TT 14: Surface Magnetism – Skyrmions (jointly with MA, O)

Time: Monday 9:30–12:45 Location: EB 301

TT 14.1 Mon 9:30 EB 301

Dynamics of spin spirals and skyrmions in temperature gradient — •Rocio Yanes, Denise Hinzke, and Ulrich Novak — Universität Konstanz, Konstanz, Germany

Recently, Dzyaloshinskii-Moriya (DM) interaction has attracted attention in magnetism since it can lead to the formation of skyrmions and spin spirals with promising applications in spintronics [1,2]. Furthermore, it has been shown that temperature gradients can cause magnonic spin currents and with that spin transfer torques leading to a movement of a domain wall in a magnetic nanowire [3,4]. In this work, we combined both topics to analyze the dynamics of two dimensional non-collinear magnetic textures subject to a temperature gradient.

Numerical calculations of the dynamics of helical spin spiral (HSS), skyrmion lattices and isolated skyrmions are carried out for different values of the temperature gradient and damping parameter. Our results show that the HSS moves towards the hotter area driven by the temperature gradient. The velocity of this movement is asymmetric with respect to the sign of the temperature gradient due to the effect of the DM interactions. We observe a clear difference between the movement of isolated skyrmions and skyrmion lattices. While in the first case, the skyrmion motion is determine by the temperature gradient and the Magnus force, in the case of a lattice of skyrmions the interaction between skyrmions plays a fundamental role.

[1] A. Fert et al. Nature Nanotech., 8, 152, (2013). [2] N. Nogoasa et al., Nature Nanotech., 8, 899 (2013). [3] D. Hinzke and U. Novak, PRL, 107, 027205 (2011). [4] Schlickeiser et al., PRL, 113, 097201 (2014).

TT 14.2 Mon 9:45 EB 301

Interlayer Exchange Coupling: A route to stabilize skyrmions in magnetic multilayers — •Ashis K. Nandy, Nikolai S. Kiselev, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Magnetic skyrmion is a topologically nontrivial spin texture with particle like properties, which may emerge quite generally under an applied magnetic field of appropriate strength in any magnetic thin layer or multilayer with surface or interface induced Dzyaloshinskii-Moriya interaction (DMI). DMI chooses chirality i.e. the proper sense of rotation of spins [1]. However, the required magnetic field to stabilize skyrmions can be excessively large. We present a multiscale approach based on DFT calculations and atomistic spin-dynamic simulations, which allows us to stabilize skyrmions in magnetic multilayers even at zero magnetic field. It is based on fine tuning the interplay between internal and interfaces induced interactions by adjusting the thicknesses and interface compositions of multilayers. Our approach predicts the existence of a skyrmion lattice as well as isolated skyrmions in a thin film of a transition-metal monolayer grown on a heavy metal substrate. The simulated skyrmions exhibit high stability in an applied magnetic field and temperature. We provide a description for the complex phases occurring in such systems and present a magnetic phase diagram for a prototype example of Mn/W(001).

[1] M. Bode *et al.*, Nature **447**, 190 (2007).

TT 14.3 Mon 10:00 EB 301

Observation of spin transfer torques in the transverse magnetic susceptiblity of the Skyrmion lattice phase of MnSi — •Felix Rucker, Christoph Schnarr, Andreas Bauer, Alfonso Chacon, Philipp Köhler, and Christian Pfleiderer — Lehrstuhl für Topologie korrelierter Systeme, Technische Universität München, Garching, Germany

In the skyrmion lattice phase of MnSi the observation of sizeable spin transfer torques [1-3] in small angle neutron scattering and the Hall resistivity for current densities already five orders of magnitude smaller as compared to conventional magnetic materials promises easy experimental access to the precise qualitative and quantitative form of the Landau Lifshitz Gilbert equation. We report measurements of the transverse magnetic susceptibility, $\chi_\perp$, in the skyrmion lattice phase of MnSi. As our main result we find a distinct increase of $\chi_\perp$ with increasing current density around the critical current density j_c. We discuss the broader implications of our experimental findings, which provide, for the first time, a direct link between a thermodynamic property and the effects of spin transfer torques in skyrmion lattices.

[1] F. Jonietz et al., Science **330**, 1648 (2010)
[2] T. Schulz et al., Nat. Phys. **8**, 301 (2012)
[3] K. Everschor et al., Phys. Rev. B **86**, 054432 (2012)

TT 14.4 Mon 10:15 EB 301

Magnetic skyrmions stabilized at zero field — •Nikolai S. Kiselev[1], Ashis K. Nandy[1], Changhoon Heo[2], Theo Rathing[2], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Molecules and Materials, Radboud University Nijmegen, 6525 AJ Nijmegen, Netherlands

Magnetic skyrmions may appear as a metastable state in thin magnetic layers at zero magnetic field within certain range of Dzyaloshinskii-Moriya interaction and the uniaxial anisotropy. We present a comprehensive theoretical study of the statics and dynamics of such skyrmions. Important feature of this solution is a coexistence of two type of skyrmion solutions characterized by opposite polarity and opposite topological charge. We consider such skyrmions as a conceptually new approaches in data storage where switching between two of such skyrmion states is provided by sort magnetic field pulse. We discuss complex mechanism of such switching. The role of field pulse duration, damping, size and shape of host system are discussed in details. Our results are based on stochastic spin dynamics simulation applied to an extended Heisenberg model for different type of crystal lattices.

TT 14.5 Mon 10:30 EB 301

Emergent electrodynamics in $Mn_{1-x}Fe_xSi$ — •Christoph Schnarr, Felix Rucker, Christian Franz, Robert Ritz, Andreas Bauer, and Christian Pfleiderer — Lehrstuhl für Topologie korrelierter Systeme, Technische Universität München, Garching, Germany

The emergent electrodynamics of the skyrmion lattice phase in chiral magnets comprise of an emergent magnetic field of one flux quantum per skyrmion that gives rise to an emergent electric field, when the skyrmion lattice moves under the application of spin currents exceeding a critical current density j_c [1,2]. We report a study of the emergent electrodynamics in $Mn_{1-x}Fe_xSi$, where we exploit a well understood increase of the topological Hall resistivity by an order of magnitude with increasing Fe concentration [3]. On the one hand, this allows us to track j_c for increasing emergent magnetic field in the presence of increasing disorder. On the other hand, we observe evidence for emergent electric fields even in the magnetoresistance, reflecting, in combination with the emergent electric field in the Hall signal, the direction of motion of the skyrmion lattice.

[1] F. Jonietz et al., Science **330**, 6011, 1648-1651 (2010)
[2] T. Schulz et al., Nature Physics **8**, 4, 301-304 (2012)
[3] C. Franz et al., Physical review letters **112**, 18, 186601 (2014)

15 min. break

TT 14.6 Mon 11:00 EB 301

Advanced characterization of helical spin structures and domains in Skyrmion systems — •Peggy Schönherr[1], Antoine Dussaux[1], Naoya Kanazawa[2], Yoshinori Tokura[2], Christian Degen[1], Manfred Fiebig[1], and Dennis Meier[1] — [1]ETH Zürich, 8093 Zürich, Switzerland — [2]University of Tokyo, 113-8656 Tokyo, Japan

Magnetic whirls, so-called Skyrmions, emerge in various chiral magnets and attract tremendous attention due to their exotic properties. Skyrmions can, e.g., be moved at ultra-low current densities and give rise to the topological Hall Effect. Much less is known about the magnetic phases that surround the Skyrmion state, including fundamental aspects such as the domain formation and spin-defect interactions. The fragmented knowledge is partially due to the challenging experimental access and the general difficulty to image antiferromagnetic order at the nanoscale. Here, we show how helical magnetic structures in the Skyrmion system FeGe emerge and transform as a function of temperature and magnetic field. We discuss the magnetic field-driven response of multi-domain states, the influence of defects, as well as fingerprints of spontaneous jump-like movements of the periodic spin arrangement. The results are gained near room temperature using magnetic force microscopy (MFM) and diamond nitrogen-vacancy center microscopy. Besides providing new insight to the physics of Skyrmion materials, our results foreshadow a promising pathway for measuring complex spin textures with high spatial and temporal resolution.

TT 14.7 Mon 11:15 EB 301

Field-dependent Size and Shape of Single Magnetic Skyrmions — •Niklas Romming, André Kubetzka, Christian Hanneken, Kirsten von Bergmann, and Roland Wiesendanger — Department of Physics, University of Hamburg, 20355 Hamburg, Germany

Skyrmions are spatially localised solitonic magnetic whirls with axial symmetry and fixed rotational sense. They have recently been observed in both non-centrosymmetric bulk crystals and in ultrathin transition metal films on heavy-element substrates as a result of sizable Dzyaloshinskii-Moriya interactions. In addition to their protected topology and nano-scale size, skyrmions can easily be moved by lateral spin currents and written as well as deleted by vertical spin-current injection. Here we use spin-polarised scanning tunnelling microscopy to directly reveal the field-dependent internal spin structure of individual skyrmions in a biatomic PdFe layer on Ir(111) [1] with atomic-scale precision. An analytical expression for the description of skyrmions is proposed, which can establish a connection between the original work - predicting magnetic skyrmions - and their experimentally determined magnetic-field dependent size and shape. Thus, the relevant material parameters responsible for skyrmion formation can be determined. [1] N. Romming et al., Science 341, 636 (2013).

TT 14.8 Mon 11:30 EB 301

Spin dynamics of spin-orbit coupled dimers on Pt(111) — •Manuel dos Santos Dias and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany

The interaction between two magnetic adatoms becomes anisotropic in the presence of strong spin-orbit coupling (SOC). The broken inversion symmetry at the surface leads in particular to the Dzyaloshinksii-Moriya interaction, enabling chiral magnetic ground states. We study the impact of this interaction on the spin dynamics of magnetic dimers (e.g. Fe) on the Pt(111) surface, in connection to possible inelastic scanning tunneling spectroscopy (ISTS) experiments [1]. We employ our recently developed time-dependent density functional theory including SOC, based on the Korringa-Kohn-Rostoker Green function approach. An extension of our theoretical ISTS method [2] to incorporate SOC is in progress.

Work funded by the HGF-YIG Programme FunSiLab - Functional Nanoscale Structure Probe and Simulation Laboratory (VH-NG-717).

[1] A. A. Khajetoorians et al., Phys. Rev. Lett. **111**, 157204 (2013)
[2] B. Schweflinghaus et al., Phys. Rev. B **89**, 235439 (2014)

TT 14.9 Mon 11:45 EB 301

First-principles study of confined magnetic skyrmions in Pd/Fe/Ir(111) — •Dax Michael Crum[1,2], Benedikt Schweflinghaus[1], Mohammed Bouhassoune[1], Juba Bouaziz[1], Stefan Blügel[1], and Samir Lounis[1] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany — [2]Microelectronics Research Center, The University of Texas at Austin, Austin Texas, 78758 USA

We investigate for the first time confined skyrmionic magnetic defects in an otherwise ferromagnetic thin film from first-principles. The system of choice is Pd/Fe on Ir(111) [1,2]. Utilizing the full-potential relativistic Korringa-Kohn-Rostoker Green functions formalism, we investigate in real-space the energetics of creating single chiral magnetic textures purely from *ab initio*. We find that the nano-skyrmion structures become energetically more favorable with increasing size. We interpret the results by extracting the tensors of magnetic exchange interactions and modeling the system within an extended Heisenberg Hamiltonian, where the Dzyaloshinskii-Moriya interaction plays a key role. We also investigate the theoretical scanning tunneling microscopy spectra by analysing the local density of states in vacuum near the skyrmion surface and make connection to available experiments [1].

This work is supported by the HGF-YIG Programme VH-NG-717 (Functional Nanoscale Structure and Probe Simulation Laboratory – Funsilab) and the US National Science Foundation (NSF).

[1] Romming *et al.*, Science **341**, 636 (2013).
[2] B. Dupé *et al.*, Nature Communications **5**, 4030 (2014).

TT 14.10 Mon 12:00 EB 301

Energy-dependent magnetic contrast of a nanoscale spin helix measured by STM — •Safia Ouazi, Soo-Hyon Phark, Jeison A. Fischer, Dirk Sander, and Jürgen Kirschner — Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany

Helical spin order has been revealed for Fe bilayer islands on Cu(111) by spin-polarized scanning tunneling spectroscopy (SP-STS) in a magnetic field at 10 K [1]. We measure the magnetic contrast, as given by the difference in differential conductance for states with and without spin helix [1], as a function of the gap voltage applied between tip and sample. Thus, we obtain the first spatially- and energy-resolved map of spin contrast for a nanoscale spin spiral. The wave vector describing the helical spin order remains constant in the energy range -0.8eV to +0.5eV, whereas the spin contrast shows a strong modulation. This result identifies a novel aspect of SP-STM to characterize complex spin order with respect to the corresponding electronic band structure. We discuss the results in view of a partial energy gap associated with the non-collinear spin order.

[1] S.-H. Phark, J.A. Fischer, M. Corbetta, D. Sander, K. Nakamura, J. Kirschner, Nat. Commun. 5:5183 doi:10.1038/ncomms6183 (2014).

TT 14.11 Mon 12:15 EB 301

A Magnetic Nano-Skyrmion Lattice observed in a Si-wafer based Multilayer System — •Stefan Krause[1], Anika Schlenhoff[1], Philipp Lindner[1], Johannes Friedlein[1], Roland Wiesendanger[1], Michael Weinl[2], Matthias Schreck[2], and Manfred Albrecht[2] — [1]Department of Physics, University of Hamburg, Germany — [2]Institute of Physics, University of Augsburg, Germany

Recently, an atomic-scale two-dimensional magnetic skyrmion lattice at the Fe/Ir(111) interface has been discovered using spin-polarized scanning tunneling microscopy (SP-STM).[1] Skyrmions offer new exciting possibilities for spintronic applications, using them as digital information carriers. For these applications the mass production of devices using multilayer growth on large-scale substrates is indispensable.

In 2009, the heteroepitaxial growth of single crystal Ir(111) films on Si(111) wafers with yttria-stabilized zirconia buffer layers has been demonstrated.[2] For our study we epitaxially grow one monolayer of Fe on top of this multilayer substrate. The SP-STM experiments reveal a magnetic skyrmion lattice, being fully equivalent to the magnetic ground state that has previously been observed on an Ir(111) bulk single crystal substrate. In addition, it is found to be robust against local atomic lattice distortions induced by multilayer preparation. Our work paves the way towards spintronic applications of nano-skyrmions in ultrathin films and multilayer systems.

[1] S. Heinze *et al.*, Nature Physics **7**, 713 (2011).
[2] S. Gsell *et al.*, J. Cryst. Growth **311**, 3731 (2009).

TT 14.12 Mon 12:30 EB 301

Tailoring a Spin Spiral by Uniaxial Strain — •Pin-Jui Hsu, Aurore Finco, Lorenz Schmidt, Andre Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — Department of Physics, Hamburg Univerisyt, 20355 Hamburg, Germany

Spin spirals typically result from competing magnetic interactions. In the presence of a sizable Dzyaloshinskii-Moriya (DM) interaction, the spin spirals exhibit a unique rotational sense and their periodicity is governed by the ratio of the exchange and DM-interaction strength. Spin-polarized scanning tunneling microscopy (SP-STM) experiments have already revealed several examples of cycloidal and conical spin spiral states in ultrathin films of magnetic transition metals (e.g. Fe, Mn, Cr) on heavy-element substrates (e.g. W, Ir). Here, we report on a SP-STM study on two monolayers of Fe on Ir(111) where a regular dislocation line structure with a periodicity of 3.71 ± 0.47 nm is observed due to the strain relief of bcc(110) Fe grown epitaxially on the Ir(111) substrate. SP-STM reveals the presence of cycloidal spin spirals with a period of 1.82 ± 0.15 nm which are guided by the dislocation lines to form a well-defined spin-ordered state. These ordered spin spirals form an undulating pattern perpendicular to the dislocation lines wiggling with an angle of about 155^o, indicating an interaction between structural relaxation and the observed spin structure, particularly along the three symmetrically equivalent crystallographic axes. In contrast, a disordered spin spiral state, which locally exhibits a period of 1.38 ± 0.22 nm is observed in the regions without dislocation lines.