Skyrmions in magnetic materials

This session has been organised in collaboration with the Association MaNEP.

Thursday, 29.08.2019, Room G 95

Time	ID	Skyrmions in magnetic materials *Chair: Oleg V. Yazyev, EPFL*
14:00	**661**	**Topological Magnetization Solitons: From Fundamentals to Technology** *Stefan Blügel, Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA* Chiral magnetic skyrmions arise due to the Dzyaloshinskii-Moriya interaction (DMI) as a result of the spin-orbit interaction in magnets lacking bulk or structure inversion asymmetry. I start my talk with a micromagnetic formulation of the energy functional and discuss briefly some general fundamental aspects. Using then a three-pronged scale-bridging approach combining DFT calculations with a generalized spin-lattice model containing the Heisenberg, DMI as well as magnetic anisotropy and dipolar interaction, with micromagnetism, we explore materials combinations for interfaces that offer great potentials hosting skyrmions, investigate their phase diagram, stability, lifetime and dynamics, their size as function external magnetic and temperature. We study optimal parameters for the detection by transport. I present our efforts to find skyrmions compatible to technology requirements.
14:30	**662**	**Topological Magnons and Edge States in Antiferromagnetic Skyrmion Crystals** *Sebastián Díaz, Jelena Klinovaja, Daniel Loss, University of Basel* Antiferromagnetic skyrmion crystals are spatially periodic noncollinear magnetic phases predicted to exist in antiferromagnets with Dzyaloshinskii-Moriya interactions. We show for the first time that their bulk magnon band structure, characterized by nonzero Chern numbers, is topologically nontrivial and that they support topologically-protected chiral magnonic edge states. Of particular importance for experimental realizations, magnonic edge states appear within the first bulk magnon gap, at the lowest possible energies they can exist and where magnon-magnon interactions are reduced. Thus, antiferromagnetic skyrmion crystals show great promise as novel platforms for topological magnonics. [1] S. A. Díaz, J. Klinovaja, and D. Loss, arXiv:1812.11125; Phys. Rev. Lett. (accepted).
14:45	**663**	**Imaging topological electron-spin textures by using atomic-resolution Lorentz TEM** *Xiuzhen Yu, RIKEN Center for Emergent Matter Science* The nanometer-scale vortex-like spin textures, such as vortex-antivortex pairs in ferromagnetic (FM) domain walls [1], votices in superconductors [2], skyrmion (lattice) [3] and antiskyrmions [4] in magnets with inversion symmetry, have recently attracted enormous attention owing to their topological manner [5]. To confirm such minute complex spin textures and their dynamics with external stimuli, the real space observation have been performed by Lorentz transmission electron microscopy (TEM). [1] X. Z. Yu, et al., Adv. Mater. 29, 1603958 (2017). [2] A. Tonomura, et al., Nature 397, 308 (1999). [3] X. Z. Yu, et al., Nature 465, 901 (2010). [4] Ajaya K. Nayak, et al., Nature 548, 561 (2017). [5] N. Nagaosa and Y. Tokura, Nat. Nanotechnol. 8, 899 (2013). [6] X. Z. Yu, et al., Nature 564, 95 (2018).
15:15	**664**	**Field-induced skyrmion inversion in the room-temperature chiral magnet $Co_9Zn_9Mn_2$** *Victor Ukleev [1], Daisuke Morikawa [2], Kosuke Karube [2], Akiko Kikkawa [2], Kiyou Shibata [2], Jonathan S. White [1], Yasujiro Taguchi [2], Yoshinori Tokura [2], Taka-Hisa Arima [2]* *[1] Paul Scherrer Institut, [2] RIKEN Center for Emergent Matter Science (CEMS)* In a β-Mn-type chiral magnet $Co_9Zn_9Mn_2$, we demonstrate the magnetic field-driven collapse of a room temperature metastable skyrmion lattice (SkL) to pass through a regime of partial topological

charge inversion. Using Lorentz transmission electron microscopy, we observe the magnetization distribution directly as magnetic fields are applied antiparallel to the original skyrmion core magnetization. Topological protection prevents the transition of the SkL to the helical state, instead, for increasingly negative fields, the metastable SkL transforms into giant topological bubbles. These structures give way to form a near-homogeneously magnetized medium that hosts isolated skyrmions with inverted cores. From micromagnetic simulations, we find that the observed regime of partial topological charge inversion has its origin in the topological protection of the starting SkL.

15:30 | **665**

Investigating Stability and Metastability in the Skyrmion system zinc-doped Cu_2OSeO_3

Peter D. Hatton [1], Max T. Birch [1], Murray N. Wilson [1], Rina Takagi [2], Shinichiro Seki [2], Yoshinori Tokura [2,3], Marta Crisanti [4], Ales Štefančič [5], Jonathon S. White [6], Geetha Balakrishnan [5], Robert Cubitt [4].
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[2] RIKEN, Center for Emergent Matter Science, Japan
[3] Department of Physics, University of Tokyo
[4] Large Scale Structures Group, Institut Laue-Langevin, France
[5] Department of Physics & Astronomy, University of Warwick, United Kingdom
[6] Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut

Skyrmions are topologically protected spin textures that appear in certain chiral magnetic materials. One bulk chiral material in which skyrmions are observed is the multiferroic insulator Cu_2OSeO_3. In this talk I will present small angle neutron scattering (SANS) and magnetometry work studying skyrmion metastability in zinc-substituted Cu_2OSeO_3. This substitution dramatically increases the metastable lifetime of skyrmions, by a factor 50 with just 2.5% Zn. Furthermore, we can use SANS to measure the formation time of skyrmions out of the conical state when an electric field is applied to Zn substituted Cu_2OSeO_3. The temperature dependence of these formation times follow an Arrhenius law dependence, allowing us to extract an energy barrier for the formation of skyrmions of 1.57 eV.

16:00 | **666**

Bulk Magnon Modes in Cu_2OSeO_3 Detected by Brillouin Light Scattering Microscopy at Low Temperature

Ping Che [1], Bin Lu [1], Helmuth Berger [2], Andreas Bauer [3], Christian Pfleiderer [3], Dirk Grundler [1]
[1] Institute of Materials and Laboratory of Nanoscale Magnetic Materials and Magnonics, EPFL, 1015 Lausanne
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[3] Physik Department E51, Technische Universität München, DE-85748 Garching

The chiral ferrimagnet Cu_2OSeO_3 hosts topologically protected spin textures known as magnetic skyrmion lattices and exhibit characteristic magnon band structures. We conducted scanning Brillouin light scattering (BLS) spectroscopy on bulk-shape single crystals of Cu_2OSeO_3 at low temperature with magnetic field applied along (100). Multiple magnon modes were observed in conical and field-polarized state and attributed to bulk magnon modes with a high wavevector of up to k = 35.6 rad/micrometer. BLS studies hence enable one to explore anisotropic characteristics of magnon bandstructures for differently oriented Cu_2OSeO_3 crystals.
This work is support by SNSF via 171003 and DFG TRR80.

16:15 | **667**

Spiral spin-liquid and the emergence of a skyrmion-like state in $MnSc_2S_4$

Oksana Zaharko [1], Daniel Cabra [2], Shang Gao [3], Flavia Alejandra Gomez Albarracin [2], Guratinder Kaur [1], Hector Diego Rosales [2], Vladimir Tsurkan [4]
[1] Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, [2] CONICET, [3] RIKEN Center for Emergent Matter Science, [4] Lehrstuhl für Experimentalphysik V

Neutron scattering was used to study frustrated $MnSc_2S_4$ spinel with magnetic Mn^{2+} ions forming the diamond lattice [1]. We present direct experimental evidence for the existence of the spiral spin liquid, which was predicted to occur within the J1-J2 model, when the ratio between the first and second neighbour couplings is $|J2/J1| > 0.125$, unravel three long-range ordered phases supplanting each other on temperature lowering and disclose the triple-q state in applied magnetic fields. With Monte Carlo simulations we scrutinize further details of the spin Hamiltonian, ie. the 3rd neighbour coupling, single ion anisotropy and exchange anisotropy and establish that this set of parameters stabilizes the lattice of dense topological objects akin to skyrmions.

[1] S. Gao, O. Zaharko, V. Tsurkan, et al. Nature Physics,13,157–161(2016).

16:30		*END; Coffee Break*
19:00		*Transfer to Dinner*
19:30		*Conference Dinner*

ID	Skyrmions in magnetic materials Poster
671	**Low frequency resonance mode in the insulating chiral magnet Cu_2OSeO_3 at low temperature** *Jilei Chen [1], Mohammad Hamdi [1], Ping Che [1], Priya Ranjan Baral [2,3], Arnaud Magrez [3], Dirk Grundler [1]* *[1] Institute of Materials and Laboratory of Nanoscale Magnetic Materials and Magnonics, EPFL, 1015 Lausanne* *[2] Chair of Computational Condensed Matter Physics, Intitut de Physique, EPFL, 1015 Lausanne* *[3] Crystal Growth Facility, Institut de Physique, EPFL, 1015 Lausanne* The chiral-lattice ferrimagnet Cu_2OSeO_3 has been evidenced to exhibit a second skyrmion phase stabilized by cubic anisotropy well below 57 K. It is particularly interesting when aiming at an experimental investigation of magnon band structures in skyrmion lattices and their potential application for microwave devices operating at GHz frequencies. We explored spin excitations in a Cu_2OSeO_3 single crystal by broadband GHz spectroscopy by high field cooling down. Beyond modes attributed to the conventional low-temperature helical, conical and ferrimagnetic phases, we observe a further weak resonance at a relatively low frequency of about 1.5 GHz which might hint towards excitation of the second skyrmion phase. The work is supported by SNSF via grant 171003 (sinergia project Nanoskyrmionics).
672	**Crystallite size dependency on magnetic phase diagram of Cu_2OSeO_3** *Priya Ranjan Baral [1], Victor Ukleev [2], Jonathan White [2], Oleg Yazyev [1], Henrik Rønnow [1], Arnaud Magrez [1]* *[1] EPFL, [2] Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut* Due to their promising technological applications, magnetic Skyrmions in Chiral magnets, such as Cu_2OSeO_3, have been the center of attention of the scientific community. By manipulating the crystallite size in the range of a single Skyrmion (62 nm), it could be interesting to see if the magnetic phase diagram can be tuned. We have employed solution growth techniques to have controllable size of nanocrystals varying from 35 nm to 300 nm. The size-specific magnetic phase diagram of nanoparticles has been explored using DC magnetization, AC-susceptibility and Small Angle Neutron Scattering studies. Our experimental results have been further verified using micromagnetic simulations. We observe a systematical change in the magnetic phase diagram with the change in particle size.
673	**van Der Waals Epitaxy of Co-Zn-Mn on Graphene for Skyrmionic Applications** *Anna Kukolova, Simon Escobar Steinvall, Rajrupa Paul, Jean-Baptiste Leran, Ping Che, Dirk Grundler, Anna Fontcuberta I Morral, EPFL* Skyrmions are topologically protected nanometer-sized magnetic vortices interesting for spintronics applications. Current challenges lie in the discovery and synthesis of materials with high critical temperatures (T_c) and their implementation in thin-film technology. Here we present an approach for strain-free epitaxial thin-film growth of near-room temperature skyrmion-hosting material $Co_{10-x}Zn_{10-y}Mn_{x+y}$. T_c can be systematically tuned beyond room temperature by adjusting Co:Zn:Mn composition. We use graphene grown on Si as an underlying substrate for molecular beam epitaxy. Graphene allows us to exploit van der Waals interaction for strain-free growth. We report on the structural, compositional and magnetic properties of $Co_{10-x}Zn_{10-y}Mn_{x+y}$ ($1 < x, y < 3$) thin films. This growth technique opens a new route for integrating skyrmionic device concepts with silicon electronics.