MA 54: Spin Hall Effects and Skyrmions II

Time: Thursday 15:00–18:00 Location: HSZ 04

MA 54.1 Thu 15:00 HSZ 04

Dzyaloshinkii-Moriya Iinteraction and Hall Effects in Disordered Bulk Chiral Magnets From First Principle Calculations — •Jacob Gayles[1], Frank Freimuth[2], Charles Spencer[3], Rembert Duine[4], Chris Marrows[3], Yuriy Mokrousov[2], Stefan Blügel[2], and Jairo Sinova[1] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz, D-55099 Mainz, Germany — [2]Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [3]Institute for Theoretical Physics, Utrecht University, Leuvenlaan 4, 3584 CE Utrecht, The Netherlands — [4]School of Physics & Astronomy, University of Leeds, Leeds LS2 9JT, United Kingdom

We demonstrate that the electron dynamics in the skyrmion phase of Fe-rich MnFeGe and FeCoGe alloys is governed by Berry phase physics. We observe that the magnitude of the Dzyaloshinskii-Moriya interaction, directly related to the mixed space-momentum Berry phases, changes sign and magnitude with concentration x in direct correlation with the data of Shibata et al., Nature Nanotech. 8, 723 (2013). The computed anomalous and topological Hall effects in FeGe are also in good agreement with available experiments. We further develop a simple tight-binding model able to explain these findings. We show that the adiabatic Berry phase picture is violated in the Mn-rich limit of the alloys. Lastly, we make connections between experiment and computation in disordered regime.

MA 54.2 Thu 15:15 HSZ 04

Skyrmions and magnetic singularities in confined geometries — •Gideon P. Müller, Nikolai S. Kiselev, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Interest in chiral magnetic skyrmions is rising because they are suggested as new information carriers in spintronic devices, such as the skyrmion racetrack. This necessitates a deep understanding of the mechanism of skyrmion nucleation and anihilation in these systems. We apply the recently proposed geodesic nudged elastic band method to explore different skyrmion nucleation/annihilation mechanisms in the systems by analysing corresponding minimum energy paths (MEPs) and energy barriers. We compare such MEPs for skyrmion nucleation with different geometries, in particular thin films, nanostripes and nanowires. For the case of nanowires in a certain range of material parameters we found stable particle-like objects composed of coupled magnetic singularities known as Bloch points. The discovery of this effect can have potential application in spintronics.

MA 54.3 Thu 15:30 HSZ 04

Edge instabilities and skyrmion creation in magnetic layers — •Jan Müller[1], Achim Rosch[1], and Markus Garst[2] — [1]Institut für Theoretische Physik, Universität zu Köln, D-50937 Köln, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

We study both analytically and numerically the edge of two-dimensional ferromagnets with Dzyaloshinskii-Moriya (DM) interactions, considering both chiral magnets and magnets with interface-induced DM interactions. We show that in the field-polarized (FP) ferromagnetic phase magnon states exist which are bound to the edge, and we calculate their spectra within a continuum field theory. Upon lowering an external magnetic field, these bound magnons condense at a finite momentum and the edge becomes locally unstable. Micromagnetic simulations demonstrate that this edge instability triggers the creation of a helical phase which penetrates the FP state within the bulk. A subsequent increase of the magnetic field allows to create skyrmions close to the edge in a controlled manner.

MA 54.4 Thu 15:45 HSZ 04

Skyrmion-Antiskyrmion pair creation by in-plane currents — •Martin Stier[1], Wolfgang Häusler[2], Thore Posske[1], Gregor Gurski[1], and Michael Thorwart[1] — [1]Universität Hamburg, Germany — [2]Universität Augsburg, Germany

Magnetic Skyrmions are considered to be topologically protected particles. Due to this stability, their small size and the possibility to move them by low electric currents they are proper candidates for spintronic devices. However, without violating this topological protection, it is should be possible to create Skyrmion-Antiskyrmion pairs as long as the total Skyrmion number does not change. In fact, we derive a Skyrmion equation of motion and show that electric currents can create such Skyrmion-Antiskyrmion pairs. By this equation of motion we are able to give general prerequisites for this pair creation process. We confirm these results by numerical simulations. On a lattice, where topological protection gets imperfect, the Antiskyrmions in these pairs can be destroyed and only the Skyrmions remain. This eventually changes the total Skyrmion number and yields new ways of creating and controlling Skyrmions.

MA 54.5 Thu 16:00 HSZ 04

Skyrmion Hall Effect Revealed by Direct Time-Resolved X-Ray Microscopy — •Kai Litzius[1,2,3], Ivan Lemesh[4], Benjamin Krüger[1], Pedram Bassirian[1], Lucas Caretta[4], Kornel Richter[1], Felix Büttner[4], Koji Sato[5], Oleg A. Tretiakov[5,6], Johannes Förster[3], Robert M. Reeve[1], Markus Weigand[3], Iuliia Bykova[3], Hermann Stoll[3], Gisela Schütz[3], Geoffrey S. D. Beach[4], and Mathias Kläui[1,2] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, 55128 Mainz, Germany — [3]Max Planck Institute for Intelligent Systems, 70569 Stuttgart, Germany — [4]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [5]Tohoku University, Sendai 980-8577, Japan — [6]School of Natural Sciences, Far Eastern Federal University, Vladivostok

Magnetic skyrmions are topologically stabilized nanoscale spin structures that show promise for future spintronic devices if they can be moved reliably. Employing scanning transmission x-ray microscopy, we demonstrate reproducible skyrmion trajectories at room temperature in ultrathin multilayer films driven by spin orbit torques [1]. We identify a sizeable skyrmion Hall effect that depends on the velocity, which is not captured using the previously used rigid skyrmion model. We explain our observation based on eigenmode excitations that deform the skyrmion during motion [1].

[1] K. Litzius et al., Nature Physics (in press 2016), arxiv:1608.07216.

15 min. break.

MA 54.6 Thu 16:30 HSZ 04

Impact of the chemical nature of defects on the pinning of magnetic skyrmions. — •Imara L. Fernandes, Juba Bouaziz, Stefan Blügel, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Owing to their topology, magnetic skyrmions are considered as potential particles for future information technology. The low current densities estimated to move them in a racetrack memory promises devices of low energy consumption. One issue that is currently discussed is the speed of skyrmions. Experiments indicate that skyrmions are more than one order of magnitude slower than domain walls. In a device, skyrmions interact with defects, affecting their creation, stability and motion. Following our previous study [1], we investigate purely from a full *ab initio* description based on density functional theory (DFT) the impact of 3d and 4d impurities on the energetics, electronic and magnetic properties of realistic nano-skyrmions created in Pd/Fe/Ir(111) substrate. With a careful analysis of the hybridization of the electronic states, we identify the important mechanisms behind the expulsion or pinning of single magnetic skyrmions as function of the chemical nature of the impurities that translate on a bigger picture to an energy landscape with attractive and repulsive potentials determining the skyrmion motion.

[1] D.M. Crum *et al.*, Nat. Comms. **6**, 8541 (2015).

Funding provided by the ERC-consolidator grant Dynasore and CNPq (Brazil).

MA 54.7 Thu 16:45 HSZ 04

Hydrogen-Induced Skyrmions in Ultrathin Iron Films — •Pin-Jui Hsu, Lorenz Schimdt, Aurore Finco, Niklas Romming, Andre' Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — Department of Physics, University of Hamburg, Germany

Chiral magnetic states, such as chiral domain walls, spin spirals, and magnetic skyrmions, have recently been observed in magnetic films on heavy metal substrates due to a sizable interfacial Dzyaloshinskii-Moriya (DM) interaction and a lack of spatial inversion symmetry at surfaces and interfaces. In the present work, we report on the emergence of individual magnetic skyrmions by dosing atomic hydrogen onto Fe double-layers (Fe-DL) grown on Ir(111). A spin spiral ground state was recently found for clean pseudomorphic Fe-DL with a rather short period of about 1.3 nm, which remains stable up to 9 T out-of-plane field without transition to a skyrmionic state [1]. After introducing atomic hydrogen, the pseudomorphic strained Fe-DL exhibits a p(2x2)-structure and a spin spiral ground state in zero field with an increased periodicity of up to 4.0 nm. Upon application of an external out-of-plane magnetic field, isolated magnetic skyrmions appear on the hydrogenated Fe-DL as directly observed by in-situ SP-STM measurements. Hydrogenation of magnetic thin films therefore appears as an interesting alternative for tuning the properties of chiral non-collinear spin textures, besides magnetic multilayer technologies.[1] P.-J. Hsu, A. Finco, L. Schmidt, A. Kubetzka, K. v. Bergmann, R. Wiesendanger, Phys. Rev. Lett. 116, 017201 (2016)

MA 54.8 Thu 17:00 HSZ 04

Theory of inelastic electron scattering by spin waves in noncollinear magnets — •Flaviano José Dos Santos, Manuel Dos Santos Dias, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52428 Jülich, Germany

Electron Energy Loss Spectroscopy is an invaluable tool for probing the spin wave excitations of thin ferromagnetic films [1]. However, to our knowledge no EELS experiment has been attempted for antiferromagnetic or non-collinear magnetic systems. With the aim to characterize the spin wave excitations in novel magnetic phases of matter, we developed and implemented a quantum mechanical description of inelastic electron scattering for arbitrary magnetic structures, using information from first principles calculations. We discuss the role of the spin polarization of the incoming and outgoing electrons, and the contribution from the four possible scattering channels to the inelastic cross-section. We illustrate the formalism for three model systems: a ferromagnet with Dzyaloshinksii-Moriya interaction, its spin spiral counterpart, and a skyrmionic lattice. For the latter we also make use of first-principles calculations for the experimentally well-characterized Pd/Fe/Ir(111) bilayer [2,3].

This work is supported by the HGF-YIG Programme VH-NG-717 (Funsilab) and by the Brazilian funding agency CAPES.

References: [1] Ibach, H., Surf. Sci. 630, 301-310 (2014) [2] Romming, N., et al. Phys. Rev. Lett. 114, 177203 (2015) [3] Crum, D., et al. Nat. Commun. 6, 8541 (2015)

MA 54.9 Thu 17:15 HSZ 04

Spin Pumping And Inverse Spin-Hall Effect In PEDOT:PSS — •Mohammad Qaid[1], Tim Richter[1], Alexander Müller[1], Christoph Hauser[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, 06120 Halle — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich Damerow Straße 4, 06120 Halle

Recently the inverse spin-Hall effect in conducting polymers was measured [1,2]. Here we present a study of spin pumping and ISHE in hybrid structures composed of thin film yttrium-iron garnet (YIG) and PEDOT:PSS and Pt contacts. Our experiments indicate an ISHE indeed exists but is much smaller than previously published. Control experiments show that spin pumping through the PEDOT:PSS can be highly efficient and massive artifacts can occur due to ISHE in the electrical contacts. Large magnon propagation lengths in the YIG can induce spin pumping far away from the excitation source and underneath the contacts. Only for dedicated geometries it is possible to prevent these artifacts and to quantify the ISHE in the conducting polymer. We will discuss the ISHE and also strategies to avoid a number of highly relevant artefacts which have exactly the same signature as the ISHE.

References
1.K. Ando, et al., Nat. Mater. 12, 622 (2013)
2.D. Sun, et al., Nat. Mater.15, 863 (2016)

MA 54.10 Thu 17:30 HSZ 04

Magnetic and chiral properties of epitaxial Pt/Co$_n$/Ir(111) films investigated by SP-STM — •Marco Perini, André Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — Department of Physics, University of Hamburg, D-20355 Hamburg, Germany

Magnetic skyrmions are promising candidates for future spintronics technology. They have been recently observed at room temperature with different techniques in cobalt-based multilayered thin films [1,2]. The cobalt layer is placed between two heavy metals to provide a strong interfacial Dzyaloshinskii-Moriya interaction (iDMI). However, the details of the spin structure in these films remain elusive due to the limited spatial resolution of the applied techniques.

In this work we performed low-temperature spin-polarized scanning tunneling microscopy (SP-STM) on epitaxially grown Co/Ir(111) and Pt/Co/Ir(111) ultrathin films. We observe large-scale magnetic domains, on the order of hundreds of nanometers, separated by sharp domain walls, only a few nanometers wide. We show that these walls possess a unique rotational sense, a sign of a strong DMI at the Co/Ir interface, which produces Néel-type domain walls. In addition, measuring the domain wall width as a function of Co and Pt thickness provides information on the magnetic parameters of these systems, such as A, K and D.

[1] Moreau-Luchaire et al., Nat. Nano. 11, 444-448 (2016), [2] Boulle et al., Nat. Nano. 11, 449-454 (2016)

MA 54.11 Thu 17:45 HSZ 04

Magnetic skyrmions in Pt/Co/Ir at zero field — •Jochen Wagner[1], Robert Frömter[1], Kai Bagschik[1], André Philippi-Kobs[2], Rustam Rysov[2], Leonard Müller[2], Gerhard Grübel[2], and Hans Peter Oepen[1] — [1]Institut für Nanostruktur- und Festkörperphysik, Uni Hamburg, Germany — [2]DESY, Hamburg, Germany

X-ray holographic microscopy (XHM) has become a competitive technique to investigate magnetic domain patterns with sub-20-nm spatial resolution exploiting the x-ray magnetic circular dichroism [1].

We employed XHM to study a wedge-grown $(Pt_{1nm}/Co_{0-2nm}/Ir_{1nm})_6$ multilayer. The absence of inversion symmetry yields a strong interfacial Dzyaloshinskii-Moriya interaction (DMI), which causes domain walls to be Néel like – in contrast to Pt/Co/Pt, where Bloch walls are expected. As a further, the consequence stabilization of skyrmionic bubbles and even skyrmion lattices through magnetic fields has been reported recently [2].

In the demagnetized state, we find the maze domain pattern with cobalt-thickness dependent domain sizes ranging from 100 nm to a few microns. In addition, circular domains of about 30 nm diameter are observed, unlike in symmetrical systems like Pt/Co/Pt. With the strong DMI present, these bubble domains can be considered as skyrmions. The skyrmions can be deleted by fully saturating the sample, and reappear after another demagnetization cycle. We assume therefore local defects to be responsible for their creation and zero-field stability.

[1] D. Stickler, et al., Appl. Phys. Lett. 96, 042501 (2010).
[2] C. Moreau-Luchaire et al., Nature Nanotech 11, 444-448 (2016).