MA 35: Skyrmions III

Time: Thursday 9:30–12:00 Location: HSZ 04

MA 35.1 Thu 9:30 HSZ 04

Skyrmion dynamics and applications — •Ismael Ribeiro de Assis, Ingrid Mertig, and Börge Göbel — Martin-Luther-Universität Halle-Wittenberg, Halle, Germany

Skyrmionics and neuromorphics are among the most promising fields of physics with the perspective of creating future devices and technologies. Magnetic skyrmions are nanoscale magnetic whirls that are topologically protected and can be moved by currents, leading to the prediction of several applications. Its topological charge leads to high stability; however, it also leads to the skyrmion Hall effect. From memory storage devices, like the racetrack memory [1], to computing devices, like artificial neurons[2,3], this shortcoming is one of the primary reasons why skyrmion-based spintronic devices have yet to be achieved. Here, we study the motion of skyrmions with different topological charges and helicities. Using an effective center-of-mass description of these magnetic quasiparticles, namely, the Thiele equation, we analyze their dynamics under different gradient landscapes and interactions aiming to suppress or take advantage of the skyrmion Hall effect. Additionally, we discuss possible applications in neuromorphic computing. [1] A. Fert et al., Nature Nanotechnology 8, 152-156(2013) [2] S. Li et al., Nanotechnology 28, 31LT01 (2017) [3] I.R. de Assis et al., arXiv preprint arXiv:2209.11017 (2022).

MA 35.2 Thu 9:45 HSZ 04

Moving Antiferromagnetic Skyrmions with Spin Waves — •Michael Lau[1,2], Wolfgang Häusler[3], and Michael Thorwart[1,2] — [1]I. Institut für Theoretische Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg — [3]Institute of Physics, University of Augsburg

The possibility to move magnetic Skyrmions opens the pathway of technical applications in the form of nanoscale information carriers. While it is well-studied for ferromagnetic materials that spin waves are able to move Skyrmions, driving antiferromagnetic Skyrmions with spin waves is a relatively new topic. We present simulations on a two-dimensional lattice, with classical magnetic moments on each site, which reveal that antiferromagnetic Skyrmions can be accelerated by spin waves injected at one edge of the lattice. We consider in detail various forms of spin waves and draw connections between Skyrmion behavior and the spin wave attributes. To this end we analytically and numerically investigate classical antiferromagnetic spin waves at first. We derive a consistent analytical description of circularly- and linearly polarized spin waves and the two modes of each polarization. Using this knowledge we investigate their impact on the Skyrmion and show that the symmetries of the spin wave modes is reflected in the resulting Skyrmion motion. One example is the non-vanishing Skyrmion Hall effect for circularly polarized spin waves. It turns out that also frequency and amplitude of the spin waves significantly influence the Skyrmion motion.

MA 35.3 Thu 10:00 HSZ 04

Geometry-induced motion of magnetic skyrmions in curved ferro- and antiferromagnetic films — •Kostiantyn V. Yershov[1,2], Attila Kákay[3], and Volodymyr P. Kravchuk[2,4] — [1]Leibniz Institute for Solid State and Materials Research, Dresden, Germany — [2]Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine — [3]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, Germany — [4]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie, Germany

Here, we present the effect of the spontaneous drift of a magnetic skyrmion in curved films under the action of the curvature gradients without any external stimuli [1]. The strength of the curvature-induced driving is determined by the type of the intrinsic Dzyaloshinskii–Moriya interaction, while the trajectory is determined by the type of magnetic ordering: ferro- or antiferromagnetic. Using rigid particle approximation, we show that for the case of Néel skyrmion the driving force is linear with respect to the gradient of the curvature, while for Bloch skyrmion the driving is proportional to the product of mean curvature and its gradient. During the motion along the surface, skyrmion experiences deformation which depends on the skyrmion type. Equations of motion for Néel and Bloch magnetic skyrmions in curved ferromagnetic and antiferromagnetic materials are obtained in terms of collective variables. [1] K. Yershov et al, PRB **105** (2022), 054425.

MA 35.4 Thu 10:15 HSZ 04

Non-equilibrium dynamics of quantum skyrmion upon projective measurements — •Fabio Salvati, Andrey Bagrov, Tom Westerthout, and Mikhail I. Katsnelson — Institute for Molecules and Materials, Radboud University, Heijendaalseweg 135, 6525 AJ Nijmegen, The Netherlands

Magnetic skyrmions are particle-like spin structures characterized by nanometer size and long lifetime. These remarkable properties make them a promising candidate for the role of information carriers in magnetic information storage and processing devices.

Although considerable progress has been made in studying skyrmions in classical systems, little is known about skyrmions in quantum systems, since the quantum skyrmion state cannot be directly observed probing the local magnetization of the system. A characterization is possible using the scalar chirality - a particular local three-spin correlation function defined on neighboring lattice sites - as a quantum analog of the skyrmionic topological index.

In our work, we use the scalar chirality to investigate the local dynamics of a quantum skyrmion on a triangular lattice, following a projective measurement. Findings reveal the robustness of the quantum skyrmion state supported by spin waves. Besides we identify a feature to detect experimentally quantum skyrmions, performing the analysis of the Fourier transform of the spin-spin correlation function.

MA 35.5 Thu 10:30 HSZ 04

Nonlinear dynamics of skyrmion strings — •Volodymyr Kravchuk[1,2] and Markus Garst[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine, 03143 Kyiv, Ukraine

A skyrmion core, percolating the magnet volume, forms a skyrmion string – the topological Dirac string-like object. Here we analyze the nonlinear dynamics of a skyrmion string in a low-energy regime by means of the collective variables approach generalized for the case of strings. Using the perturbative method of multiple scales (both in space and time), we show that the weakly nonlinear dynamics of the translational mode propagating along the string is captured by the Nonlinear Schrödinger equation of the focusing type. As a result, the fundamental helix-shaped "planar-wave" solution experiences modulational instability, which leads to the formation of cnoidal waves. Both types of cnoidal waves, dn- and cn-waves, as well as the separatrix soliton solution [1], are confirmed by the micromagnetic simulations. Beyond the class of the traveling-wave solutions, we found Ma-breather propagating along the string. Finally, we proposed a generalized approach, which enables one to describe nonlinear dynamics of the modes of different symmetries, radially symmetrical, elliptical, etc.

[1] V.P. Kravchuk, U.K. Rößler, J. van den Brink, M. Garst, Phys. Rev. B 102, 220408(R) (2020).

15 min. break

MA 35.6 Thu 11:00 HSZ 04

Manipulation of Skyrmion Helicity in Frustrated Magnets — •Ross Knapman[1,2], Timon Tausendpfund[1], Sebastián A. Díaz[2], and Karin Everschor-Sitte[2,3] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [3]Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 47057 Duisburg, Germany

Aside from the well-studied mechanisms of the stabilisation of magnetic skyrmions via the Dzyaloshinskii-Moriya interaction, skyrmions can be stabilised with magnetic frustration. [1] In such a system, the helicity becomes a degree of freedom which can be manipulated using externally-applied electric and magnetic fields. [2,3] In our work, we use a Ginzburg-Landau description of the system [4] to model the dynamics of the skyrmion using analytical and numerical approaches. In tuning in the time dependences of the electric and magnetic fields, we can manipulate the energy landscape to induce interesting phenomena, including helicity rotations.

[1] Okubo, T., Chung, S., Kawamura, H., Phys. Rev. Lett. **108**,

017206 (2012)
[2] Y., X., Chen, J., Dong, S., New J. Phys. **22**, 083032 (2020)
[3] Psaroudaki, C., Panagopoulos, C., Phys. Rev. Lett. **127**, 067201 (2021)
[4] Lin, S. Z., Hayami, S., Phys. Rev. B **93**, 064430 (2016)

MA 35.7 Thu 11:15 HSZ 04

Non-synthetic antiferromagnetic multi-meronic Néel spin-textures in thin films — •Amal Aldarawsheh[1,2], Moritz Sallermann[1,3,4], Muayad Abusaa[5], and Samir Lounis[1,2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany — [3]RWTH Aachen University, 52056 Aachen, Germany — [4]Science Institute and Faculty of Physical Sciences, University of Iceland, VR-III, 107 Reykjavík, Iceland — [5]Arab American University, Jenin, Palestine

The realization of topological antiferromagnetic (AFM) solitons in real materials is a major goal towards their use in information technology. In contrast to their ferromagnetic version, they are expected to be insensitive to the Hall effect and dipolar interactions. Here, based on density functional theory in conjunction with atomistic spin dynamics, we predict the emergence in a triangular lattice of complex Néel AFM vortex-antivortex structures in transition metallic thin films interfaced with Ir and Pd layers. These topological structures are intrinsic, i.e. they form in a single AFM material, but are different from the recently predicted intrinsic AFM skyrmions [1]. They can carry various topological charges and can combine in hexameronic or dodecameronic textures, which can show enhanced stability with respect to external magnetic field depending on the electronic nature of the interfaces. [1] A. Aldarawsheh et al., ArXiv:2202.12090 (2022). Work funded by the PGSB (BMBF-01DH16027) and DFG (SPP 2137; LO 1659/8-1).

MA 35.8 Thu 11:30 HSZ 04

Investigation of the stability of exchange-stabilized skyrmions — •Sarina Lebs[1], Markus Hoffmann[1], Moritz Sallermann[1,2], and Stefan Blügel[1] — [1]Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, Jülich, Germany — [2]Science Institute of the University of Iceland, VR-III, Reykjavík, Iceland

To utilize magnetic skyrmions, localized topologically nontrivial textures, in technological applications, a long lifetime at room temperature is required. Therefore, a major focus of magnetism research is the analysis of the stability of such skyrmions. The main focus in the past was on DMI-stabilized skyrmions, little is known about exchange stabilized ones.

In this presentation, we discuss the significance of the different stabilization mechanisms for the skyrmion lifetimes. Using the Spirit code [1], we perform LLG, GNEB, as well as HTST simulations to calculate skyrmion profiles, transition paths, and lifetimes for both DMI- as well as exchange-stabilized skyrmions. We discuss similarities as well as differences between the stabilization mechanisms for the lifetime.

We acknowledge funding by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant No. 856538, project 3D MAGiC).

[1] `Spirit` – spin simulation framework, https://spirit-code.github.io

MA 35.9 Thu 11:45 HSZ 04

Lifetime of coexisting sub-10 nm zero-field skyrmions and antiskyrmions — •Moritz A. Goerzen[1], Stephan von Malottki[1,2,3], Sebastian Meyer[1,4], Pavel F. Bessarab[2,5], and Stefan Heinze[1] — [1]ITAP, University of Kiel, Germany — [2]Science Institute of the University of Iceland, Iceland — [3]Thayer School of Engineering, Dartmouth College, USA — [4]Nanomat/Q-mat/CESAM Université de Liège, Belgium — [5]Department of Physics and Electrical Engineering, Linnaeus University, Sweden

Localized spin structures such as magnetic skyrmions have raised high hopes for future spintronic devices. For many applications it can be of great advantage to have more than one particle-like texture available. The coexistence of skyrmions and antiskyrmions has been proposed in inversion symmetric magnets with exchange frustration. However, so far only model systems have been discussed and the interplay with the Dzyaloshinskii-Moriya interaction (DMI) has not been studied. Here, we predict that skyrmions and antiskyrmions with diameters below 10 nm can coexist at zero magnetic field in a Rh/Co bilayer on the Ir(111) surface. Based on an atomistic spin model parameterized from density functional theory, we show that the lifetimes of metastable skyrmions and antiskyrmions in the ferromagnetic ground state are above one hour for temperatures up to 75 K and 48 K, respectively. The entropic contribution to nucleation and annihilation rates is different for skyrmions and antiskyrmions. This opens the route to thermal control of coexisting skyrmions and antiskyrmions in frustrated magnets with DMI.