MA 2: Skyrmions I

Time: Monday 9:30–12:00 Location: HSZ 02

Invited Talk MA 2.1 Mon 9:30 HSZ 02

Two-dimensional Skyrmions in the real three-dimensional world — •Nikolai Kiselev — Institute for Advanced Simulation and Peter Grünberg Institute, Forschungsyentrum Jülich, 52425 Jülich Germany

Chiral skyrmions (CSs) emerging in noncentrosymmetric magnetic crystals are a prominent example of topological magnetic solitons – objects possessing properties of ordinary particles. In three-dimensional (3D) bulk samples, CSs usually form vortex-like strings penetrating the whole sample. Although CSs emerge as 3D objects, the two-dimensional (2D) model of a chiral magnet still represents a powerful tool for the theoretical study of CSs. In this talk, I'll present an overview of those phenomena predicted by the 2D model that found its experimental confirmation. In particular, I'll discuss the diversity of CSs with arbitrary topological charge [1] – skyrmions bags, the effect of turning skyrmions inside out [2], and the related phenomenon of skyrmion-antiskyrmion coexistence [3]. The discussion of the above phenomena is supported by a high-resolution transmission electron microscopy experiment. As an illustration of a phenomenon that cannot be described in a simplified 2D model, I'll present the theoretical and experimental study of so-called skyrmion braiding – the emergence of superstructures of skyrmion strings that wind around one another [4].

[1] F. N. Rybakov & N. S. Kiselev, Phys. Rev. B 99, 064437 (2019). [2] V. M. Kuchkin & N. S. Kiselev, Phys. Rev. B 101, 064408 (2020). [3] F. Zheng et al., Nature Phys. (2022) 18, 863 (2022). [4] F. Zheng et al., Nature Commun. 12, 5316 (2021).

MA 2.2 Mon 10:00 HSZ 02

Comparing Thiele-model computer simulations and experiments of skyrmion interactions and lattice formation — •Jan Rothörl[1], Yuqing Ge[1,2], Maarten A. Brems[1], Raphael Gruber[1], Mathias Kläui[1], and Peter Virnau[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Department of Physics, Chalmers University of Technology, Göteborg, Sweden

Magnetic skyrmions in thin films are often described as quasi-particles evolving according to the Thiele equation. Due to their effective 2D nature, their phase behavior can be compared to phase transitions described by the KTHNY theory. To allow for this analysis, we compare experimental and simulation results for skyrmion lattice formation [1] and determine skyrmion-skyrmion interaction potentials using the Iterative Boltzmann Inversion method [2]. These resulting potentials are then compared to the work describing the dependence of the kind of 2D phase transition on the shape of particle interactions [3].

[1] Zázvorka et al., Adv. Funct. Mater. 30 (46), 2004037 (2020). [2] Ge et al., arXiv:2110.14333 [cond-mat.mtrl-sci] (2021). [3] Kapfer, Krauth, Phys. Rev. Lett. 114 (3), 035702 (2015).

MA 2.3 Mon 10:15 HSZ 02

Machine learning based skyrmion detection with Kerr microscopy data — Isaac Labrie-Boulay[1], Thomas Winkler[1], Daniel Franzen[2], •Kilian Leutner[1], Alena Romanova[1], Hans Fangohr[3,4], and Mathias Kläui[1] — [1]Johannes Gutenberg University, Mainz, Institute of Physics, Staudinger Weg 7, Germany — [2]Johannes Gutenberg University, Mainz, Institute of Informatics, Staudinger Weg 9, Germany — [3]Max-Planck Institute for the Structure and Dynamics of Matter, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]University of Southampton, SO17 1BJ, Southampton, United Kingdom

Magnetic skyrmions are topologically stabilized quasi-particles and are a potential enabler for unconventional computing devices [1]. A common method for detecting skyrmions is to use a Kerr microscope. Experimental data is affected by noise, low contrast, intensity gradients, or defects. Therefore, manual data treatment is necessary to evaluate the observations. To automatize Kerr microscopy data analysis, we have used a special type of convolutional neural network, called U-Net, to determine the shapes and positions of skyrmions [2]. Different methods were used to optimize the classification and to detect the skyrmions quickly with high reliability and to minimize manual work [3]. Our approach can also be extended to other magnetic structures, such as stripe domains or vortices.

[1] Klaus Raab et al., Nat. Commun. 13, 6982 (2022)
[2] Olaf Ronneberger et al., arXiv:1505.04597 [cs.CV] (2015)
[3] Isaac Labrie-Boulay et al. (in preparation)

MA 2.4 Mon 10:30 HSZ 02

Topological Hall effect in Pd/Fe/Ir(111) induced by electron scattering on magnetic skyrmions — •Adamantia Kosma[1], Philipp Rüssmann[2,3], Stefan Blügel[3], and Phivos Mavropoulos[1] — [1]Department of Physics, National and Kapodistrian University of Athens, Panepistimioupolis 15784, Athens, Greece — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

This work comprises an ab-initio computational study of the topological Hall effect (THE) arising from magnetic skyrmions [1], which are formed in ultrathin films Pd/Fe/Ir(111) [2]. The investigation of the THE in these systems is of great importance, as it provides a way of electrically detecting magnetic skyrmions. We analyse the resistivity and the Hall angle of the system, which are calculated employing the non-collinear spin-density-functional theory within the full-potential relativistic Korringa-Kohn-Rostoker (KKR) Green function method combined with the semiclassical Boltzmann transport equation [3,4]. We discuss the dependence of the THE on additional electron scattering, modelled as random disorder broadening. Our findings predict a strong dependence of the topological Hall angle on the degree of disorder of a sample. [1] D. Maccariello et al., Nature Nanotechnology, vol. 13, 233-237 (2018). [2] N. Romming et al., Science, vol. 341, 6146, 2013. [3] https://jukkr.fz-juelich.de/. [4] A. Kosma et al., Phys. Rev. B, vol. 102, 144424.

15 min. break

MA 2.5 Mon 11:00 HSZ 02

Observation of the sliding mode of the magnetic texture in Fe/Ir(111) — •Wulf Wulfhekel[1], Hung-Hsiang Hang[1], Louise Desplat[2], Volodymyr Kravchuk[1], Marie Hervé[3], Timofey Balashov[4], Philipp Markus[1], Markus Garst[1], and Bertrand Dupé[5] — [1]Karlsruhe Institute of Technology, Karlsruhe — [2]IPCMS, Université de Strasbourg, Strasbourg — [3]Université Sorbonne, Paris — [4]RWTH Aachen, Aachen — [5]Université de Liège, Liège

The fourfold non-collinear spin texture of Fe on the sixfold surface of Ir(111) is known to be incommensurate along one of the diagonals of the unit cell, while it is commensurate along the other. As the periodicity of the spin texture is only a few atoms, the magnetic energy of the structure experiences the atomic lattice rather strongly. Theoretically, the sliding mode of the spin texture with respect to the crystal lattice becomes gapped in the commensurate direction while it stays soft along the incommensurate one. We report on a combined theoretical and experimental study of the sliding mode along the soft direction excited by microwave fields in the junction of a spin-polarized STM.

MA 2.6 Mon 11:15 HSZ 02

Chemical pressure tuning of a skyrmion lattice with giant topological Hall effect — •Leonie Spitz[1,2], Max Hirschberger[1], Shang Gao[1], Taro Nakajima[1,3], Christian Pfleiderer[2], Takahisa Arima[1,4], and Yoshinori Tokura[1] — [1]RIKEN CEMS, Wakoshi, Saitama 351-0198, Japan — [2]Physik-Department, Technical University of Munich, 85748 Garching, Germany — [3]Institute for Solid State Physics, University of Tokyo, Kashiwa 277-8581, Japan — [4]Department of Advanced Materials Science, University of Tokyo, Kashiwa, Chiba 277-8561, Japan

A skyrmion lattice accompanied by a large topological Hall effect was found in the centrosymmetric frustrated triangular lattice magnet Gd_2PdSi_3 [1]. In contrast to non-centrosymmetric compounds, the skyrmion spin-vortices are not stabilized by the Dzyaloshinskii-Moriya interaction, but rather by exchange frustration and the Ruderman-Kittel-Kasuya-Yosida interaction [2,3]. The nanometer-scale size of the skyrmions is a further novelty giving rise to a large emergent magnetic field. We study the effect of isoelectronic doping on Gd_2PdSi_3 to gain a deeper understanding of the material's magnetic and electronic properties. Via alloying we manipulate the lattice constants and polytypism of the structure [4]. We report the impact of chemical pressure tuning on the magnetic order and the topological Hall effect.

[1] T. Kurumaji, et al., Science 365, 914-918 (2019) ; [2] T. Okubo, et al., Phys. Rev. Lett. 108, 017206 (2012) ; [3] A. O. Leonov, et al., Nat. Commun. 6, 8275 (2015) ; [4] L. Spitz, et al., J. Am. Chem. Soc. 144, 16866-16871 (2022).

MA 2.7 Mon 11:30 HSZ 02

Relationship of charge and spin density waves in the skyrmion compound $EuGa_2Al_2$ — •Steven Gebel[1], Jaime Moya[2], Jochen Geck[1], and Marein Rahn[1] — [1]Institute for Solid State and Materials Physics, Technical University of Dresden, 01062 Dresden, Germany — [2]Department of Physics and Astronomy, Rice University, Houston, TX, 77005, USA

The interplay of spin and charge density waves (SDW/CDW) in rare earth intermetallics is a matter of great interest, since it may reveal a recipe of how to taylor an antiferromagnet to yield certain topological properties. The centrosymmetric skyrmion host series $Eu(Ga,Al)_4$ provides an ideal setting to explore this scenario: The electronic structure can be tuned by chemical and hydrostatic pressure, which induces CDWs, which, in turn, determine a landscape of frustrated itinerant electronic correlations. To clarify the origin and character of such nesting instabilities, we studied subtle structural variations with temperature and pressure, and related them to density functional structure calculations. As magnetic structure determinations of more members of the series become available, this may explain exactly which factors toggle the magnetism's topological character.

MA 2.8 Mon 11:45 HSZ 02

Influence of interlayer Dzyaloshinskii-Moriya interactions on magnetic textures — •Elena Vedmedenko — University of Hamburg

An overview of magnet/non-magnetic metal/magnet trilayers with strong interlayer Dzyaloshinskii-Moriya interactions promoting out-of-plane as well as in-plane chirality between the magnetic layers will be presented [1-2]. Magnetic structuring in systems with the interlayer as well as intralayer Dzyaloshinskii-Moriya interactions will be discussed. An emphasis on the topological stability of those objects will be made.

1. A. Fernandez-Pacheco, E. Y. Vedmedenko et al., Symmetry-breaking interlayer Dzyaloshinskii* Moriya interactions in synthetic antiferromagnets, Nature Mat. 18, 679 (2019)

2. J. A. Arregi, P. Riego, A. Berger, and E. Y. Vedmedenko, Large Interlayer Dzyaloshinskii-Moriya interactions across Ag-layers, submitted.