MA 47: Skyrmions IV

Time: Friday 9:30–12:30 Location: HSZ 04

MA 47.1 Fri 9:30 HSZ 04

Systematic parameter study of magnetic skyrmions and antiskyrmions stabilised by exchange interactions — •Stephan von Malottki and Geoffroy Hautier — Thayer School of Engineering at Dartmouth College, Hanover, NH, USA

It is a major ongoing task to optimize the thermal stability of magnetic skyrmions (Sk) and antiskyrmions (ASk), which is in particular limited for sub-10 nm Sk and ASk in 2D magnetic materials. We focus on a stabilisation of Sk and ASk by exchange frustration [1] and higher order exchange interactions (HOI) [2]. We explore the large interaction parameter space of the atomistic Heisenberg model, consisting of exchange interaction beyond nearest neighbours, DMI, magnetocrystalline anisotropy and HOI by means of highly automatised energetic optimisation and geodesic nudged elastic band method (GNEB) simulations. Here we present the resulting sizes and energy barriers for SK and ASK in ferromagnetic and antiferromagnetic lattices with hexagonal and square geometry. This enables us to identify systematically the areas of parameters space in which metastable Sk and ASk can exist and how much their energy barriers can be enhanced in the framework of the atomistic extended Heisenberg model beyond nearest neighbours.

[1] S. von Malottki et al., Sci. Rep. 7, 12299 (2017)
[2] S. Paul et al., Nat. Commun. 11, 4756 (2020)

MA 47.2 Fri 9:45 HSZ 04

Coarse-graining skyrmion ensemble analysis — •Thomas Brian Winkler[1], Jan Rothörl[1], Maarten A. Brems[1], Hans Fangohr[2,3], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Germany — [2]Faculty of Engineering and Physical Sciences, University of Southampton, United Kingdom — [3]Max Planck Institute for the Structure and Dynamics of Matter Hamburg, Hamburg

Magnetic skyrmion are heavily investigated due to their interesting physics and their potential for unconventional computing schemes [1,2]. In confined geometries the thermal diffusion of skyrmions depends heavily on the ability of the skyrmion ensemble to arrange with respect to the confinement in a commensurate manner [3,4]. If external forces like spin-orbit torques are applied to such systems, the steady states of the system might change. We use a coarse-graining to analyse the system with methods from statistical physics [5] to ascertain the relevant states that the collective system is entering. We find in a simulational case study of four skyrmions in a triangular geometry that the steady states of a system are changing when external forces are applied. Such analysis is useful to optimise geometries or readout positions of magnetic tunnel junctions for skyrmion-based devices.
[1] K. Everschor-Sitte et al., Journal of Applied Physics 124, 240901 (2018). [2] K. Raab et al., Nat. Comm. 13, 6982 (2022). [3] C. Song et al., Adv. Funct. Mater. 31, 2010739 (2021). [4] A. F. Schäffer et al., Commun Phys 2, 72 (2019). [5] B. Reuter et al., J Chem. Theory Comput. 14, 3579 (2018).

MA 47.3 Fri 10:00 HSZ 04

Dzyaloshinskii-Moriya interactions in skyrmionic lacunar spinel GaV_4S_8 — •Vladislav Borisov[1], Patrik Thunström[1], Anna Delin[2,3], and Olle Eriksson[1,4] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Department of Applied Physics, School of Engineering Sciences, KTH Royal Institute of Technology, Stockholm, Sweden — [3]SeRC (Swedish e-Science Research Center), KTH Royal Institute of Technology, Stockholm, Sweden — [4]Örebro University, Örebro, Sweden

Using the first-principles full-potential linear muffin-tin orbital method and magnetic force theorem we study the Heisenberg and Dzyaloshinskii-Moriya interactions in the lacunar spinel GaV_4S_8. This material hosts magnetic Néel skyrmions, in contrast to most other bulk magnets. The symmetry of the calculated DM vectors agrees with the C_{3v} structural symmetry and supports the stability of Néel skyrmions. The sizes of the magnetic interactions show some variations as a function of electronic correlations. These changes are also reflected in the estimated wavelength of the helical magnetic state. Our theoretical results indicate that the electronic and magnetic properties depend strongly on the spin configuration of the V_4 clusters, on which there is no clear consensus in the literature, and we make a suggestion for the configuration that fits better to the known measurements.

MA 47.4 Fri 10:15 HSZ 04

On the correlation between spin, orbital and chiral magnetizations of skyrmions — Imara Lima Fernandes[1] and •Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen & CENIDE, 47053 Duisburg, Germany

Skyrmions are spin-swirling textures hosting wonderful properties with potential implications in information technology. The magnetization carried by such objects is prospected as a mean of encoding magnetic bits while their topological nature gives rise to a plethora of exquisite features such as topological protection, the skyrmion Hall effect, topological Hall effect and topological orbital moment [1]. Here, the emergent magnetic field, which is directly proportional to the three-spin scalar chirality χ, plays a key role. We explore from ab-initio the rich set of magnetizations carried by single small magnetic skyrmions generated in PdFe bilayer on Ir(111) surface and focus on the correlation between spin, orbital, chiral magnetizations and χ after being excited by single atomic defects [2]. We identify a universal pattern that can guide the design of storage devices by engineering the magnitude of the magnetization carried by skyrmions via controlled implantation of defects.
–Work funded by the Priority Programmes SPP 2137 “Skyrmionics” and SPP 2244 "2D Materials" of the DFG (Projects LO 1659/8-1 and LO 1659/7-1). [1] dos Santos Dias et al. Nat. Commun. 7, 13613 (2016); [2] Lima Fernandes et al. Nat. Commun. 9, 4395 (2018).

MA 47.5 Fri 10:30 HSZ 04

Nature of magnetic Exchange interactions in Centrosymmetric Hexagonal NiMnGa — •Sunil Wilfred DSouza[1], Sanjay Singh[2], and Jan Minár[1] — [1]New Technologies Research Centre, University of West Bohemia, Univerzitní 8, CZ-306 14 Pilsen, Czech Republic. — [2]School of Materials Science and Technology, Indian Institute of Technology (Banaras Hindu University) Varanasi-221005, India.

Hexagonal NiMnGa hosts Novel magnetic biskyrmion state in which vortex-like nanometric spin textures are stable over a wide temperature range extending upto the Curie temperature making it a contender for potential applications in future high-performance spintronic devices. We present, The Heisenberg exchange couplings determined from the paramagnetic phase using the disordered local moment theory which is found to give a significantly more realistic description in comparison with the treatment of the material as a ferromagnet. Frustration caused by competing ferromagnetic and antiferromagnetic exchange couplings at the nearest-neighbor Mn-Mn interactions has been noticed in NiMnGa which is known to lead to non-collinear magnetic ordering. Total energy calculations establishes a non-collinear spin-structure which is stable at a specific Mn spin canting angle in c-plane which is resulting from the magnetocrystalline anisotropy. The Mean-Field Curie temperature determined from the exchange interactions is in good agreement with experiment.

MA 47.6 Fri 10:45 HSZ 04

Skyrmions in 4*d*- and 5*d*-doped B20 compounds — •Vladislav Borisov[1], Qichen Xu[2,3], Nikolaos Ntallis[1], Rebecca Clulow[4], Vitalii Shtender[4], Johan Cedervall[5], Martin Sahlberg[4], Kjartan Thor Wikfeldt[6], Danny Thonig[7,1], Manuel Pereiro[1], Anders Bergman[1], Anna Delin[2,3], and Olle Eriksson[1,7] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Department of Applied Physics, School of Engineering Sciences, KTH Royal Institute of Technology, Stockholm, Sweden — [3]SeRC (Swedish e-Science Research Center), KTH Royal Institute of Technology, Stockholm, Sweden — [4]Department of Chemistry, Uppsala University, Sweden — [5]Department of Materials and Environmental Chemistry, Stockholm University, Sweden — [6]PDC Center for High Performance Computing, KTH Royal Institute of Technology, Stockholm, Sweden — [7]Örebro University, Örebro, Sweden

Based on theoretical calculations, we predict that 4*d*- and 5*d*-doped FeSi and CoSi compounds host skyrmions with a size between 50 nm for (Co,Os)Si and 148 nm for (Fe,Co)Si. Calculations are done using

the full-potential linear muffin-tin orbital method and magnetic force theorem which allow to address the Heisenberg and Dzyaloshinskii-Moriya (DM) interactions, and the skyrmionic properties were determined using micromagnetic simulations. We find that the $5d$ doping (by Ir or Os) is particularly efficient in terms of enhancing the DM interaction. Convex-hull analysis suggests that the doped compounds are structurally stable, and we have managed to synthesize and characterize $Co_{1-x}Ru_xSi$ systems both in powder and single-crystal forms.

15 min. break

MA 47.7 Fri 11:15 HSZ 04

Bloch points in the ground state of chiral magnet nanocylinder — •Andrii Savchenko[1], Fengshan Zheng[2,3], Nikolai Kiselev[1], Luyan Yang[1,2], Qianqian Lan[1,2], Filipp Rybakov[4], Stefan Blügel[1], and Rafal Dunin-Borkowski[1,2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Spin-X Institute, South China University of Technology, Guangzhou 511442, China — [4]Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden

Experimental observation of Bloch points (BPs) is challenging since these topological defects represent energetically unfavorable configurations and usually appear only as a metastable state. The present study aims to find the systems where due to the competition between short-range and long-range interactions the BPs can emerge in the ground state of the system. A nanocylinder of an isotropic chiral magnet might be a good candidate for such a system. We found that the dipole string - the configuration containing two coupled BPs of opposite topological charge, at some geometrical parameters corresponds to the lowest energy state in such nanocylinder. Our micromagnetic simulations with realistic parameters agree well with the results of the transmission electron microscopy experiment on the FeGe sample.

MA 47.8 Fri 11:30 HSZ 04

Quantum correlation functions of magnetic skyrmions in chiral magnets — •Sopheak Sorn[1] and Markus Garst[1,2] — [1]Institute of Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Recent research activities have turned to studying quantum effects in skyrmion-hosting ordered phases within the context of numerical diagonalization of quantum spin Hamiltonians as well as semiclassical magnonic theories. In the later, one can expand various operators in magnon fields around a classical spin-texture background. In this talk, I will present results from such a semiclassical theory for chiral magnets, focusing on various correlation functions involving the topological charge and the energy-momentum tensor at zero and nonzero temperature. I will also discuss how these correlation functions are related to linear responses of skyrmions to external perturbation.

MA 47.9 Fri 11:45 HSZ 04

Modeling stray fields using Bi-axial anisotropy in in-inplane magnets — •Venkata Krishna Bharadwaj[1], Karin Everschor-Sitte[2], Jairo Sinova[1,3], and Ricardo Zarzuela[1] — [1]Johannes Gutenberg-University, Mainz — [2]Faculty of Physics, University of Duisburg-Essen, D-47057 Duisburg, Germany — [3]Institute of Physics Academy of Sciences of the Czech Republic, Cukrovarnická 10, 162 00 Praha 6, Czech Republic

Recently [1,2], magnetic bimreons, skyrmion analogs in in-plane magnetized films have gained interest due to their stark difference in current-driven dynamics with respect to Neel skyrmions showing unidirectional motion with SOT-driven torques. The other technological advantage is that they can be densely stacked without worrying about stray fields between the layers. However, the stray fields need to be handled carefully as they are not trivial as in out-of-plane films. In this work, we study the bi-axial anisotropy to model the stray field in in-plane magnetized films. We provide the phase diagram and look at the deformations of spin spiral phases and the presence of titled fields. Finally, we study the shape deformation of skyrmions due to stary fields and the effects in current-driven dynamics. [1] R. Zarzuela et al., Physical Review B 101, 054405 (2020), [2] B. Göbel, et al., Phys. Rev. B 99, 060407(R) (2019).

MA 47.10 Fri 12:00 HSZ 04

Magnetoelectric Cavity Magnonics in Skyrmion Crystals — Tomoki Hirosawa[1,2], •Alexander Mook[1,3,4], Jelena Klinovaja[1], and Daniel Loss[1] — [1]University of Basel, Basel, Switzerland — [2]Aoyama Gakuin University, Sagamihara, Kanagawa, Japan — [3]Technical University of Munich, Garching, Germany — [4]Johannes Gutenberg University, Mainz, Germany

We present a theory of magnetoelectric magnon-photon coupling in cavities hosting noncentrosymmetric magnets. Analogously to nonreciprocal phenomena in multiferroics, the magnetoelectric coupling is time-reversal and inversion asymmetric. This asymmetry establishes a means for exceptional tunability of magnon-photon coupling, which can be switched on and off by reversing the magnetization direction. Taking the multiferroic skyrmion host Cu_2OSeO_3 with ultralow magnetic damping as an example, we reveal the electrical activity of skyrmion eigenmodes and propose it for magnon-photon splitting of "magnetically dark" elliptic modes. Furthermore, we predict a cavity-induced magnon-magnon coupling between magnetoelectrically active skyrmion excitations. We discuss applications in quantum information processing by proposing protocols for all-electrical magnon-mediated photon quantum gates, and a photon-mediated split operation of magnons. Our study highlights magnetoelectric cavity magnonics as a novel platform for realizing coherent transduction between photons and magnons.

Reference: Tomoki Hirosawa*, Alexander Mook*, Jelena Klinovaja, and Daniel Loss, PRX Quantum 3, 040321 (2022)

MA 47.11 Fri 12:15 HSZ 04

Artificial surface conductivity on metallic metamaterials and its effect on localized plasmon skyrmions — •Amin Khavasi[1] and Karin Everschor-Sitte[1,2] — [1]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Center for Nanointegration Duisburg-Essen (CENIDE), Duisburg, Germany

Metallic metamaterials have been widely investigated for realizing different peculiar effects such as spoof surface plasmons [1] and extraordinary transmission of light [2]. Recently, topologically robust localized plasmonic skyrmions have been realized by spiral metallic meta-structures [3, 4].

For metal films with a periodic arrangement of cut-through slits, Khavasi and others have shown that the structure can be modeled by an anisotropic medium with an artificial surface conductivity [5]. In the subwavelength regime, the surface conductivity is imaginary considering lossless systems representing non-specular higher diffracted orders. We investigate the consequences of such artificial surface conductivities for the skyrmionic modes of the spiral meta-structures to obtain more insight on the behavior of the localized plasmonic skyrmions.

References:
[1] Pendry, J. B., et al., science 305, (2004): 847-848.
[2] Porto, J. A., et al., Physical review letters 83,(1999): 2845.
[3] Davis, T. J., et al. Science 368, (2020): eaba6415.
[4] Deng, Z., et al., Nature Communications 13, (2022): 1-7.
[5] Edalatipour, M., et al., Journal of lightwave technology 30, (2012): 1789-1794.