MA 34: Magnetic textures: Transport and dynamics II

Time: Wednesday 15:00–19:00 Location: H37

Invited Talk MA 34.1 Wed 15:00 H37

Reservoir Computing with Random Skyrmion Fabrics — •Daniele Pinna[1], George Bourianoff[2], and Karin Everschor-Sitte[1] — [1]Johannes Gutenberg Universität Mainz Institute of Physics TWIST Group Staudingerweg 7 D 55128 Mainz — [2]Intel Corp., retired

In this talk we will discuss how a random skyrmion "fabric" composed of skyrmion clusters embedded in a magnetic substrate can be effectively employed to implement a functional Reservoir Computing device for recognizing and predicting spatio-temporal events. This is achieved by leveraging the nonlinear resistive response of the individual skyrmions arising from their current dependent anisotropic magneto-resistance effect (AMR). Complex time-varying current signals injected via contacts into the magnetic substrate are shown to be modulated nonlinearly by the fabric's AMR due to the current distribution following paths of least resistance as it traverses the geometry. By tracking resistances across multiple input and output contacts, we show how the instantaneous current distribution effectively carries temporally correlated information about the injected signal. This in turn allows us to numerically demonstrate simple pattern recognition. We argue that the fundamental ingredients for such a device to work are three-fold: i) Concurrent probing of the magnetic state; ii) stable ground state when forcings are removed; iii) nonlinear response to input forcing. Whereas we demonstrate this by employing skyrmion fabrics, the basic ingredients should be general enough to spur the interest of the greater magnetism and magnetic materials community to explore novel reservoir computing systems.

MA 34.2 Wed 15:30 H37

Insight into enhanced stability of nanoscale magnetic skyrmions — •Anastasiya S. Varentsova[1], Stephan von Malottki[3], Grzegorz Kwiatkowski[2], Stefan Heinze[3], and Pavel F. Bessarab[1,2] — [1]ITMO University, St. Petersburg, Russia — [2]University of Iceland, Reykjavík, Iceland — [3]University of Kiel, Kiel, Germany

Experimental data [1,2] demonstrates that nanoscale magnetic skyrmions are only stable at low temperature, but room temperature stability is required for future applications. Here it is demonstrated by means of transition state theory [3] and atomistic spin Hamiltonian that the stability of nanoscale skyrmions can be enhanced to the desired level by a concerted adjustment of material parameters preserving the skyrmion size [4]. Both increase in the energy barrier and the entropy barrier for the skyrmion collapse contribute to the stabilization, but it is the entropic effect that plays a dominant role, leading to the variation of skyrmion lifetime by more than ten orders of magnitude within the chosen parameter range. The pronounced enhancement of the entropy barrier is explained in terms of magnon-skyrmion bound states.

[1] N. Romming *et al.*, Phys. Rev. Lett. **114,** 177203 (2015).
[2] K. Litzius *et al.*, Nat. Phys., **13**. 170–175, (2017).
[3] P.F. Bessarab *et al.*, Sci. Rep., **8**, 3433, (2018).
[4] A.S. Varentsova *et al.*, Nanosyst.:Phys.Chem.Math., **9**, 356, (2018).

MA 34.3 Wed 15:45 H37

Approaching the Skyrmion shift register — •Christian Denker[1], Sören Nielsen[2], Malte Römer-Stumm[2], Nina Meyer[1], Neha Jha[1], Enno Lage[2], Markus Münzenberg[1], and Jeffrey McCord[2] — [1]Institut für Physik, Universität Greifswald, Germany — [2]Nanoscale Magnetic Materials - Magnetic Domains, Institute for Materials Science, Universität Kiel, Germany

The experimental realization of Skyrmion race track memories or shift registers requires a material system able to host Skyrmions with reasonable lifetime and allowing control of skyrmion motion and pinning, preferably by electric currents or fields. Ta/CoFeB/MgO fulfills these requirements and shows the highest reported TMR ratios for magnetic tunnel junctions (MTJ) and is, therefore, an ideal candidate for all electrical generation and detection by MTJs which is desirable but to our knowledge still lacking. We will show our results on current induced Skyrmion motion in Ta/CoFeB/MgO trilayers, as well as our experiments on Skyrmions in MTJ layer stacks.

MA 34.4 Wed 16:00 H37

Impact of transition metals clusters on the stability and dynamics of skyrmions — Jonathan Chico, •Imara Lima Fernandes, I Gede Arjana, Stefan Blügel, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Magnetic skyrmions are prime candidates for future spintronic devices. However, incorporating them as possible information carriers hinges on their interaction with inhomogenities present in any device. Recently, it was shown that $3d$ and $4d$ single-atomic defects can either repel or pin skyrmions [1]. Using first-principles calculations in conjunction with atomistic spin dynamics, we investigate the complex motion of technologically relevant small skyrmions in Pd/Fe/Ir(111) with $3d$ and $4d$ transition metal single-atomic defects and clusters. The obtained dynamical behaviour is richer and goes beyond the expected from the Thiele equation. This allows us to study the impact of different types of defects on the skyrmions dynamics and the complexity of different motion regimes is revealed and compared with what is known for larger skyrmions. The present study may give guidance on how such defects can be used to engineer tracks for controlled skyrmion motion which is of great importance for the design of future spintronic devices. – Funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 - DYNASORE).

[1] I. Lima Fernandes. et al., Nat. Commun. **9**, 4395 (2018).

MA 34.5 Wed 16:15 H37

Dynamics in confined skyrmion ensembles on different time scales — •Alexander F. Schäffer[1], Levente Rózsa[2], Jamal Berakdar[1], and Elena Y. Vedmedenko[2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany — [2]Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, D-20355 Hamburg, Germany

In this study, ensembles of magnetic skyrmions on confined geometries are shown to exhibit characteristic temperature driven motion on two different time-scales. The intrinsic fluctuating dynamics ($t \sim 1$ ns) is governed by short-ranged symmetric and antisymmetric exchange interaction, whereas the long-time limit ($t \gtrsim 10\,\mathrm{ns}$) is determined by the coaction of skyrmion-skyrmion-repulsion and the system's geometry.

Full micromagnetic simulations along with quasiparticle model Monte Carlo calculations for realistic island shapes and sizes are performed and analyzed, indicating the special importance of skyrmion dynamics at finite temperatures including skyrmion-skyrmion and skyrmion-boundary repulsion effects.

Our results highlight the conflict between skyrmion-mobility and finite observation times, directly affecting the addressability of skyrmionic bits, which is a key challenge on the path of developing skyrmion-based room-temperature applications.

The presented quasiparticle Monte Carlo approach bears great potential for a computationally effective description of the diffusive motion of skyrmion ensembles on finite geometries like racetrack memory setups.

MA 34.6 Wed 16:30 H37

Skyrmions for non-conventional computing — •Klaus Raab[1], Nico Kerber[1,4], Jakub Zázvorka[1], Florian Jakobs[2], Daniel Heinze[1], Niklas Keil[1], Sascha Kromin[1], Samridh Jaiswal[1,3], Kai Litzius[1,4], Gerhard Jakob[1], Peter Virnau[1], Daniele Pinna[1], Karin Everschor-Sitte[1], Andreas Donges[2], Ulrich Novak[2], and Mathias Kläui[1,4] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz, DE-55099 Mainz, Germany — [2]Fachbereich Physik, Universität Konstanz, Universitätsstraße 10, DE-78457 Konstanz, Germany — [3]Singulus Technologies AG, DE-63796 Kahl, Germany — [4]Graduate School of Excellence Materials Science in Mainz, DE-55128 Mainz, Germany

In cascading logic gates for probabilistic computing [1], undesired correlations can occur that thus impede the functionality as a logic device. To decorrelate an information stream, a reshuffler device based on skyrmoins has been proposed [1], that we realize using skyrmions in a multilayer stack [2-3] : In a Ta-based material we are able to not only stabilize and controllably nucleate the skyrmions, but also displace them by current injection due to spin-orbit torques [4]. To eliminate correlations in a skyrmion data stream, we show that we can decorrelate the signals using a device with leads for skyrmion transport and a chamber where this reshuffling occurs [4]. We study the different skyrmion transport possibilities and properties to gauge the device performance. The low reshuffler footprint and low power usage compared to e.g. CMOS [3,4] might enable more energy efficient computing.

MA 34.7 Wed 16:45 H37

Role of damping and continuity in the stability of skyrmions and antiskyrmions — •Martin Stier[1], Wolfgang Häusler[2], and Michael Thorwart[1] — [1]Universität Hamburg, Jungiusstr. 9, 20355 Hamburg — [2]Universität Augsburg, Universitätsstr. 1, 86135 Augsburg

Magnetic skyrmions are magnetic vortices with non-vanishing topological charge Q. This topological charge can not be changed by means of a continuous transformation of the magnetic texture $\mathbf{n}(x, y, t)$. This topologically protects skyrmions as well as antiskyrmions and the transition to topologically different phases is forbidden. On lattices, however, this topological protection does not hold in a strict sense and skyrmions can be created or destroyed as it is confirmed by experiment and theory. Nevertheless, on discrete lattices the topological protection is still taken as a justification for the comparably strong stability of skyrmions even without a strict theoretical support. To establish ties between the discrete and continuous limit we study the decay of skyrmions and antiskyrmions. By increasing the number lattice sites we approach the continuous limit. We discuss the according decay times with a distinct focus on the role of the damping on the decay.

15 min. break

MA 34.8 Wed 17:15 H37

Spin eigen-excitations of the antiferromagnetic skyrmion — •Volodymyr Kravchuk[1,4], Helen Gomonay[2], Denis Sheka[3], Karin Everschor-Sitte[2], Davi Rodrigues[2], Jeroen van den Brink[1], and Yuri Gaididei[4] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung, Dresden, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany — [3]Taras Shevchenko National University of Kyiv, Ukraine — [4]Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine

The spectrum of eigen-excitations of a skyrmion in a uniaxial collinear antiferromagnet with the easy-axis perpendicular to the film plane is analyzed. Two branches of the bounded eigenstates are found in the gap: the low-frequency modes demonstrate significant dependence of the eigenfrequencies on the skyrmion radius R with the characteristic asymptotic behavior $\omega \propto R^{-2}$ for large R. While the high-frequency modes are close to the magnon continuum and weakly depend on the skyrmion radius. In the absence of an external magnetic field all modes, except the radially symmetrical one, are doubly degenerate with respect to the sense of rotation, clockwise or counterclockwise. The perpendicular magnetic field results in a splitting of the degenerate modes. A general approach for describing the dynamics of the antiferromagnetic domain wall string is developed, it is utilized for estimation of eigenfrequencies of the low-frequency modes.

MA 34.9 Wed 17:30 H37

Magnetic behaviour investigation using simulations, conventional and space-time-resolved x-ray detected FMR — •Santa Pile[1], Taddäus Schaffers[1], Thomas Feggeler[2], Ralf Meckenstock[2], Detlef Spoddig[2], Katharina Ollefs[2], Verena Ney[1], Hendrik Ohldag[3], Rysard Narkowicz[4], Kilian Lenz[4], Jürgen Lindner[4], Michael Farle[2], Heiko Wende[2], and Andreas Ney[1] — [1]Johannes Kepler University Linz, 4040 Linz, Austria — [2]University of Duisburg-Essen, 47057 Duisburg, Germany — [3]SSRL, SLAC National Accelerator Laboratory, Menlo Park, CA — [4]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany

STXM, XMCD spectroscopy and FMR were combined using a synchronization scheme between the x-ray pulses of the synchrotron and the microwave excitation (STXM-FMR). This STXM-FMR setup enables the visualization of the high frequency magnetization dynamics in the GHz regime with a spatial resolution of 35 nm and a time resolution of 17.4 ps [1]. Lithographically grown combinations of magnetic micro-stripes 5x1x0.03 *m3 were investigated. The samples were precharacterised using conventional FMR [2] and micro magnetic simulations. For STXM-FMR measurements a static magnetic field was applied in the plane of the stripes. As a result several uniform and transitional spin-wave FMR modes were visualised and agree with the simulations.

[1] S. Bonetti, et. al., Rev. Sci. Instrum. 86, 093703 (2015)
[2] R. Narkowicz, et. al., Reson.175, 275 (2005)

MA 34.10 Wed 17:45 H37

Skyrmion diffusion in thin film multilayers — •Markus Weissenhofer, Andreas Donges, and Ulrich Nowak — Fachbereich Physik, Universität Konstanz, Universitätsstraße 10, DE-78457 Konstanz, Germany

While being of fundamental interest as the type of diffusion yields information on transport and dissipation processes, thermally activated diffusion processes can also serve as a sensitive tool to analyze system properties. We use the stochastic Landau-Lifshitz-Gilbert equation to simulate diffusive motion of Skyrmions in a (Pt0.95Ir0.05)/Fe-bilayer on a Pd(111) surface. Here, the frustration of the isotropic exchange interactions in connection with the Dzyaloshinskii-Moriya interaction is responsible for the creation of skyrmionic structures [1]. We demonstrate the validity of the existing analytical theory for diffusive motion in flat energy landscapes [2] by calculating the diffusion coefficient for Skyrmions with different topological charges finding a linear temperature dependence as analytically expected [3]. Simulations at low temperatures reveal that in this system skyrmionic structures which are deformed by the Dzyaloshinskii-Moriya interaction show anisotropic diffusive behaviour in combination with rotational brownian motion in a weak periodic potential. Furthermore we quantitatively investigate this rotational energy landscape for deformed skyrmions and determine the mean rotation time for different temperatures [1].

[1] Rózsa et al., Phys. Rev. B 95, 094423 (2017). [2] Schütte et al., Phys. Rev. B 90, 174434 (2014). [3] Zázvorka et al., arXiv:1805.05924 [cond-mat.mtrl-sci]

MA 34.11 Wed 18:00 H37

Deformations of magnetic skyrmions — •Davi Rohe Rodrigues[1], Artem Abanov[2], and Karin Everschor-Sitte[1] — [1]Institute of Physics, Johannes Gutenberg-University, 55128 Mainz, Germany — [2]Department of Physics & Astronomy, Texas A&M University, College Station, TX 77843-4242, USA

Dynamical deformations of skyrmions have several implications on their transport properties, like a modified skyrmion Hall angle and a maximum skyrmion velocity.[1,2,3] Furthermore, the gigahertz dynamics of skyrmion excitation modes might be exploited for nonconventional computation.[4] In this work, we derive a general framework to describe the dynamics of deformations in isolated magnetic skyrmions. This effective profile ansatz- and microscopic detail-independent theory can be applied to current and field driven dynamics of skyrmions.[5] We analyse the change in the skyrmion Hall angle due to deformation of skyrmions and derive a current-induced bimeron instability. This powerful formalism provides an efficient tool to understand the experimentally observed low-energy skyrmion dynamics as well as suggests new applications of magnetic skyrmions.

[1]Litzius et al., to be published; [2] Leliaert et al., Jour. Phys. D 52 024003 (2019); [3]Tomasello et al., arXiv:1808.01476; [4] Bourianoff et al., AIP Advances 8 (2018); [5] Rodrigues et al., Phys. Rev. B 97 134414 (2018).

MA 34.12 Wed 18:15 H37

Maximizing Skyrmion Device Efficiency by Engineering the Drive and Temperature Dependence of Skyrmion Dynamics and the Resulting Skyrmion Hall Effect — Kai Litzius[1,2,3], Jonathan Leliaert[4], Pedram Bassirian[1], Davi Rodrigues[1], Sascha Kromin[1], Ivan Lemesh[5], Jakub Zazvorka[1], Kyu-Joon Lee[1], Jeroen Mulkers[4,6], •Nico Kerber[1,2], Daniel Heinze[1], Niklas Keil[1], Robert M. Reeve[1,2], Markus Weigand[3], Bartel Van Waeyenberge[4], Gisela Schütz[3], Karin Everschor-Sitte[1,2], Geoffrey S. D. Beach[5], and Mathias Kläui[1,2] — [1]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]Ghent University, B-9000 Ghent, Belgium — [5]Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [6]University of Antwerp, B-2020 Antwerp, Belgium

To reveal the origin of the Skyrmion Hall Angle (SkHA) and the temperature-dependence of the skyrmion dynamics, we investigate skyrmion trajectories at different temperatures and drive-amplitudes. We find the velocities to be strongly temperature-dependent, whereas the mechanism of the SkHA is independent of temperature, with different slopes in the depinning and viscous flow regimes. We explain these slopes by revealing the different underlying mechanisms including skyrmion surface tension and -deformation that sets the limit of the maximum velocity in ferromagnetic devices unless counteracted.

MA 34.13 Wed 18:30 H37

Overcoming the speed limit in skyrmion racetrack devices by suppressing the skyrmion Hall effect — •Börge Göbel[1], Alexander Mook[2], Jürgen Henk[2], and Ingrid Mertig[1,2] — [1]Max-Planck-Institut für Mikrostrukturphysik, D-06120 Halle (Saale), Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany

Magnetic skyrmions are envisioned as carriers of information in racetrack storage devices. Unfavorably, the skyrmion Hall effect hinders the fast propagation of skyrmions along an applied electric current and limits the device's maximum operation speed. We show that the maximum skyrmion velocity increases by a factor of 10 when the skyrmion Hall effect is suppressed, since the straight-line motion of the skyrmion allows for the application of larger driving currents. We consider a ferromagnet on a heavy metal layer, which converts the applied charge current into a spin current by the spin Hall effect. The spin current drives the skyrmions in the ferromagnet via spin-orbit torque. We show by analytical considerations and simulations that the deflection angle decreases, when the spin current is polarized partially along the applied current direction and derive the condition for complete suppression of the skyrmion Hall effect.

[1] B. Göbel, A. Mook, J. Henk, and I. Mertig, arXiv:1808.06391 (2018)

MA 34.14 Wed 18:45 H37

Magnetotransport Fingerprints of Bloch Points in Thin Films — •Matthias Redies[1], Fabian Lux[1], Jan-Philipp Hanke[2], Patrick Buhl[1], Gideon Müller[1,3], Nikolai Kiselev[1], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [3]Science Institute of the University of Iceland, VR-III, 107 Reykjavik, Iceland

While chiral magnetic skyrmions have attracted much attention in recent years, a new type of thin-film chiral particle − of a chiral bobber − has recently been theoretically predicted and experimentally observed [1]. On the basis of theoretical arguments, here we present a clear way to use chiral bobbers for the purposes of future spintronics by revealing that these novel chiral states have inherent transport fingerprints that allow their unique electrical detection in systems of different types of chiral states [2]. We show that bobbers' unique transport and orbital features are rooted in the non-trivial magnetization distribution near the Bloch points, and show that the fine-tuning of the Bloch point topology can be used to drastically increase the emergent response properties of chiral bobbers to external fields, which holds great potential for the development of chiral dynamics and cognitive computing.

[1] Filipp N Rybakov et al, 2016 New J. Phys. 18 045002
[2] Matthias Redies et al, arXiv:1811.01584