et al., Sci Rep 8, 4464 (2018). [4] Büttner et al., Nat Nano 12, 1040 (2017). [5] Caretta et al., Nat Nano 13, 1154 (2018).

MA 34.3 Wed 10:15 POT 6

**Manipulation of magnetization and spin textures via femtosecond laser** — •Nina Novakovic[1,2], Mohamad-Assaad Mawass[1], Oleksii Volkov[3], Wolfgang-Dietrich Engel[4], Denys Makarov[3], and Florian Kronast[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, 12489, Berlin, Germany — [2]Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476, Potsdam, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf e. V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [4]Max Born Institute Berlin, Max-Born-Str. 2A, 12489 Berlin, Germany

Ultrafast optical control of magnetization recently became a rising field of study in magnetic thin film research, as micrometer sized domains manipulated at a small timescale may lead to faster and denser memory devices. We investigate different magnetic textures, such as bubbles and skyrmions under the influence of femtosecond laser pulses by means of photoelectron emission microscopy.

We present helicity dependent transition between stripe and bubble domains in CoPt multilayers. Moreover, manipulation of individual bubbles by tuning down laser fluence and external field is demonstrated. With the introduction of Ta layer at the interface in the CoPt system, we increase the influence of DMI. This allows us to study the formation and annihilation of skyrmions via fs laser and discuss important parameters which are required to attain reliable and efficient helicity dependent switching process, such as magnetic field and laser fluence and polarization.

MA 34.4 Wed 10:30 POT 6

**Quantum Damping of Characteristic Skyrmion Eigenmodes due to Spontaneous Magnon Decay** — •Alexander Mook, Jelena Klinovaja, and Daniel Loss — Department of Physics, University of Basel, CH-4056 Basel

The three characteristic and magnetically active modes of skyrmion crystals, i.e., the anticlockwise, breathing, and clockwise mode [1], are experimental probes that reveal information on the stability and behavior of the topologically nontrivial magnetic texture.

Herein, we show that the combination of a noncollinear texture and lowly dispersive Landau-level-like nature of magnon bands in skyrmion crystals installs strong three-particle interactions. These lead to spontaneously decaying magnons, i.e., to an intrinsic zero-temperature quantum damping, which manifests as lifetime broadening of the quasiparticle peak in the spectral function.

By varying the external magnetic field the characteristic modes can be brought "in resonance" with a flat mode, strongly enhancing their damping. This finding establishes skyrmion crystals as a platform to study the quantum mechanical phenomenon of spontaneous quasiparticle decay.

[1] M. Mochizuki, Phys. Rev. Lett. **108**, 017601 (2012)

MA 34.5 Wed 10:45 POT 6

**Current-driven magnetic Skyrmions in constrained geometries** — •Martin Stier[1], Richard Strobel[1], Wolfgang Häusler[2], and Michael Thorwart[1] — [1]Universität Hamburg, Jungiusstraße 9, 20355 Hamburg — [2]Universität Augsburg, Universitätsstr. 1, 86135 Augsburg

From a principle point of view, magnetic Skyrmions are ultimately stable and thus do basically not interact with their environment. This is in stark contrast to experimental findings, where Skyrmions are strongly influenced by the shape, roughness and the quality of the sample. We show how the current-driven dynamics and the number of Skyrmions are influenced by geometric constrictions in the wire, its edge roughness and magnetic impurities within the material. We discuss several scenarios in detail, e.g., Skyrmion trapping or acceleration, and Skyrmion destruction or creation. These findings may help to develop tailored microscopic memory devices involving Skyrmions.

MA 34.6 Wed 11:00 POT 6

**Evolution of topological charge during transitions between magnetic states** — •Igor Lobanov — ITMO University, Saint Petersburg, Russia — Saint Petersburg State University, Russia

Stability of magnetic skyrmions and other topological structures is an important prerequisite for the development of magnetic storage and computing devices. Evaluation of lifetime of magnetic states and the most probable transition scenario can be performed using harmonic transition state theory [1,2] and minimum energy path (MEP) calculation. Results on annihilation of skyrmionium to the ferromagnetic state are presented. There, the initial state and the final state are both of zero topological charge, but the charge is not necessarily conserved during the transition between the states. Several MEPs for the skyrmionium annihilation are identified, corresponding activation energies and transition rates are systematically compared, while variation of the topological charge along each MEP is analyzed. The dependence of lifetime on the lattice constant is studied, the resulting switching of the preferable path is demonstrated. The calculated MEPs give us a hint for optimal control of nucleation and annihilation of topologically protected structures.

This work was funded by the Russian Science Foundation (Grant No. 19-72-10138).

1. G. Fiedler, J. Fidler, J. Lee, T. Schrefl, R. L. Stamps, H. B. Braun, and D. Suess, J. Appl. Phys. 111, 093917 (2012)

2. P.F. Bessarab, V.M. Uzdin, H. Jonsson, Phys. Rev. B 85, 184409

(2012)

**15 min. break.**

MA 34.7 Wed 11:30 POT 6

**Topological Phase Transition Controls Magnon Spin Currents** — •Sebastián A. Díaz[1], Tomoki Hirosawa[2], Jelena Klinovaja[1], and Daniel Loss[1] — [1]Department of Physics, University of Basel, Basel, Switzerland — [2]Department of Physics, University of Tokyo, Tokyo, Japan

Using magnons in insulating magnets as information carriers is a highly promising approach for low-power consumption devices free of Joule heating. Here we show that a ferromagnetic skyrmion crystal provides a novel platform for switchable magnon currents. Taking advantage of a topological phase transition in the magnon spectrum, we show that an external magnetic field allows one to turn on and off chiral magnon currents carried by topological edge states. We identify concrete systems for experimental implementations. Our proposal establishes a profound connection between the fields of magnetic skyrmions and topological magnonics controlled by magnetic fields.

[1] S. A. Díaz, T. Hirosawa, J. Klinovaja, and D. Loss, arXiv:1910.05214.

MA 34.8 Wed 11:45 POT 6

**Mixed Topology Ring States in skyrmions of mixed Weyl semimetals** — •Matthias Redies[1,2], Fabian Lux[1,2], Patrick Buhl[3], Jan-Philipp Hanke[1], Stefan Blügel[1], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany

Various properties of Weyl semimetals are currently attracting significant attention. Recently, the concept of a magnetic mixed Weyl semimetal (MWS) has been put forward e.g. in 2D ferromagnets [1], and various prospects of these materials have been suggested. In such 2D materials the Weyl points are exhibited in the mixed space of **k**-vectors and the magnetization direction. We investigate the effect that skyrmionic order has on electronic transport properties of MWSs. Our analysis reveals the emergence of robust ring-like edge states, carrying local orbital moment, which mediate the transition between two different Chern insulator phases appearing in the skyrmion lattice of MWSs. We discuss the properties of such mixed topology ring states and their possible applications.

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

[1] Hanke *et al.*, Nature Comm. **8**, 1479 (2017), ibid. **10**, 3179 (2019)

MA 34.9 Wed 12:00 POT 6

**Skyrmion Breathing Modes in Synthetic Ferri- and Antiferromagnets** — •Martin Lonsky and Axel Hoffmann — Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, United States of America

Magnetic multilayers that combine strong spin-orbit interaction with lacking inversion symmetry can give rise to the presence of topologically nontrivial spin textures, so-called magnetic skyrmions, at room temperature. Recent studies have indicated strongly enhanced propagation velocities of skyrmions in antiferromagnets and compensated ferrimagnets [1]. At the same time, it is unclear how magnetic compensation may affect dynamic excitations of magnetic skyrmions, such as breathing modes which entail an oscillation of the skyrmion size at GHz frequencies [2]. Here, we present micromagnetic simulations of these excitations in synthetic ferri- and antiferromagnets. The observed features in the calculated power spectra show a systematic dependence on the coupling strength between the individual magnetic layers and are related to pure breathing modes as well as to hybridizations of breathing and spin wave modes that are characteristic for the considered geometry. Based on these simulations, we then discuss the impact of these results for potential skyrmion sensing and other applications.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) through the research fellowship LO 2584/1-1.

[1] L. Caretta et al., Nat. Nanotechnol. 13, 1154-1160 (2018)
[2] M. Garst et al., J. Phys. D: Appl. Phys. 50, 293002 (2017)

MA 34.10 Wed 12:15 POT 6

**Spin waves in skyrmions with various topological charges** — •Levente Rózsa and Ulrich Nowak — Universität Konstanz, Konstanz, Deutschland

Magnetic skyrmions offer promising prospects for the development of magnonic devices. The most widely studied mechanism to date for the stabilization of skyrmions is the Dzyaloshinsky-Moriya interaction (DMI). Although a wide variety of localized spin wave modes has been predicted theoretically in DMI-stabilized skyrmions [1], their experimental observation via excitation by a homogeneous external field has been restricted to breathing and gyrational modes. This can be attributed to the angular momentum selection rules enforced by the cylindrically symmetric spin structure. In contrast to the DMI, frustrated Heisenberg exchange interactions (FHEI) may stabilize different types of skyrmions with various topological charges [2]. Here we theoretically investigate how the types of localized magnons and the selection rules are modified in FHEI-stabilized skyrmions. The competition between FHEI and DMI is also considered, which was demonstrated to distort the shape of the different types of skyrmions [3].

[1] M. Garst et al., J. Phys. D: Appl. Phys. **50**, 293002 (2017).
[2] A. O. Leonov et al., Nat. Commun. **6**, 8275 (2015).
[3] L. Rózsa et al., Phys. Rev. B **95**, 094423 (2017).

MA 34.11 Wed 12:30 POT 6

**Transverse susceptibility of skyrmion lattice order in $Cu_2OSeO_3$ and MnSi** — •Denis Mettus[1], Felix Rucker[1], Andreas Bauer[1], Helmuth Berger[2], Markus Garst[3], Achim Rosch[4], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]École Polytechnique Federale de Lausanne, Lausanne, Switzerland, Switzerland — [3]Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany — [4]Institute for Theoretical Physics, Universität zu Köln, D-50937 Köln, Germany

The observation of skyrmion lattice flow in chiral magnets under spin-transfer torques at exceptionally small spin current densities has generated great interest concerning the underlying pinning and coupling mechanisms. While the spin currents in MnSi represent spin-polarized charge currents, similar spin torque effects due to tiny magnon currents are observed in the electrical insulator $Cu_2OSeO_3$. We report systematic measurements of the transverse ac susceptibility of MnSi and $Cu_2OSeO_3$ as a function of the amplitude and frequency of the excitation field. In our study we cover the response of the magnetization in the limits of local scales up to large scales of the entire texture. We discuss our results in the context of unpinning effects due to spin transfer torques as well as different stabiliziation mechanisms of skyrmion lattice order.

MA 34.12 Wed 12:45 POT 6

**Skyrmion-Skyrmion and Skyrmion-Edge Interactions studied with SP-STM** — •Jonas Spethmann, André Kubetzka, Roland Wiesendanger, and Kirsten von Bergmann — University of Hamburg

For the design of potential skyrmion-based devices, a deep understanding of the interactions between individual skyrmions and between skyrmions and magnetic nanostructure boundaries is fundamental. In order to study these interactions, we investigate the magnetic field dependent size and shape of multiple skyrmions confined in islands of PdFe bilayer on Ir(111) using spin-polarized STM. When the external magnetic field is reduced, the skyrmion size increases [1]. This forces adjacent skyrmions to interact with each other or with the edge of the PdFe island. Such interactions may manifest in form of skyrmion deformation, displacement or annihilation. Due to our operation temperature of 4 K or lower, the skyrmions do not spontaneously revert back to the spin spiral phase at small or even zero magnetic fields. Instead, we obtain metastable topological states, which provide an interesting starting point for further investigations. Additionally, by modification of the PdFe island-edge, we are able to study the influence of different types of edges on the spin spiral state and on the skyrmion-edge interactions.

[1] N. Romming et al., PRL 114: 177203, 2015.