Spin Dynamics in Materials with Unconventional Symmetries

847. WE-Heraeus-Seminar

06 – 09 January 2026

at the Physikzentrum Bad Honnef, Germany

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 847. WE-Heraeus-Seminar:

Magnetism has been one of the most intensively studied phenomena in condensed matter physics over the past century. The prospect of developing data storage and manipulation technologies capable of surpassing state-of-the-art schemes in both power efficiency and operational frequency has sparked a surge of interest in spin dynamics. A strong connection has been established between the symmetries exhibited by a magnetic material in equilibrium, and its spin dynamics. Recently, it has been recognized that breaking certain symmetries—either within the magnetic system itself or in other subsystems such as charge and lattice—gives rise to dynamic magnetic phenomena that challenge the traditional classification of magnetic materials into ferromagnets and antiferromagnets. The states enabling these unexpected behaviours are said to exhibit unconventional symmetries. Beyond their impact on spin dynamics, unconventional symmetries also influence the properties of topological magnetic textures, such as skyrmions, domain walls, merons, and hopfions.

Moreover, unconventional symmetries can be induced by externally driving a magnetic material into an excited state with symmetry properties distinct from its ground state. Many of these concepts have historically emerged from different research communities, each employing distinct methodologies and terminology. To bridge these gaps, this seminar aims to provide a unified platform that attracts a multidisciplinary audience, fosters the exchange of ideas, and facilitates discussions. To achieve this, the seminar is structured around four key topics: i) transport effects due to unconventional symmetries in the ground state; ii) angular momentum from chiral phonons; iii) topological magnetic textures and unconventional symmetries; iv) photoinduced unconventional symmetries in non-equilibrium states.

Distinguished international scientists and promising young talents will present groundbreaking work, stimulating knowledge exchange. Participants are encouraged to engage in discussions and contribute their findings through poster sessions, fostering a dynamic and collaborative scientific environment.

Introduction

Scientific Organizers:

Dr. Maria Azhar — Universität Duisburg-Essen, Germany
E-mail: maria.azhar@uni-due.de

Dr. Davide Bossini — Universität Konstanz, Germany
E-mail: davide.bossini@uni-konstanz.de

Administrative Organization:

Dr. Stefan Jorda
Elisabeth Nowotka

Wilhelm und Else Heraeus-Stiftung
Kurt-Blaum-Platz 1
63450 Hanau, Germany

Phone +49 6181 92325-12
Fax +49 6181 92325-15
E-mail nowotka@we-heraeus-stiftung.de
Internet: www.we-heraeus-stiftung.de

Venue:

Physikzentrum
Hauptstrasse 5
53604 Bad Honnef, Germany

Conference Phone +49 2224 9010-120

Phone +49 2224 9010-113 or -114 or -117
Fax +49 2224 9010-130
E-mail gomer@pbh.de
Internetwww.pbh.de

Taxi Phone +49 2224 2222

Registration:

Elisabeth Nowotka (WE Heraeus Foundation)
at the Physikzentrum, reception office
Tuesday (17:00 h – 21:00 h) and Wednesday morning

Program

Program

Tuesday, 06 January 2026

16:00 – 20:00	Registration	
18:00	*BUFFET SUPPER and informal get-together*	
19:30 – 19:45	Scientific organizers	**Welcome words**
19:45 – 20:30	Stefan Blügel	**Hopfions in magnetic solids: Theory, stability, material, experiment**
20:30 – 21:15	Helena Reichlova	**Towards spintronics with altermagnets**

Wednesday, 07 January 2026

08:00	*BREAKFAST*	
09:00 – 09:45	Rembert Duine	**Twist-modulated magnetic interactions in bilayer van der Waals materials**
09:45 – 10:30	Katrin Schultheiss	**Self-induced Floquet magnons in magnetic vortices**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Tobias Kampfrath	**tba**
11:45 – 12:30	Dima Afanasiev	**Shining light on 2D antiferromagnets**
12:30 – 12:40	**Conference photo**	
12:40	LUNCH	

Program

Wednesday, 07 January 2026

14:00 – 14:45	Dongwook Go	**Chiral-induced orbital selectivity by orbital topology of chiral fermions**
14:45 – 15:30	Dominik Juraschek	**Chiral phonons and multiferrons**
15:30 – 16:00	*COFFEE BREAK*	
16:00 – 16:45	Junichiro Kono	**Simulating Dicke physics with spin-magnon coupling in rare earth orthoferrites**
16:45 – 17:30	Stuart Parkin	**tba**
17:30 – 17:45	Mona Bhukta	**Spin-orbit torque driven nanosecond dynamics of topological spin textures in synthetic antiferromagnets**
17:45 – 18:00	Pieter Gunnink	**Spin demons in d-wave altermagnets**
18:00	*DINNER*	
19:30	**Poster flashes & posters** (open end)	

Program

Thursday, 08 January 2026

08:00	*BREAKFAST*	
09:00 – 09:45	Hariom Jani	**Engineering topological antiferromagnetic solitons for spintronics**
09:45 – 10:30	Aisha Aqeel	**Detection of static and dynamic magnetization of twists in (anti-)ferromagnetic insulators**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Jeroen Van Den Brink	**Altermagnetic anomalous hall effect emerging from electronic correlations**
11:45 – 12:30	Jairo Sinova	**Unconventional magnetism: the emergence of altermagnetism and beyond**
12:30	*LUNCH*	
14:00 – 15:30	**Posters & Discussions**	
15:30 – 16:00	*COFFEE BREAK*	

Program

Thursday, 08 January 2026

16:00 – 16:45	Claire Donnelly	**Mapping topological textures in compensated magnets with X-rays**
16:45 – 17:30	Nicolas Jaouen	**Time-evolution of chiral Néel magnetic domain walls in multilayers probed by soft x-ray resonant magnetic scattering.**
17:30 – 17:45	Olena Gomonay	**Phenomenology of altermagnets and altermanetic textures**
17:45 – 18:00	Sonu Kumar	**Crystal-field–driven magnetoelectricity in the triangular quantum magnet CeMgAl11O19**
18:00	HERAEUS DINNER (social event with cold & warm buffet with complimentary drinks)	
20:00	**Awards and discussion panel**	

Program

Friday, 09 January 2026

08:00	*BREAKFAST*	
09:00 – 09:45	Sayantika Bhowal	**Interplay between magnetoelectric multiferroicity and non-relativistic spin splitting**
09:45 – 10:30	Silvia Viola-Kusminsky	**Harnessing photons to probe topological magnons**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Lukas Körber	**Nonlinear spin dynamics under thermal and quantum fluctuations**
11:45 – 12:30	Maxim Mostovoy	**Dynamics of periodically driven topological magnetic defects**
12:30	*LUNCH*	

End of the seminar and departure

NO DINNER for participants leaving on Saturday; however, a self-service breakfast will be provided on Saturday morning

Posters

Posters

Akashdeep Akashdeep	**The nature of magnetic order in RuO_2: Probed via magneto transport and muons**
Nadya Amalia	**Rashba spin texture and spin hall effects in Janus 2D materials**
Sunit Das	**Symmetry-driven intrinsic nonlinear pure spin hall effect**
Patricia De Assis Almeida	**Impact of strain on the Kondo Effect in Kagome ribbons**
Andrea Eschenlohr	**Insight into electronic correlations and spin dynamics on femtosecond timescales with ultrafast x-ray spectroscopy**
Maik Gärner	**Tuning the anomalous hall effect in magnetron-sputtered Mn5Si3 thin films**
Shreenanda Ghosh	**Raman Spectroscopic fingerprints of multiferroic behavior in 2D vdW material $CuCrP_2S_6$**
Jim Groefsema	**Two distinct regimes in phonon-induced non-equilibrium magnetization dynamics**
Max Hirschberger	**A metallic p-wave magnet with commensurate spin helix**
Moritz Hirschmann	**Time-reversal symmetric f-wave magnets**
Kübra Kalkan	**Investigating magnetic material parameters from latent measures**
Lisa-Marie Kern	**Stabilizing and steering multi-skyrmion bags**
Peter Kim	**Spin wave pulses in antiferromagnetic insulators**

Posters

Michael Kitcher	**Leveraging distortion-aware magnetic symmetry groups to predict altermagnetism**
Sophie Knewitz	**Vectorial spin-to-charge conversion by supramolecular chirality**
Volodymyr Kravchuk	**Curvature-induced magnetization of altermagnetic films**
Hyunju Lee	**Enhancement of intrinsic spin hall conductivity in W1-xMox alloys**
Rein Liefferink	**Deterministic optical control of ferromagnetic domains by nanoscale stochastic switching**
Kai Litzius	**Control of spin textures in Weyl semimetals**
Ying Shing Liu	**Chirality probes of band topology in Bosonic Bogoliubov systems**
Mehak Loyal	**Emergence of a topological hall effect in the non-collinear phase of ferrimagnetic insulator terbium-iron garnet**
Alexander Mook	**Odd-parity magnon spin splitting in antialtermagnets**
Anusree Navallur	**Positional memory of skyrmions in magnetic bilayers**
Brandon Pedroza-Rojas	**Symmetry-driven topological magnetism and twist-tunable spin dynamics in antiferromagnet–ferromagnet heterostructures**
Alessandro Pignedoli	**Leveraging Interactions for Efficient Swarm-Based Brownian Computing**
Oleksandr Pylypovskyi	**Curvature-driven magnetic frustration and artificial ferrotoroidicity in nanomagnets**

Posters

Prajwal Rigvedi	**Quateranry probabilisitic switching and current induced domain wall motion in a chiral kagome antiferromagnet**
Sahana Rößler	**Magnetization processes and spin-lattice coupling in the hexagonal easy-plane altermagnet α-MnTe**
Philipp Schwenke	**Magnetization dynamics in RMn6Sn6 crystals investigated by broadband ferromagnetic resonance spectroscopy**
Zahra Shomali	**Engineering spin torque in spin–orbit coupled josephson qubits incorporating chiral ferromagnetic superconductors with unconventional symmetries**
Simon Sochiera	**Chiral molecule-induced magnetic anisotropies**
Boris Sorokin	**Capillary-based Soft X-ray ptychography for ultimate 4D spectro-microscopy with versatile sample environment**
George Theodorou	**Interaction and collision of skyrmions in chiral antiferromagnets**
Meritxell Valls Boix	**Theory of magnetization dynamics control by phonons**
Harsh Varshney	**Spin band geometry drives intrinsic thermal spin magnetization and current**
Xanthe H. Verbeek	**Strain controlled g-to d-wave transition in altermagnetic CrSb**
Maxim Wenzel	**Optical investigations of electron-doped FeSb2**
Thomas Brian Winkler	**Multi-value probabilistic computing with current-controlled skyrmion diffusion**
Jing Wu	**Optical control of RKKY coupling and perpendicular magnetic anisotropy in a synthetic antiferromagnet**

Posters

Yongbing Xu — **Probing unconventional spin materials with time and spin resolved ARPES**

Min-Jae Yoo — **Néel-vector controlled Hall and Kerr responses in collinear altermagnetic α-Fe_2O_3**

Hongbin Zhang — **DFT-based investigation of spin dynamics in unconventional magnets**

Zhibo Zhao — **Voltage-triggered emergent dynamics in a magnetic neuron network**

Abstracts of Talks

(in alphabetical order)

Detection of static and dynamic magnetization of twists in (anti-)ferromagnetic insulators

Aisha Aqeel[1]

[1]*University of Augsburg, Germany*

Magnetic insulators hosting noncollinear spin textures display a remarkable variety of static and dynamic phenomena. In chiral systems such as Cu_2OSeO_3, the lack of inversion symmetry gives rise to helices and skyrmions stabilized by Dzyaloshinskii–Moriya interactions. By contrast, in centrosymmetric compounds like $CuSeO_3$, complex antiferromagnetic spiral states can emerge purely from competing symmetric exchange interactions, providing an intriguing platform to explore magnetism without intrinsic chirality.

In this talk, I will discuss our recent efforts to detect and characterize these magnetic textures and their excitations using magnetic resonance spectroscopy, resonant X-ray scattering [1], and surface-sensitive electrical probes [2].

References

[1] S. Mehboodi, V. Ukleev, C. Luo, R. Abrudan, F. Radu, C. H. Back, A. Aqeel, Sci. Technol. Adv. Mater *26*(1) 2532366 (2025)

[2] A. Aqeel, M. Kronseder, N. Vlietstra, H. Huebl, JA Heuver, B. Noheda, ..., C. Back, Sci. Technol. Adv. Mater *26*(1) 2457320 (2025)

Interplay between magnetoelectric multiferroicity and non-relativistic spin splitting

Sayantika Bhowal

Department of Physics, Indian Institute of Technology Bombay, Mumbai 400076, India

While magnetoelectric multiferroics exhibit coexisting ferromagnetic and ferroelectric orders, properties that are typically mutually exclusive, and coupled through the magnetoelectric effect; the recent discovery of non-relativistic spin splitting (NRSS) in antiferromagnets challenges the long-standing belief of degenerate up- and down-spin bands in the antiferromagnets. Exploring the hidden orders underlying both phenomena, my talk will focus on the interplay between magnetoelectric multiferroicity and non-relativistic spin splitting. I will discuss two representative cases. In the first, I will show the emergence of multiferroicity at the surfaces of inversion-symmetric collinear antiferromagnets exhibiting NRSS [1]. Unlike the bulk, which is nonpolar, magnetically compensated, and lacks a linear magnetoelectric response, the surface displays all key signatures of multiferroicity, a net electric dipole moment, net magnetization, and a linear magnetoelectric effect, that arise even in the absence of spin–orbit coupling. This highlights the role of bulk–boundary correspondence and demonstrates how surface multiferroicity can be engineered in otherwise non-multiferroic materials. In the second case, I will discuss the coexistence of NRSS and magnetoelectric multiferroicity in inversion-broken antiferromagnets, which provides a platform for magnetoelectric tuning of non-relativistic spin splitting [2,3].

References

[1] S. Bhowal, A. Urru, S. F. W., and N. A. Spaldin, Phys. Rev. Lett. **134**, 146703 (2025).

[2] S. Bandyopadhyay, S.Picozzi, and S. Bhowal, Phys. Rev. B **112**, 064405 (2025).

[3] A. Ray, S. Bandyopadhyay, S. Bhowal, arXiv: 2509.20041 (2025).

Spin-Orbit Torque Driven Nanosecond Dynamics of Topological Spin Textures in Synthetic Antiferromagnets

Mona Bhukta[1], Takaaki Dohi[1,2], Fabian Kammerbauer[1], Maria-Andromachi Syskaki[1], Duc Minh Tran [1], Markus Weigand[3,4], Sebastian Wintz[3,4], Robert Frömter[1], and Mathias Kläui[1]

[1]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany
[2]Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba, Sendai 980-8577, Japan
[3]Max Planck Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany
[4]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 14109 Berlin, Germany

Intrinsic antiferromagnets (AFM) provide natural advantages for hosting skyrmions and bimerons, as they inherit the characteristic features of AFM order, such as cancellation of the skyrmion Hall effect and negligible stray fields [1]. Synthetic antiferromagnets (SyAFMs), however, offer an additional degree of freedom by enabling independent engineering of the properties of two ferromagnetic sublattices. This sublattice-specific tunability has profound consequences. By tuning the magnetic compensation (renders the system analogous to ferrimagnets), SyAFMs hosts three-dimensional spin textures such as hybrid skyrmion tubes [2], where was a fully compensated SyAFM host homochiral bimerons [3] and skyrmions [4]. Moreover, by exploiting the sublattice-selective tunability of SyAFMs, we achieve real-space, element-resolved visualization of an orthogonally coupled skyrmion–bimeron pair residing in two magnetic sublattices that are mutually orthogonal. We directly visualize, in real time, the nanosecond current-driven dynamics of an AFM skyrmion lattice using element-specific pump–probe X-ray microscopy. By tuning spin–orbit torque relative to local pinning potentials, we reveal two regimes: incoherent flow, where mobile skyrmions scatter from pinned ones, inducing recoil dynamics with 3–20 ns relaxation, and coherent flow, where the lattice translates uniformly [4].

References

[1] A. Ross *et al.* Phys. Rev. B 102, 094415 (2020), H. Jani *et al.* Nature 590, 74-79 (2021).

[2] T. Dohi, M. Bhukta *et al.* Nat. Commun. 15, 8285 (2025).

[3] M. Bhukta et al., Nat. Commun. 15, 1641(2024).

[4] M. Bhukta *et al.* arXiv:2508.17967 (2025).

Hopfions in magnetic solids
Theory, Stability, Material, Experiment

S. Blügel[1,2]

[1]*Peter Grünberg Institute, Forschungszentrum Jülich and JARA, 52425 Jülich*
[2] *Institute for Theoretical Physics, RWTH Aachen University, 52062 Aachen*

Topological magnetization texturonics—an emerging branch of spintronics centered on nanoscale, particle-like 2D and 3D magnetic textures such as skyrmions—has rapidly evolved into a vibrant multidisciplinary field uniting theory, computation, materials synthesis, advanced magnetic characterization, and device engineering. 3D magnetization textures in bulk solids such as twisted skrymion strings [1], hybrid particles like bobbers [2] or hopfions [3, 4] open a novel dimension, but their investigation defines also a major international challenge. It is very fascinating to observe that simple spin models, which can be linked to real materials by density functional theory calculations, lead to micromagnetic equations whose solutions are localized topological textures in an homogeneous solid that can now be studied by experimental methods, e.g. by means of quantitative off-axis electron holography [1, 2, 4]. I will give an elementary overview about this field, but then focus on hopfions in bulk solids, introduce the primary interactions that are responsible for their existence. In this presentation I report on our advanced micromagnetic theory [5] in which we derived analytical conditions of Heisenberg exchange parameters under which isolated Hopfions can be expected. We combine atomistic spin-dynamics with harmonic transition state theory [6] to investigate the lifetime of hopfions and related decay mechanisms. I report on our recent experimental observation of hopfion rings on skyrmions strings [4] and comment on its impact on the extension of the classification from topological groups to product groups.

The work was carried out in collaboration with Nikolai Kiselev, Filipp Rybakov, Fengshan Zheng, and Rafal Dunin-Borkowski. Funding is provided by the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (Grant 856538 – 3D MAGiC).

References

[1] Fengshan Zheng et al., Nature Commun. **12**, 5316 (2021).
[2] Fengshan Zheng et al., Nature Nanotech. **13**, 451 (2018).
[3] N. Kent et al., Nature Commun. **12**, 1562 (2021).
[4] Fengshan Zheng et al., Nature **623**, 718 (2023).
[5] F.N. Rybakov et al., Apl. Mater. **10**, 111113 (2022).
[6] M. Sallermann et al., Phys. Rev. B 107, 104404 (2023).

Mapping topological textures in compensated magnets with X-rays

Claire Donnelly[1]

[1]*Max Planck Institute for Chemical Physics of Solids, Dresden, Germany*

Extending spin systems to three dimensions promise significant opportunities for applications, for example providing higher density devices and new functionalities associated with complex topology and greater degrees of freedom [1,2].
Until now, however, insight into three dimensional spin systems has mainly been limited to ferromagnetic and ferrimagnetic systems through X-ray magnetic tomography [3] – where a variety of topological textures [3,4], as well as 3D dynamics [5,6], have been observed.
In this talk I will describe our recent work mapping topological textures in compensated systems. I will first describe the development of X-ray linear orientation tomography [7], which we have harnessed to map three-dimensional orientation fields – both crystallographic [7], and antiferromagnetic [8] – at the nanoscale. Second, I will present our recent mapping of topological textures in altermagnets [9,10], harnessing both X-ray circular and linear magnetic dichroism.
These insights into the formation of topological textures in compensated magnets not only paves the way not only for enhanced understanding of these systems, but also towards the next generation of technological devices.

References

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[3] C. Donnelly et al., Nature **547**, 328 (2017).
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[8] A. Apseros et al., *In Prep.*
[9] R. Yamamoto et al., Phys. Rev. Appl. **24**, 034037 (2025)
[10] R. Yamamoto et al., *In Prep.*

Twist-modulated magnetic interactions in bilayer van der Waals materials

Tomas T. Osterholt[1], D. O. Oriekhov[2], Lumen Eek[1], Cristiane Morais Smith[1], and Rembert A. Duine[1,3]

[1]Institute for Theoretical Physics, Utrecht University, 3584CC Utrecht, The Netherlands
[2]Kavli Institute of Nanoscience and QuTech, Delft University of Technology, 2628CJ Delft, The Netherlands
[3]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

The ability to control magnetic interactions at the nanoscale is crucial for the development of nextgeneration spintronic devices and functional magnetic materials. In this work, we investigate theoretically, by means of many-body perturbation theory, how interlayer twisting modulates magnetic interactions in bilayer van der Waals systems composed of two ferromagnetic layers. We demonstrate that the relative strengths of the interlayer Heisenberg exchange interaction, the DzyaloshinskiiMoriya interaction, and the anisotropic exchange interaction can be significantly altered by varying the twist angle between the layers, thus leading to tunable magnetic textures. We further show that these interactions are strongly dependent on the chemical potential, enabling additional control via electrostatic gating or doping. Importantly, our approach is applicable to arbitrary twist angles and does not rely on the construction of a Moir ´e supercell, making it particularly efficient even at small twist angles.

References: arXiv:2509.14122 [cond-mat.mes-hall]

Chiral-Induced Orbital Selectivity by Orbital Topology of Chiral Fermions

Dongwook Go[2]

[1]*Department of Physics, Korea University, Seoul, Korea*

In chiral structures such as DNA molecules, spin-polarized electrons exhibit non-reciprocal transport, which is known as chiral-induced spin selectivity (CISS). Despite its fundamental importance and potential applications, the microscopic origin of CISS has yet to be unveiled. A big mystery of CISS is the exceptionally high spin-polarization ratio (~50%) of electrons in chiral molecules, despite the negligible spin-orbit interaction (SOI) of their constituent atoms. This implies that electrons carry a magnetic moment not from the spin but from the orbital angular momentum (OAM).

Motivated by recent advances in orbitronics, we propose an alternative picture of CISS, based on the OAM of electrons instead of the spin, which we denote as chiral-induced orbital selectivity (CIOS). One of the main features of CIOS is that it does not require SOI, because the OAM directly couples to the structure. We demonstrate CIOS in the topological chiral semimetal CoSi, which comes in two crystal structures with opposite handedness and also hosts orbital-polarized chiral fermions in the band structure. From first-principles calculations, we demonstrate that CIOS is about 300 times stronger than CISS, which is attributed to the OAM textures of orbital chiral fermions. Importantly, we find that CIOS is stronger by an order of magnitude at surfaces due to strong orbital polarization of the helicoid Fermi arc, which originates from the nontrivial orbital topology in the bulk.

At the end of the talk, we propose how to experimentally confirm CIOS and how to utilize it in orbitronic applications. We also discuss the implications of CIOS on the ongoing controversy regarding the mechanism of CISS.

References

[1] Kenta Hagiwara, Ying-Jiun Chen, Dongwook Go, Xin Liang Tan, Sergii Grytsiuk, Kui-Hon Ou Yang, Guo-Jiun Shu, Jing Chien, Yi-Hsin Shen, Xiang-Lin Huang, Fang-Cheng Chou, Iulia Cojocariu, Vitaliy Feyer, Minn-Tsong Lin, Stefan Blügel, Claus Michael Schneider, Yuriy Mokrousov, and Christian Tusche, ***Orbital Topology of Chiral Crystals for Orbitronics,*** Advanced Materials 2418040 (2025).

[2] Dongwook Go *et al.*, In Preparation.

Phenomenology of altermagnets and structure, dynamics and control of altermanetic textures

O. Gomonay

JGU, Mainz, Germany

We present a phenomenological theory of altermagnets, that captures their unique magnetization dynamics and allows modelling magnetic textures in this new magnetic phase. The main ingredient of the theory is an altermagnetic order parameter that describes the local environment of the magnetic atoms. In combination with the sublattice magnetizations of the Néel, this order parameter allows to generalize a standard micromagnetic approach to the dynamics of altermagnetic systems and to predict non-trivial magnetic contributions in transport and optical tensors (e.g. crystal Hall conductivity or odd magneto-optical dichroism).

We illustrate the application of the theory to the different types of altermagnets and show nontrivial altermagnetic effects that appear in the altermagnetic textures and their dynamics. In particular, we show that the altermagnetic domain walls, in contrast to antiferromagnets, have a finite gradient of the magnetization, even for 180^0 domain walls. This effect is explained by the emergence of an effective sublattice-dependent anisotropic spin stiffness arising naturally from the phenomenological theory. We also show that bending the film without stretching induces a local magnetization proportional to the gradient of the film curvature. The amplitude of the magnetization directly reflects the altermagnetic symmetry and depends on the direction of bending. Its angular distribution correlates with that of the altermagnetic splitting of the magnon and electronic bands.

Spin Demons in *d*-wave Altermagnets

P.M. Gunnink[1], J. Sinova[1] and A. Mook[2]

[1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany
[2]University of Münster, Institute of Solid State Theory, 48149 Münster, Germany

Demons are a type of plasmons, which consist of out-of-phase oscillations of electrons in different bands [1,2]. Here, we show that d-wave altermagnets, a recently discovered class of collinear magnetism, naturally realize a spin demon, which consists of out-of-phase movement of the two spin species [2]. The spin demon lives outside of the particle-hole continuum of one of the spin species, and is therefore significantly underdamped, reaching quality factors of >10. We show that the spin demon carries a magnetic moment, which inherits the d-wave symmetry. Finally, we consider both three- and two-dimensional d-wave altermagnets, and show that spin demons exist in both.

References

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[3] P. M. Gunnink, J. Sinova, A. Mook, Phys. Rev. Lett. 135, 126701 (2025)

Engineering Topological Antiferromagnetic Solitons for Spintronics

Hariom Jani

University of Oxford, Oxford, UK

Platforms hosting topological spin solitons, such as skyrmions, merons and bimerons, offer promising pathways toward non-volatile, low-power spintronic and magnonic devices. While ferromagnetic systems have been widely explored over the last decade, their performance is inherently limited by sensitivity to stray magnetic fields, long-range magnetostatic coupling, and slow gyrotropic motion.

Antiferromagnets provide a compelling alternative. Their compensated spin order eliminates dipolar fields, enabling robust, scalable solitons that exhibit ultrafast terahertz dynamics – up to three orders of magnitude faster than ferromagnetic counterparts.[1] However, experimental progress in this field has been hampered by spin compensation of antiferromagnets, making it challenging to design and harness antiferromagnetic solitons.

I will discuss how we discovered these elusive textures by combining advances in quantum materials engineering and X-ray spectro-microscopy.[2] By emulating the topological physics of the Kibble-Zurek mechanism,[3] originally proposed in cosmology, we generated a broad family of nanoscale solitons in hematite (α-Fe_2O_3) at room temperature. These textures behave as emergent magnetic charges (including monopoles, dipoles, and quadrupoles), allowing direct readout of soliton vorticity.[4] Importantly, we show that soliton hosting antiferromagnets can be precisely engineered using fields,[4,5] doping,[6] and strain,[7,8] thereby, enabling unprecedented control over soliton structure, dimension, and dynamics.

I will conclude by outlining emerging opportunities for harnessing antiferromagnetic solitons in ultrafast, energy-efficient spintronic and magnonic devices operating at terahertz frequencies.

References

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[7] H Jani,* J Harrison,* et al. *Nature Materials* **23**, 619 (2024).
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Time-evolution of chiral Néel magnetic domain walls in multilayers probed by soft x-ray resonant magnetic scattering.

N. Jaouen[2]

[1]Synchrotron SOLEIL,Saint-Aubin, BP48, 91192 Gif-sur-Yvette, France

Non-collinear spin textures in ferromagnetic ultrathin films are attracting a renewed interest fueled by possible fine engineering of several magnetic interactions, notably the interfacial Dzyaloshinskii-Moriya interaction in magnetic multilayers. This allows the stabilization of complex chiral spin textures such as chiral magnetic domain walls (DWs), spin spirals, and magnetic skyrmions among others. We have recently shown that circular dichroism in x-ray resonant magnetic scattering (XRMS) is a powerful tool to determine the domain wall characteristics, i.e., their type (Néel or Bloch) and sense of rotation (chirality) in ferromagnetic or antiferromagnetic multilayers [1,2,3].

In the first part of this presentation, we will report on the ultra-fast (in the first few picoseconds) evolution of the magnetic chirality in multilayers as well as their recovery on longer timescale (few hundreds of picoseconds) using XRMS [4]. Beyond the simple evolution of the magnetic domains' period in magnetic multilayers with large perpendicular anisotropy we have investigated how the chirality of the non-collinear spin texture, and their long-range ordering, evolves in the few picoseconds after a strong optical pulse. The change in the ratio between the chiral and magnetic signals have been related to an ultra-fast distortion of the homo-chiral Néel shape to transient Bloch Néel-Bloch domain wall. After a few ps, the DWs return to a homochiral Néel configuration preserving the original sense of rotation (i.e., chirality). At longer timescale, the whole system relaxes towards its original homochiral Néel type equilibrium but the chiral magnetic order in the domain walls recovers faster than the collinear magnetic order in the domains.

In the second part, we will present new result obtained from spin-spiral in synthetic antiferromagnetic multilayers [5]. This recent work has been done thanks to a new mode of operation of FERMI light source allowing to perform time resolved XRMS at Fe L edges (700eV) [6] following the approach we developed at synchrotron [3].

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Chiral phonons and multiferrons

Dominik M. Juraschek[1]
[1]*Eindhoven University of Technology, Eindhoven, Netherlands*

Chiral phononics is an emerging field that utilizes the angular momentum and effective magnetic fields produced by circularly polarized lattice vibrations to manipulate the properties of quantum materials. In this talk, I will present an overview of the field of chiral phonons and then discuss how they lead to novel magnetic lattice excitations in inversion-symmetry broken materials. In particular, we show how anharmonic elliptical phonons in ferroelectrics carry both a net electric and magnetic dipole moment (Fig. 1, left) and can be treated as a new quasiparticle: the *multiferron* [1, 2]. We further show that these multiferrons carry net electric and magnetic quadrupole moments, making them *multipolons* at the same time. In addition, we show that multiferron-like excitations are possible in nonpolar materials, when elliptical phonons are nonlinearly coupled to infrared-active phonons (Fig. 1, right) [3].

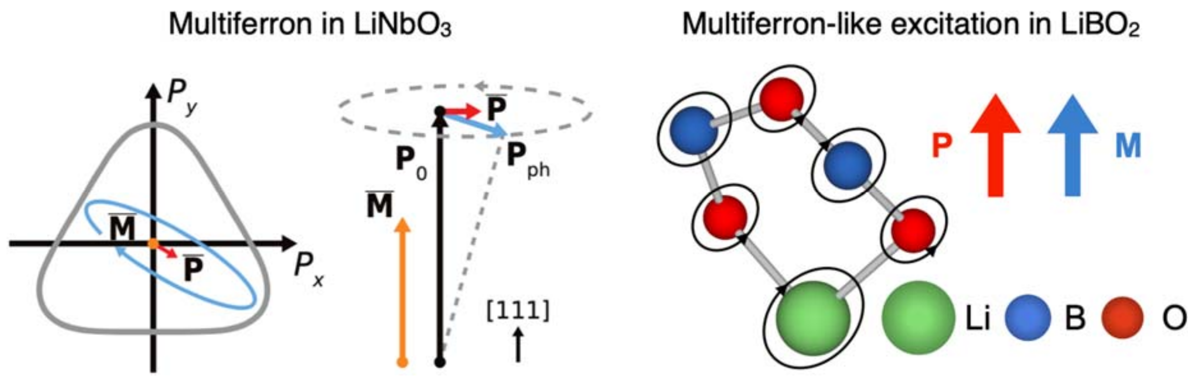

Fig. 1: Lattice excitations carrying both electric and magnetic dipole moments. Left, schematic of a multiferron in $LiNbO_3$, arising from an anharmonic elliptical phonon. Right, schematic of a multiferron-like excitation in $LiBO_2$, arising from an elliptical phonon coupled nonlinearly to an infrared-active phonon.

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Nonlinear spin dynamics under thermal and quantum fluctuations

Lukas Körber, Rein Liefferink, Pim Coenders, and Johan H. Mentink

Radboud University, Institute of Molecules and Materials,
Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands

Although magnetism is fundamentally quantum mechanical, classical nonlinear models such as micromagnetism and atomistic spin dynamics have proven remarkably successful in describing a wide range of static and dynamic phenomena — including topological solitons and spin textures, parametric resonance, ultrafast switching, auto-oscillations, and even chaos. In quantum mechanics, the nonlinearity of magnetism originates from the angular-momentum algebra of spin operators and manifests in classical theories through spin vectors of fixed length. This geometric constraint gives rise to the rich nonlinear behavior of magnetic systems. It also plays a key role in the existence of topologically nontrivial spin textures, such as skyrmions, which can appear in chiral magnets and whose emergent dynamics are captured by collective-variable theories, such as the Thiele model. However, the aforementioned theories begin to fail when fluctuations, both thermal and quantum, become strong.
Here, we present two complementary theoretical frameworks that address this breakdown from different directions. Firstly, strong laser excitation of chiral magnets can induce significant thermal fluctuations, leading to the ultrafast nucleation of skyrmions. As the Thiele model cannot capture these nonlinear dynamics, they require numerical modeling using Langevin atomistic spin models. To describe them at the emergent soliton level, we propose an effective theory in which the skyrmion number is treated as a stochastic variable evolving through thermally activated nucleation and annihilation events [1]. Secondly, on even shorter spatiotemporal scales, quantum fluctuations become increasingly essential and undermine the very notion of classical spin vectors [2]. While numerical quantum many-body techniques can capture particular nonlinear spin dynamics, they are computationally demanding and often obscure the connection between nonlinear dynamics and its geometric origin in angular momentum algebra. To bridge this gap, we introduce a semiclassical spin-correlation theory that evolves spin correlations on the bonds of a lattice, rather than individual spins, thereby incorporating nonlinear dynamics beyond classical models while retaining the su(2) geometry — and thus the intrinsic nonlinearity — of the spins. These two approaches provide stepping stones towards the understanding of nonlinear spin dynamics in regimes of strong thermal or quantum fluctuations.

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Simulating Dicke Physics with Spin-Magnon Coupling in Rare Earth Orthoferrites

Junichiro Kono

Rice University, Houston, Texas, U.S.A.

This talk describes our recent studies of Dicke cooperativity — the many-body enhancement of light-matter interaction, a concept in quantum optics — realized in condensed matter systems [1]. This enhancement enables the ultrastrong coupling (USC) regime, where new phenomena emerge from the breakdown of the rotating wave approximation (RWA) [2]. We first describe our observation of USC in a 2D electron gas in a high-*Q* terahertz cavity under a magnetic field [3]. The electron cyclotron resonance peak exhibited a polariton splitting whose magnitude is proportional to the square root of the electron density, a hallmark of Dicke cooperativity. Additionally, we have obtained definitive evidence for the vacuum Bloch-Siegert shift [4], a direct signature of the breakdown of the RWA.

Furthermore, we have demonstrated that cooperative USC also occurs in magnetic solids through matter-matter interactions, specifically spin-magnon [6] and magnon-magnon [7] interactions in rare-earth orthoferrites [8]. Particularly, the exchange interaction of N paramagnetic Er^{3+} spins with an Fe^{3+} magnon field in $ErFeO_3$ exhibited a vacuum Rabi splitting whose magnitude is proportional to $N^{1/2}$ [6]. In the lowest temperature range, these cooperative interactions lead to a magnonic superradiant phase transition [9-11], where the role of atoms (photons) is played by Er^{3+} spins (Fe^{3+} magnons). Through terahertz magnetospectroscopy measurements, we demonstrated the existence of a novel atomically ordered phase in addition to the superradiant and normal phases that are expected from the standard Dicke model. These results provide a route for understanding, controlling, and predicting novel phases of condensed matter using concepts and tools available in quantum optics.

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Crystal-Field–Driven Magnetoelectric Coupling in the Triangular-Lattice Quantum Magnet $CeMgAl_{11}O_{19}$

Sonu Kumar[1,2], Gael Bastien[1], Petr Proschek[1], Maxim Savinov[3], Karol Zaleski[4], Malgorzata Sliwinska-Bartkowiak[2], Ross Colman[1], Stanislav Kamba[3]

[1]*Charles University, Faculty of Mathematics and Physics,*

Department of Condensed Matter Physics, Prague, Czech Republic

[2]*Adam Mickiewicz University, Faculty of Physics and Astronomy,*

Department of Experimental Physics of Condensed Phase, Poznań, Poland

[3]*Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic*

[4]*Adam Mickiewicz University, NanoBioMedical Centre, Poznan, Poland*

Abstract

$CeMgAl_{11}O_{19}$ represents a unique materials platform in which a triangular-lattice Kramers 4f magnet coexists with a geometrically frustrated antipolar structural lattice, allowing direct biquadratic coupling between magnetic and electric-dipole fluctuations in a centrosymmetric ($P6_3/mmc$) crystal [1].

We present temperature- and magnetic-field-dependent dielectric permittivity and magnetization measurements. Above 25 K, the permittivity follows the Barrett quantum-paraelectric form. On cooling, a broad minimum appears near 3 K without evidence of long-range magnetic or ferroelectric order. Application of magnetic fields up to 9 T systematically shifts this anomaly to higher temperatures, revealing a strong and continuously tunable magnetoelectric response.

Detailed analysis shows that the characteristic temperature T* of the dielectric anomaly scales exactly as $T^* \propto M^2$ across the entire field range, where M is the magnetization described by a Brillouin function. This linear T^*–M^2 relation constitutes direct experimental proof of dominant biquadratic P^2M^2 magnetoelectric coupling permitted by the crystal symmetry.

A quantitative microscopic model based on the Ce^{3+} crystal-field level scheme [2] demonstrates that virtual crystal-field excitations within the ground-state Kramers doublet fully account for the observed coupling strength, without invoking higher multipoles or exchange striction.

These findings establish $CeMgAl_{11}O_{19}$ as a model system for fluctuation-driven magnetoelectricity in frustrated rare-earth compounds and highlight general design rules for engineering sizable magnetoelectric responses via orbital-active ions in centrosymmetric lattices. Ongoing experiments probing coupled spin and dipolar dynamics under simultaneous electric and magnetic fields will also be discussed.

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Dynamics of periodically driven topological magnetic defects

Maxim Mostovoy

Zernike Institute for Advanced Materials, University of Groningen,

Nijenborgh 3, 9747 AG Groningen, The Netherlands

Low-energy dynamics of magnetic topological defects is governed by collective modes, e.g., center-of-mass coordinates and helicity of skyrmions, as well as the local excitations of the defects with energies below the magnon continuum. The coupling between these modes makes it possible to excite complex, large-amplitude dynamics by periodically oscillating electromagnetic fields and electrical currents. In particular, skyrmions in frustrated magnets with a centrosymmetric crystal lattice can have a local electromagnon mode that can be excited by both electric and magnetic fields and is coupled to the skyrmion chirality. This mode is responsible for the deformation of a moving skyrmion that makes it massive. I will discuss the dynamics of periodically driven topological defects, simulated numerically and described analytically using generalized Thiele equations. I will also consider the motion of topological defects embedded into an inhomogeneous magnetic background, such as the spin-spiral state.

Towards Spintronics with Altermagnets

Helena Reichlová[1]* *et al.*
[1]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic
*reichlh@fzu.cz

Altermagnets represent a newly emerging class of magnetic materials that combine favorable properties of ferromagnets and antiferromagnets, offering great promise for future spintronic applications. A range of theoretical predictions has highlighted their unique electronic structure and spin-transport phenomena. In this talk, I will first summarize the potential of altermagnets for spintronics, providing an overview of known material systems and the current experimental evidence supporting altermagnetic behaviour. In the second part, I will focus on our spin transport experiments in altermagnets. I will present some of the initial experimental verifications performed on single-layer samples. Particular attention will be given to the anomalous Hall effect, which is symmetry-forbidden in conventional collinear antiferromagnets but can arise in altermagnets due to time-reversal symmetry breaking in their electronic band structures. This effect thus serves as a key experimental signature for identifying altermagnetic materials. Finally, I will discuss our ongoing spin transport studies in multilayer structures with altermagnets.

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Self-induced Floquet magnons in magnetic vortices

C. Heins[1,2], L. Körber[1,2,3], J.-V. Kim[4], T. Devolder[4], J. H. Mentink[3], A. Kakáy[1], J. Fassbender[1,2], H. Schultheiss[1], K. Schultheiss[1]

[1]*Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany*
[2]*Technische Universität Dresden, Dresden, Germany*
[3]*Radboud University, Nijmegen, The Netherlands*
[4]*Université Paris-Saclay, Palaiseau, France*

Magnetic vortices are prototypical examples of topological textures in magnetism, characterized by a rich magnon spectrum as well as the eigen-resonance of the vortex texture itself, the gyration of its core. These two types of excitations are usually well separated in frequency: the vortex core typically gyrates in the sub-GHz range, while magnon eigenmodes appear in the lower GHz range. This frequency separation provides a unique opportunity to study the interaction between collective spin-wave excitations and the time-periodic modulation of the magnetic ground state.

When the vortex core gyration is coherently driven, it imposes a temporal periodicity on the system that couples back to the magnon spectrum. In this driven regime, Floquet magnon bands emerge: energy states that are shifted by integer multiples of the drive frequency, in close analogy to Bloch states in crystalline lattices. Our experimental results, corroborated by micromagnetic simulations, reveal how regular magnon modes hybridize with this temporal lattice and transform into new Floquet states. These excitations are distinct from both the static magnon spectrum and the vortex core resonance, representing new quasiparticles in driven magnetic systems.

Beyond their fundamental interest, Floquet-engineered magnons display frequency comb formation, where resonant mode coupling generates a set of equidistant spectral lines. This effect provides a versatile mechanism for frequency down-conversion and broadband signal generation across the GHz range. These results illustrate how time-periodic driving can induce non-equilibrium states with novel dynamical properties, opening pathways for tailored spin dynamics and new functionalities in magnon-based information processing.

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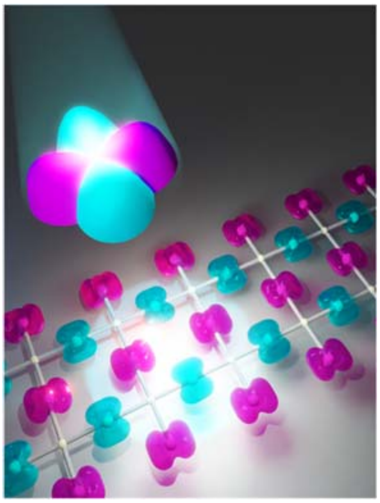
Unconventional Magnetism: the emergence of altermagnetism and beyond

Jairo Sinova

Johannes Gutenberg University Mainz, Germany

Antiferromagnetic spintronics has been a very active research area of condensed matter in recent years. As we have learned how to manipulate collinear antiferromagnets actively and their emergent topology by means of new types of spin-orbit torques, a key problem remained: the inefficiency of relativistic mechanism. The necessity of relativistic effects to manipulate and detect Néel order arises from the spin degeneracy of collinear antiferromagnets in the non-relativistic limit – or at least it was thought. The discovery of d-wave magnetic order in momentum space motivated a closer look at the symmetry classification of collinear magnetic systems. This has emerged as the third basic collinear magnetic ordered phase of altermagnetism, which goes beyond ferromagnets and antiferromagnets. Altermagnets exhibit an unconventional spin-polarized d/g/i-wave band structure in reciprocal space, originating from the local sublattice anisotropies in direct space. This gives properties unique to altermagnets (e.g., the spin-splitter effect), while also having ferromagnetic (e.g., polarized currents) and antiferromagnetic (e.g., THz spin dynamics and zero net magnetization) characteristics useful for spintronics device functionalities. I will cover the basic introductory view to altermagnetism and its consequences to spintronics as well as new emerging exchange driven phenomena akin to spin-orbit coupling effects, such as p-wave magnetism, emerging from the basic concepts that gave rise to the discovery of altermagnetism.



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Jeroen van den Brink

Institute for Theoretical Solid State Physics, IFW Dresden, Germany

Altermagnetic materials are characterized by collinear magnetic order with a vanishing net magnetic moment, but nevertheless have a spin-splitting in their non-relativistic electronic band structure. From ab initio calculations, we have identified around 60 altermagnetic materials. From a theoretical point of view, several physical properties that render altermagnets different from canonical antiferro-, ferro- and ferri-magnets will be discussed. These include certain spin and heat transport features and piezomagnetic responses. By symmetry in principle also an anomalous Hall effect (AHE) is allowed in certain altermagnets. In particular we introduce an altermagnetic model in which the emergence of an AHE is driven by interactions. Quantum Monte Carlo simulations show that the system undergoes a finite temperature phase transition governed by a primary antiferromagnetic order parameter accompanied by a secondary altermagnetic one. The emergence of both orders turns the metallic state of the system, away from half-filling, into an altermagnet with zero net moment but a finite AHE.

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Harnessing photons to probe topological magnons

S. Viola Kusminskiy[1]

[1]*Institute for Theortical Solid State Physics, RWTH Aachen University, Otto-Blumenthal-Straße 26, Aachen, 52056 Germany*

In this talk I will go over different examples on how the coupling to photons in topological magnets can be harnessed to probe the quantum geometric properties of the magnon bands. I will show that two-magnon Raman processes, either via photon scattering or photon absorption, provide a tool to probe topology, in particular the Chern number and the topological gap, or by directly accessing the topological edge states.

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Abstracts of Posters

(in alphabetical order)

The Nature of Magnetic Order in RuO_2: Probed via Magneto Transport and Muons

A. Akashdeep[1], E.M. Ababneh[2], S. Krishnia[1], T. Kuschel[1], Z. Salman[3], V. Amin[2] M. Kläui[2] and G. Jakob[1]

[1]*Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany*
[2] *Department of Physics, Indiana University, Indianapolis, Indiana 46202, USA*
[3] *PSI Center for Neutron and Muon Sciences, 5232 Villigen PSI, Switzerland*

The fundamental magnetic state of ruthenium dioxide (RuO_2), a leading candidate material for a new class of altermagnets, is still being debated. This complicates its use in spintronic devices [1, 2]. To clarify the origin of spin-dependent phenomena in reduced-dimensional systems, we combine magnetotransport analysis with direct depth-resolved magnetic probing. First, we investigate spin-charge conversion via angular-dependent magnetoresistance (ADMR) measurements in epitaxial RuO_2/Permalloy (Py) heterostructures [2]. Second, we employ depth-resolved low-energy muon spin rotation/relaxation (LE-μSR) to map the spatial extent of magnetic order within RuO_2 thin films [3]. Transport measurements on RuO_2/Py consistently reveal a robust negative ADMR signal governed by the interface-generated spin current (IGSC) effect combined with the inverse spin Hall effect [2,4]. LE-μSR data confirm that static magnetic order is confined to the near-surface region (top few nm) and exhibits inhomogeneous character. There is no evidence for magnetic order bulk of thin film [3]. Together, these results demonstrate that the complex spin transport observed in RuO_2 originates overwhelmingly from interfacial spin-orbit coupling and surface-localized magnetism, which dominates or obscures potential bulk antiferromagnetic contributions. These findings underscore the critical role of surface dimensionality and interface quality in controlling spin phenomena in RuO_2, paving the way for optimized RuO_2-based spintronic memory and sensing applications [2, 3].

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Rashba spin texture and spin Hall effects in Janus 2D materials

N. Amalia

Asia Pacific Center for Theoretical Physics, Pohang, Gyeongbuk 37673, Republic of Korea

Rashba spin–orbit coupling (SOC) plays a key role in controlling spin polarization and spin-transport properties in two-dimensional materials for spintronics applications. In 2H transition-metal dichalcogenide monolayers, the presence of out-of-plane mirror symmetry suppresses Rashba SOC and limits intrinsic spin Hall responses. Janus structures break this symmetry by placing different chalcogen atoms on opposite sides of the transition-metal plane, generating an intrinsic dipole and a built-in perpendicular electric field. Monolayer MoSeTe is expected to exhibit notable Rashba splitting due to the stronger relativistic SOC associated with the heavier chalcogen component. The resulting Rashba-driven spin texture is anticipated to modify the Berry-curvature distribution and influence intrinsic spin Hall conductivity near the band edges. This work focuses on the role of structural asymmetry and internal electric-field effects in determining the Rashba mechanism in MoSeTe, together with the possibility of electrically tuning intrinsic spin Hall behavior in polar two-dimensional systems.

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Symmetry-driven Intrinsic Nonlinear Pure Spin Hall Effect

Sayan Sarkar,[1] Sunit Das,[1,*] and Amit Agarwal[1]
[1] *Department of Physics, Indian Institute of Technology, Kanpur-208016, Uttar Pradesh, India*

ABSTRACT

The generation of *pure* spin current, spin angular momentum transport without charge flow, is crucial for developing energy-efficient spintronic devices with minimal Joule heating. Here, we introduce the intrinsic nonlinear *pure* spin Hall effect (NPSHE) [Fig. 1], where both linear and second-order charge Hall currents vanish [1]. We show intrinsic second-order spin angular momentum transport in metals and insulators through a detailed analysis of the quantum geometric origin of different spin current contributions. Our comprehensive symmetry analysis identifies 39 magnetic point groups that support NPSHE, providing a foundation for material design and experimental realization. Our first principle calculations demonstrate a significant NPSHE in a prototypical Kramers-Weyl metal RhGe, even at room temperature. This positions Kramers-Weyl metals as potential candidates for NPSHE-based spin-torque devices. Our work lays a practical pathway for realizing charge-free angular momentum transport for the development of next-generation, energy-efficient spintronic devices.

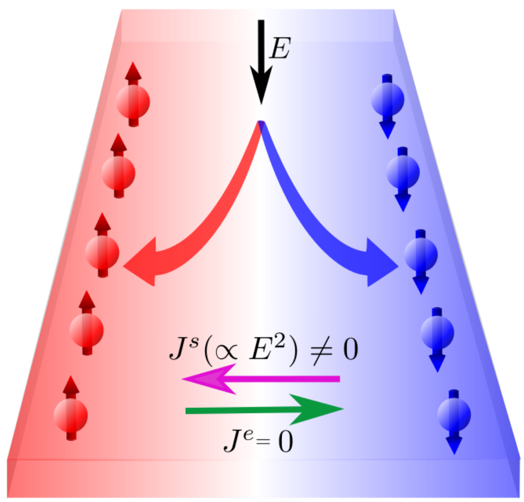

FIG. 1. **Schematic of the pure spin Hall effect.** In the pure spin Hall effect, equal and opposite spin flows cancel the net charge response, resulting in higher energy efficiency. The nonlinear *pure* spin Hall effect dominates where the linear response vanishes.

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* sunitd@iitk.ac.in

Impact of Strain on the Kondo Effect in Kagome Ribbons

P.A.Almeida,[2,1] G.B.Martins,[2] and S.E.Ulloa[1]

[1] Department of Physics and Astronomy and Nanoscale and Quantum Phenomena Institute, Ohio University, Athens, Ohio 45701-2979, Brazil
[2]Instituto de Física, Universidade de São Paulo, C.P. 66318, 05315--970 São Paulo, SP, Brazil

Kagome systems have received significant attention in recent years, primarily due to the discovery of several Kagome metals, such as AV3Sb5 [1]. These systems present rich physics that can be explored across different branches. Essentially, the Kagome lattice, in a *tight binding* description, is a 2D monolayer that features a unique band structure, combining dispersive bands-like graphene-with a completely flat band in its energy spectrum. This makes it an ideal system for analyzing both topology and correlation effects. Here, we focus on the latter by analyzing the Kondo effect in Kagome nanoribbons under the action of strain. To analyze the model itself, we use the Single Impurity Anderson Model (SIAM) and the numerical renormalization group (NRG). Our results indicate that by manipulating the strain, we can control the suppression or realization of the Kondo effect in our impurity-plus-ribbon system, as well as the size of the Kondo cloud.

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Insight into electronic correlations and spin dynamics on femtosecond timescales with ultrafast x-ray spectroscopy

Andrea Eschenlohr[1]

[1] *Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany*

Electronic correlations are crucial in determining the equilibrium properties of many materials. Under non-equilibrium conditions, specifically the excitation with ultrashort optical pulses, their influence is less well understood, although laser-driven states become increasingly interesting not just from the perspective of understanding fundamental dynamics processes involving the charge, spin and lattice degrees of freedom on femto- to picosecond timescales but also inducing new material properties or metastable states. Femtosecond time-resolved, nearly shot-noise limited x-ray absorption spectroscopy at the European X-ray Free Electron Laser [1] gives insight into the role of electronic correlations in non-equilibrium. Two different material systems will be discussed: In transition metal ferromagnets, the interplay of local electronic correlations of the 3*d* states with ultrafast spin dynamics involves band structure modifications on few 100 fs timescales [2]. In a correlated transition metal oxide, namely the prototypical charge transfer insulator NiO, resonant photoexcitation of charge carriers, so-called photodoping, results in transient energy shifts induced by Coulomb interaction, which are distinguished from non-thermal local multiplet occupations via characteristic spectral signatures [3]. It will further be outlined how femtosecond time-resolved x-ray magnetic circular dichroism complements this analysis through direct probing of spin dynamics, and how to transfer the strength of these methods to unconventional magnetically ordered materials.

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Tuning the anomalous hall effect in magnetron-sputtered Mn_5Si_3 thin films

M. Gaerner[1], M. Koll[1], J. Bünte[1], F. Peters[1], A. Hütten[1], K. Rott[1], J. Schmalhorst[1], M. Wortmann[1,2], G. Reiss[1]

[1]Bielefeld University, Faculty of Physics, 33615 Bielefeld, Germany

[2]Bielefeld University of Applied Sciences and Arts, Faculty of Engineering and Mathematics, 33619 Bielefeld, Germany

In the field of magnetic materials with unconventional symmetries, altermagnetism plays a key role. Mn_5Si_3 thin films are a prominent platform in which signatures of altermagnetism, such as the anomalous hall effect [1] or the anomalous Nernst effect [2,3], have been observed. These responses are consistent with a theoretically predicted unconventional d-wave altermagnetic state that breaks time reversal symmetry while exhibiting zero net magnetization as well as THz spin current dynamics [4]. Here, we report on the growth of epitaxial Mn_5Si_3(0001) on Al_2O_3(0001) via magnetron-sputtering. We demonstrate that a high-temperature Mn_5Si_3 seed layer significantly enhances the crystallinity of the thin films while maintaining a smooth surface morphology. Finally, we show that the emergence of a spontaneous anomalous hall effect in the Mn_5Si_3 thin films is highly sensitive to the Mn content as well as the annealing procedure, underscoring the roles of crystalline quality and vacancy concentration in stabilizing the altermagnetic state. The controlled growth of Mn_5Si_3 on Al_2O_3, which exhibits a high optical transparency compared to frequently used Si(111) substrates [1,2], paves the way for many magneto-optical experiments on the altermagnetic state of Mn_5Si_3.

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Raman Spectroscopic fingerprints of ferroelectric Soft Modes and antiferromagnetic Excitations in 2D vdW material $CuCrP_2S_6$

Shreenanda Ghosh [1,2], **Yu Fei Liu**[1], **Tiffany Soetojo**[1], **Rabindra Basnet**[3], **Ramesh Budhani**[3], **Natalia Drichko**[1]

[1]*Department of Physics and Astronomy, Johns Hopkins University, USA*
[2]*Insitute of Physics, University of Münster, Germany*
[4] *Department of Physics, Morgan State University, USA*

Multiferroic behavior in two-dimensional van der Waals materials are extremely rare, making the discovery and study of such systems both fundamentally and technologically significant. Materials that combine (anti)ferroelectricity, (anti)ferromagnetism, and ferroelasticity at the 2D limit are scarce, and despite theoretical prediction[1-2], experimental demonstrations remain elusive[3].

We use polarization-resolved Raman spectroscopy to investigate the interplay between spin, charge, and lattice dynamics in the 2D van der Waals material $CuCrP_2S_6$[4]. Below the Néel temperature ($T_N = 32$ K), two-magnon excitations appear, featuring the antiferromagnetism originating from the Cr moments. The low-frequency soft modes of Cu^{+2} ions track the transition from a paraelectric state to a glassy quasi-antipolar phase near 190 K and a fully antiferroelectric phase at ~145 K. Remarkably, the soft mode hardens and becomes more harmonic in the magnetically ordered state, providing clear spectroscopic evidence of magnetoelectric coupling. The intertwined evolution of lattice and spin degrees of freedom offers pathways to control spin dynamics via structural tuning through transition to an antiferroelectric state. $CuCrP_2S_6$ thus provides a platform to explore spin-lattice coupling, magnetoelectric interactions, and symmetry-driven dynamic phenomena in low-dimensional van der Waals materials, linking emerging concepts of unconventional symmetries and their impact on spin excitations.

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Two Distinct Regimes in Phonon-Induced Non-Equilibrium Magnetization Dynamics

Jim Groefsema[1], Viktoriia Radovskaia[1], Thom Janssen[5], Nils Dessmann[5], Peter K. Kim[1], Timur T. Gareev[1], Meng Xing Na[1], Jorrit R. Hortensius[2,3], Andrea D. Caviglia[4], Theo H. M. Rasing[1], Andrei I. Kirilyuk[5], Carl S. Davies[5], Alexey V. Kimel[1], Dmytro Afanasiev[1]

[1] Radboud University, Institute for Molecules and Materials, 6525 AJ Nijmegen, Netherlands
[2] Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, Netherlands
[3] Electromagnetic Signatures and Propagation, TNO, 2597 AK The Hague, The Netherlands
[4] Université de Genève, Department of Quantum Matter Physics, 24, Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland
[5] HFML-FELIX Laboratory, Radboud University, 6525 ED Nijmegen, The Netherlands

Intense pulses of mid-infrared radiation, tuned in resonance with infrared (IR) active phonons, known as phonon pumping, can induce non-equilibrium structural distortions in the crystal lattice, significantly affecting their electronic properties. Recent years have witnessed a rapid advance of this approach for ultrafast control of ordered spins. Starting from the excitation of coherent spin precession [1] and subtle demagnetization [2] the phonon-pumping has led to tantalizing demonstrations of ultrafast coherent switching between magnetic orders [3], and complete reversal of the spin orientation [4].

The spontaneous Morin phase transition in dysprosium orthoferrite ($DyFeO_3$) is an interesting example of a first-order magnetic phase transition, where the magnetic system can be thermally switched between antiferromagnetic and weakly ferromagnetic spin orders. Recently, we demonstrated that by resonantly pumping IR-active phonons this phase transition can be driven nonthermally on an ultrafast timescale. Our findings showed that the transition proceeds via a transient metastable state not accessible in equilibrium, suggestive of a dynamic competition and thus inhomogeneous spin dynamics.

In this study, we visualize the spatio-temporal evolution of the phonon-driven phase transition in $DyFeO_3$ using the unique capabilities of single-shot pump-probe magneto-optical imaging at Nijmegen's Free Electron Laser (FELIX). We reveal not only spatio-temporal snapshots of the phonon-induced magnetization dynamics but also demonstrate that the direction of the magnetization inherent to the phonon-induced weakly ferromagnetic order can be unambiguously controlled by the polarization of the IR-driven phonon. We further discuss potential pathways enabling such control.

Figure 1: Three magnetooptical images of $DyFeO_3$ highlighting the photo-induced magnetization effects and the antiferromagnetic domains determined by the polarization of the incoming pump pulse. These images were obtained by removing the background as obtained from images with no photo-induced effects.

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A metallic *p*-wave magnet with commensurate spin helix

Max Hirschberger[1,2], Rinsuke Yamada[1], Max T. Birch[2], Moritz M. Hirschmann[2]

[1]Department of Applied Physics and Quantum-Phase Electronics Center, The University of Tokyo, Japan, [2]RIKEN Center for Emergent Matter Science, Wako, Japan

Antiferromagnets with nonrelativistic spin splitting in their electronic structure are drawing significant attention. Among these are *p*-wave magnets as well as *d*- or *g*-wave altermagnets [1]. All of these are thought to be suitable for next-generation applications in spintronics, but the *p*-wave magnet is especially appealing due to a nonrelativistc Edelstein effect, which corresponds to a spin-accumulation driven by an electric current [2,3].

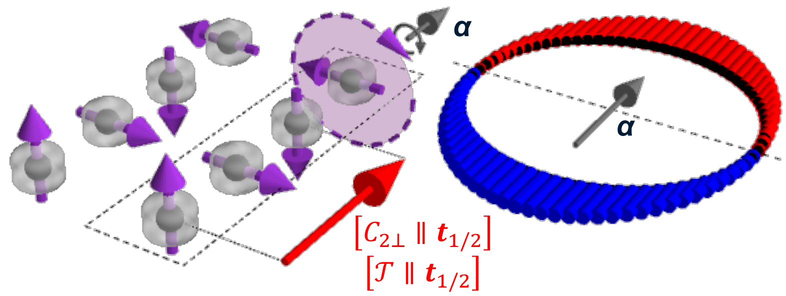

Figure: *p*-wave magnetism (conceptual). Left: commensurate magnetic structures with a coplanar but noncollinear arrangement are required according to Ref. [1]. They must break inversion symmetry but satisfy certain symmetries (red arrow and labels), such as spin rotation + translation. Right: The spin polarization in momentum space is collinear along $\boldsymbol{\alpha}$, i.e., perpendicular to the spin rotation plane (purple circle) in real space. From Ref. [4].

The electronic structure of a *p*-wave magnet features parity-odd spin splitting. In Fig. 1 (right side), the red and blue bars indicate the average spin polarization in a certain sector of momentum space. The region where spin-up and spin-down bands are degenerate is called a nodal plane (dashed line in the image). Ref. [1] points out symmetry conditions for *p*-wave magnetism, stressing the requirement of a lattice-commensurate, noncollinear (but coplanar) magnetic texture.

We have tuned a helimagnetic material to the lattice-commensurate limit by careful tuning of the chemical potential, and observe giant responses in the electronic properties only in the *p*-wave state [4].

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Time-reversal symmetric f-wave magnets

Moritz M. Hirschmann[1] and Max Hirschberger[1,2]

[1] *RIKEN Center for Emergent Matter Science, Wako, Japan*
[2] *Department of Applied Physics and Quantum-Phase Electronics Center, The University of Tokyo, Japan*

When electrons couple to a magnetic order, the resulting angular dependence of the electronic band splitting can be expanded in real spherical harmonics. Given a well-defined spin axis, the splitting can be categorized into even-parity magnets (ferro- and altermagnets) and the more recently introduced odd-parity magnets [1,2]. As an extension of the latter class, we discuss a spin splitting restricted to a single f-wave component, enforced by spin-space symmetries. A coplanar magnetic order with these symmetries coupled to electrons leads to three intersecting spin nodal lines (in 2D) or nodal planes (in 3D) that separate the regions of opposite spin splitting.

To quantify the f-wave character, we analytically determine the spin splitting and spin polarization (Fig. 1) in the continuum limit in terms of hopping and exchange coupling. Linear Boltzmann transport theory of f-wave magnets in a ribbon geometry predicts an inhomogeneous, anisotropic Edelstein effect. The spin accumulation qualitatively depends on position (edge vs. bulk) and the orientation of the edge.

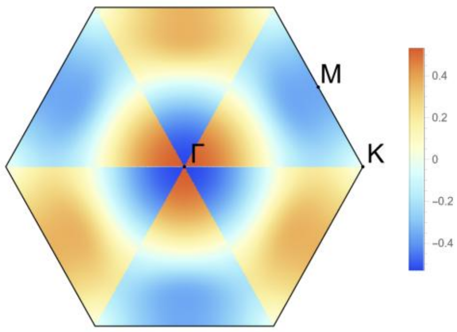

Figure 1: Spin polarization for an *f*-wave magnet.

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Investigating Magnetic Material Parameters From Latent Measures

Kübra Kalkan[1], Ross Knapman[1,2], Atreya Majumdar[1], and Karin Everschor-Sitte[1]

[1]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, 47057 Duisburg, Germany

[2]Institute of Mechanics, University of Duisburg-Essen, Germany

Ideal magnetic materials would significantly enhance the performance and energy efficiency of modern technological devices [1]. In practice, however, real magnetic samples inevitably exhibit spatial inhomogeneities that weaken magnetic properties and limit device capabilities. Understanding how these imperfections affect magnetization dynamics is therefore essential for advancing both fundamental insight and effective material optimization. In this study, we investigate how spatial variations in exchange stiffness and uniaxial anisotropy affect high-temperature magnetization dynamics in thin films. By applying physically inspired latent-inference methods [2, 3] to micromagnetic simulations, we develop a physics-informed, data-driven framework for quantifying the impact of inhomogeneities. This approach enables the inference of material parameters directly from highly fluctuating magnetization behavior, offering a route toward a deeper understanding and the design of more energy-efficient magnetic materials.

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Stabilizing and Steering Multi-Skyrmion Bags

<u>L.-M. Kern</u>[1,2], V. M. Kuchkin[3], V. Deinhart[4], C. Klose[2], T. Sidiropoulos[2], M. Auer[2], S. Gaebel[2], K. Gerlinger[2], R. Battistelli[5,6], S. Wittrock[5], T. Karaman[6], M. Schneider[2], C.M. Günther[7], D. Engel[2], I. Will[2], S. Wintz[5], M. Weigand[5], F. Büttner[5,6], K. Höflich[4], S. Eisebitt[2,8], and B. Pfau[2].

[1]Massachusetts Institute of Technology, Cambridge, MA, USA.
[2] Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany.
[3]University of Luxembourg, Luxembourg.
[4]Ferdinand-Braun-Institut, Berlin, Germany.
[5]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany.
[6]University of Augsburg, Augsburg, Germany.
[7]TU Berlin, Zentraleinrichtung Elektronenmikroskopie, Berlin, Germany.
[8]TU Berlin, Institut für Optik und Atomare Physik, Berlin, Germany.

Topologically non-trivial magnetic solitons such as skyrmions are complex spin textures with particle-like properties [1]. While unit-charge (π) skyrmions have been widely explored for their potential in spintronic applications, higher-order topological textures—such as skyrmion bags—have remained largely theoretical [2,3] due to challenges in experimental realization.

We have recently demonstrated the controlled formation and stabilization of isolated higher-order skyrmion configurations in ferromagnetic thin films [4]. Specifically, we achieve the nucleation of skyrmionium (2π-skyrmion), target skyrmion (3π-skyrmion), and tunable-charge skyrmion bags through the introduction of localized anisotropy defects via focused ion irradiation [5]. These engineered defects act as preferential sites for the generation of these complex topological textures. In addition, we compare two formation pathways—magnetic fields and ultrafast laser pulses—and find that laser pulses produce a significantly higher conversion rate of π-skyrmions into higher-order skyrmion bags. High-resolution x-ray magnetic circular dichroism (XMCD) imaging enables direct observation of the stabilized textures. Micromagnetic simulations further reveal that defect geometry, especially diameter, plays a key role in stabilizing closed-loop spin structures.

These findings provide a practical approach for their controlled generation in a scalable material platform. Skyrmion bags show exciting potential: their response to currents or laser pulses could trigger internal motion, shape changes, or oscillations [6]. These dynamic effects could be ideal for energy-efficient neuromorphic computing and future applications in sensing and complex data processing.

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Spin wave pulses in antiferromagnetic insulators

P. Kim[1], B.A. Ivanov[1], J. Groefsema[1], M.X. Na[1], V. Radovskaia[1], M.B. Strugatsky[2], A. Kimel[1], D. Afanasiev[1]

[1]*Radboud University, Nijmegen, the Netherlands*

[2]*Taurida National University, Simferopol*

Coherent magnons, or spin waves, provide a powerful platform for information processing and transport in magnetic devices due to their lack of Joule heating, short wavelengths, and intrinsic nonlinearities [1]. However, achieving controlled, high velocity spin wave pulses (SWPs) that remain nondispersive during propagation has remained a central challenge. To this end, antiferromagnets offer key advantages with their THz operating frequencies and linear magnon dispersions near the Brillouin zone center, in contrast to the GHz frequencies and quadratic dispersions typically found in ferro- and ferrimagnetic systems [2]. In this work, we demonstrate the generation of highly spatially- and temporally-confined coherent SWPs in the canted antiferromagnet FeBO3, where the linear magnon dispersion is essential to achieving nondispersive propagation over several microns. We experimentally and theoretically investigate ultrafast optical excitation above the band gap to impulsively generate coherent spin waves in a spatially confined region, thereby accessing large bandwidths in both frequency and k-space [3,4]. The resulting SWPs propagate over distances greater than 8 microns at a velocity of 14.5 km/s. These findings lay the groundwork for high speed and long-range spin wave transport, opening opportunities for ultrafast antiferromagnetic spin-wave technologies.

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Leveraging Distortion-Aware Magnetic Symmetry Groups to Predict Altermagnetism

M. Kitcher[1] **and G. Beach**[1]

1. Massachusetts Institute of Technology, Cambridge, MA 02139

Altermagnets—materials exhibiting crystal-compensated magnetic order and non-relativistic spin splitting—have gained attention for their unconventional physics and technological promise [1]. In altermagnets, crystallographic rotations connect opposite spin sublattices, distinguishing them from antiferromagnets and ferromagnets under the spin group classification scheme [2]. While their nonrelativistic order parameters [3] can engender large tunneling magnetoresistance and spin-splitter torques [1], other magneto-transport phenomena, such as anomalous Hall conductivity, are mediated by spin–orbit coupling (SOC) [4]. The symmetries of such relativistic properties are therefore dictated by the magnetic symmetry groups, which do not differentiate between altermagnetic and purely relativistic effects [5]. In this work, we present a new framework for identifying altermagnetism, leveraging a recent formalism for capturing the latent symmetries of structural distortions with respect to a parent crystal [6]. By assigning a magnetic distortion point group (MDPG) to a magnetic crystal, we can determine if it hosts a nonrelativistic coupling between antiferromagnetic order and staggered distortions that break both translation-time and parity-time symmetries. Using MDPGs, we can also predict the symmetries of SOC-mediated altermagnetic properties and distinguish them from purely relativistic effects based on how they couple to distortions. Our work provides valuable insights into the synergies between multiferroicity, altermagnetism, and spin-orbit coupling—and affirms magnetic distortion symmetry groups as powerful tool for classifying and characterizing magnets.

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Vectorial spin-to-charge conversion by supramolecular chirality

Sophie Knewitz[1] , **Guillaume Schweicher**[2], **Ashish Moharana**[1], **Yves Geerts**[2], **and Angela Wittmann**[1]

[1]Johannes Gutenberg-Universität, Mainz, Germany
[2]Université libre, Brussels, Belgium

The chiral-induced spin selectivity (CISS) effect describes how electrons get spin-polarized due to the presence of chiral molecules. The high polarization efficiency makes it promising for future sustainable hybrid chiral molecule magnetic applications. While there are many experimental reports of different aspects of the CISS effect, a complete understanding of the fundamental mechanisms remains an open challenge. In this work, we investigate the role of supramolecular chirality and atomic spin-orbit coupling on the CISS effect in hybrid metal thin film / chiral organic crystal heterostructures. Using spin pumping to inject a pure spin current in the metal thin film, we probe the spin-to-charge conversion at the chiral interface. Based on our recent finding that CISS is a vectorial effect [1], we use a molecular chiral crystal to probe the CISS effect in a well-ordered system in order to maximize the polarization efficiency. Our angle-dependent measurements confirm that the spin selectivity of the chiral supramolecular crystal is highly sensitive to its orientation relative to the spin direction in the metal thin film under the applied magnetic field. These results open new ways for the vectorial manipulation of hybrid spintronic devices by chirality.

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Curvature-Induced Magnetization of Altermagnetic Films

K. Yershov[1,2], O. Gomonay[3], J. Sinova[3], J. van den Brink[1], V. Kravchuk[1,2]

[1]Leibniz-Institut für Festkörper- und Werkstoffforschung, IFW Dresden, 01171 Dresden, Germany
[2]Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine, 03143 Kyiv, Ukraine
[3]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55099 Mainz, Germany

The altermagnetic nature of a large class of magnetically ordered materials is the source of a wide range of new effects. Here, we show [1] that the merging of two areas, namely the altermagnetism and the physics of curvilinear low-dimensional magnets, gives rise to a distinct novel physical effect: a curvature-induced magnetization in bent altermagnetic films. This effect opens a promising possibility for imaging the domain structure in the magnetically compensated structures. We consider a thin film of a d-wave altermagnet bent in a stretching-free manner and demonstrate that gradients of the film curvature induce a local magnetization that is approximately tangential to the film. The magnetization amplitude directly reflects the altermagnetic symmetry and depends on the direction of bending. It is maximal for the bending along directions of the maximal altermagnetic splitting of the magnon bands. A periodically bent film of sinusoidal shape possesses a total magnetic moment per period proportional to A^2q^4, where A and q are the bending amplitude and wave vector, respectively. The total magnetic moment is perpendicular to the plane of the unbent film, and its direction (up or down) is determined by the bending direction. A film roll-up to a nanotube possesses a toroidal moment directed along the tube. The toroidal moment per coil is proportional to $\delta r/r^2$, where r and δr are the coil radius and the pitch between coils, respectively. All these analytical predictions agree with numerical spin-lattice simulations.

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Enhancement of Intrinsic Spin Hall Conductivity in $W_{1-x}Mo_x$ alloys

Hyun Ju Lee[1*], Quynh Anh T. Nguyen[2], and S. H. Rhim[1†]

[1]*Department of Physics, University of Ulsan, Ulsan 44610, Republic of Korea.*
[2]*Quantum Magnetic Sensing Group, Korea Research Institute of Standards and Science, Daejeon 34113, Republic of Korea*

Spintronics applications based on spin-orbit torque (SOT) have been attracted interest due to their fast switching speed and low switching current. [1-2] β-tungsten with the A15 structure exhibits strong spin-orbit coupling and large spin Hall angle (up to -0.4), enabling efficient spin current generation in SOT-driven switching. Notably, improvement of spin Hall conductivity (SHC) is achieved in alloys such as W-Si, W-N, and W-Ti. [3-8] Here, SHC of $W_{1-x}Mo_x$ (x = 12.5%, 25%, 50%), is investigated using first-principle calculations. At each concentration, various configurations are considered, where the chain site substitution consistently showed higher SHC. In particular, W-Mo alloys reach SHC of -1857 S/cm at x = 12.5%, a 47 % increase over pure β-W. The increase of SHC is analyzed with Berry curvature analysis, where the negative Berry curvature along XM and RX is responsible. With increasing doping concentration, the number of peaks contributing to positive Berry curvature increases along XM, resulting in a gradual decrease in total SHC.

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Deterministic optical control of ferromagnetic domains by nanoscale stochastic switching

R. Liefferink1, D. Khusyainov1, L. Körber1, Th. Rasing1, J.H. Mentink1

1 Radboud University, Institute for Molecules and Materials, Nijmegen, The Netherlands

Ultrashort laser pulses generally cause ultrafast demagnetization in ferromagnetic films through laser heating. While heating inherently introduces stochastic effects, repeated excitation with tens to thousands of circularly polarized pulses can drive deterministic evolution of magnetic domains. Explaining this remarkable effect requires understanding how micrometer-scale effects follow from strongly fluctuating nanoscale dynamics.

Inspired by recent experiments with enhanced resolution, we introduce a mesoscopic model of Ising-like grains on the 100 nm scale that undergo optically induced probabilistic switching. Our model incorporates both helicity-dependent laser heating and inter-grain interactions. We find that cumulative dynamics are controlled both by the local magnetization and the surrounding domain-wall structure. These key ingredients allow deterministic evolution, despite the nanoscale stochasticity.

Applying our model to experimentally relevant conditions, we show that it provides a unified description of all major observations: (i) deterministic helicity-dependent switching; (ii) its strong dependence on laser-pulse parameters [1]; (iii) apparent domain-wall motion [2]; and (iv) high-efficiency switching by pulse pairs [3]. Moreover, the model points to a pathway by which stochastic nanoscale switching mimics coherent domain wall motion, potentially bypassing the speed limits imposed for magnetic-field-driven walls. This demonstrates that our multiscale method not only unifies a variety of experimental results, but also enables predictions for controlling emergent deterministic evolution beyond the limits of fully deterministic dynamics.

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K. Litzius[1], F. Büttner[1,2]

[1]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany

[2]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

Materials with spin-momentum locking and gauge constraints are predicted to host qualitatively new spin dynamics and spin textures. Understanding and controlling these dynamics is a key step towards ultrafast, energy-efficient spintronic technologies. Magnetic Weyl semimetals, due to unconventional charge–spin conversion at Weyl nodes, display giant anomalous Hall effects and potential for efficient switching. Similarly, frustrated magnets are governed by gauge constraints, suggesting entirely new pathways to drive and switch spin textures such as domain walls and skyrmions. While theory predicts these effects, experimental confirmation is still at an early stage. We investigate the possibility of driving magnetic domain walls and skyrmions in magnetic Weyl semimetals at unusually high speeds [1] and seek efficient, gate-controlled manipulation of spin textures and phase transitions [2] in these novel materials. To access device-relevant speed limits, time-resolved MOKE and micromagnetic simulations can be used to resolve ultrafast switching via nucleation, radial expansion, and defect-mediated relaxation [3]. X-ray and high-resolution TEM imaging identify local chirality variations and twisted wall segments that govern late-stage dynamics and equilibrium, enabling design rules for reproducible high-speed switching. Together, we aim to establish a framework for deterministic, low-energy generation and ultrafast manipulation of skyrmions and domain walls in next-generation spintronic devices.

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Chirality Probes of Band Topology in Bosonic Bogoliubov Systems

Ying Shing Liu,[1] Emil Viñas Boström,[2, 3] and Silvia Viola Kusminskiy[1, 4]

[1]*Institute for Theoretical Solid State Physics, RWTH Aachen University, 52074 Aachen, Germany*

[2]*Max Planck Institute for the Structure and Dynamics of Matter,*

Luruper Chaussee 149, 22761 Hamburg, Germany

[3]*Nano-Bio Spectroscopy Group, Departamento de Física de Materiales,*

Universidad del País Vasco, 20018 San Sebastian, Spain

[4]*Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany*

Quasi-free bosonic systems are ubiquitous as low energy models for the quasi-particles of condensed matter systems. However, due to their exchange statistics, general bosonic Bogoliubov-de Gennes (BdG) systems fall outside the topological classification scheme of Hermitian systems. While it is still possible to define a topological Chern index for the quasi-particle bands, the lack of a chemical potential in particle non-conserving system (such as photons, phonons and magnons) make direct probes of band topology elusive. It is therefore desirable to identify new probes of band topology that work for such systems. Here, we show that the Raman circular dichroism acts as a probe of quasi-particle chirality, and in extension of band topology, for the general class of two-dimensional bosonic BdG systems. In particular, we establish an analytical relation between the Raman circular dichroism and the magnon Berry curvature of canted antiferromagnets, and propose a pump-probe scheme to measure the corresponding Chern number. Our work establishes chirality probes as a general means of measuring band topology in free bosonic systems. This work is an extension of the previous study [1].

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Emergence of a topological Hall effect in the non-collinear phase of ferrimagnetic insulator Terbium-Iron garnet

M. Loyal[1], A. Akashdeep[1], E. Mangini[1], E. Galíndez-Ruales[1], M. Eich[1], N. Wang[2], Q. Lan[2], L. Jin[2], R. Dunin-Borkowski[2], M. Kläui[1] and G. Jakob[1]

[1]Institute of Physics, Johannes Gutenberg University Mainz, Mainz, Germany
[2] Ernst Ruska-Centre for microscopy and Spectroscopy with Electrons (ER-C-1), Forschungszentrum Jülich GmbH, Jülich, Germany

Rare-earth iron garnets are ferrimagnetic insulators with two iron sublattices, which are antiferromagnetically coupled to each other, and a rare-earth sublattice, which is antiferromagnetically coupled to the net iron moment. This gives rise to a well-defined compensation temperature, at which the magnetizations of the rare-earth and iron sublattices cancels exactly. Below this temperature, the rare-earth sublattice dominates the net magnetization. Above the compensation point the relative orientation of the sublattice moments is inverted, and the iron sublattice becomes dominant. The collinear arrangement of the sublattices is preserved. But, near the compensation temperature, the system may enter a canted magnetic phase [1].

In this work, we focus on TbIG ($Tb_3Fe_5O_{12}$). While bulk TbIG has a compensation temperature of ~240 K, thin-film studies show that this temperature can shift significantly, with reports of near–room-temperature compensation in TbIG films [2, 3]. Here we have investigated TbIG/Pt heterostructures across the magnetic compensation region using transverse magnetoresistance measurements complemented by polar Kerr microscopy. We identify a distinct topological-Hall-like contribution that emerges only within a compensation-driven non-collinear multidomain regime. Kerr imaging confirms the absence of skyrmions or bubble domains in this window, and the field dependence of the Hall response is inconsistent with a simple two-component anomalous Hall effect. These observations demonstrate that compensation-enabled non-collinear textures in TbIG can generate a genuine emergent-field response without skyrmion formation, revealing a previously unexplored topological transport regime in ferrimagnetic garnets.

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Odd-parity magnon spin splitting in antialtermagnets

R. Neumann[1,2], R. Jaeschke Ubiergo[1], R. Zarzuela[1], J. Sinova[1] and A. Mook[3]

[1] *Johannes Gutenberg University, Mainz, Germany*
[2] *Martin Luther University, Halle-Wittenberg, Germany*
[3] *University Münster, Münster, Germany*

Antialtermagnets are a recently proposed class of magnets with zero net magnetic moment in real space but characteristic odd-parity spin splitting with *p*-/*f*-/*h*-wave symmetry of electronic bands [1]. In this work, we explore the magnonic counterpart of this phenomenon by studying *odd-parity magnon spin splitting* in minimal models of paradigmatic antialtermagnets. Our analysis reveals how specific spin symmetry operations suppress or enable certain spin splitting components in the magnon spectrum, providing a foundation for understanding the broader landscape of spin dynamics in antialtermagnets.

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Positional memory of skyrmions in magnetic bilayers

Bruno Barton-Singer,[1,2] Anusree Navallur,[2] and Stavros Komineas[2,1]

[1] *Institute of Applied and Computational Mathematics, FORTH, Heraklion, Crete, Greece*

[2] *Department of Mathematics and Applied Mathematics,*
University of Crete, 70013 Heraklion, Crete, Greece

We numerically and analytically study the transient dynamics of magnetic skyrmions in synthetic antiferromagnets under a magnetic field gradient. We consider skyrmions in a bilayer with antiferromagnetic coupling between the layers. The skyrmions in the two layers move almost perpendicular to the field gradient and the motion is eventually halted with the two skyrmions at a distance from each other. Below a critical magnetic field gradient strength, the system displays an unusual 'remembering' dynamics: when the magnetic field gradient is removed, the skyrmions return to their original positions to a high degree of accuracy. We explain this observation and other quantitative features using a moduli space dynamics approximation.

Symmetry-Driven Topological Magnetism and Twist-Tunable Spin Dynamics in Antiferromagnet–Ferromagnet Heterostructures

Brandon Pedroza-Rojas[1,3†], **Ariadna Sánchez-Castillo**[2], **and Sergio E. Ulloa**[3]

[1] *Institute of Basic Sciences and Engineering, Autonomous University of the State of Hidalgo, Mineral de la Reforma, Hidalgo, 42184, Mexico*

[2] *Superior School of Apan, Autonomous University of the State of Hidalgo, Apan, Hidalgo, 43920, Mexico*

[3] *Nanoscale and Quantum Phenomena Institute and Dept. of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA*

In order to accurately capture the quasiparticle physics of the CrSBr/Fe_3GeTe_2 interface, it is necessary to move beyond the limitations of standard Wannier downfolding, which frequently obscures the physical origin of orbital interactions. Crucially, we abandon the ambiguous metric of continuous "nanometer thickness" due to its inability to capture the discrete quantization of interlayer hybridization. Instead, we treat the layer index as an exact quantum degree of freedom. This ensures that parity-dependent magnetic couplings and confinement-induced band splittings—often omitted in continuum approximations—are rigorously preserved.

We construct a constitutive tight-binding Hamiltonian directly from symmetry group irreducible representations and orbital-resolved Slater-Koster parametrizations. This physically transparent approach facilitates the precise treatment of the $\mathbf{R}$-space quantum metric tensor, thereby circumventing numerical artifacts.

Our model demonstrates that the symmetry mismatch at the interface imposes a distinct 3θ-periodicity on the Dzyaloshinskii-Moriya Interaction (DMI). Furthermore, this twist-dependent texture generates a robust, field-free Spin-Orbit Torque (SOT). We find that while the magnitude of the effective field remains constant, its direction is deterministically locked to the stacking angle. This offers a purely geometric method for controlling magnetic switching.

Finally, we map the topological landscape of the system. Applying the Poincaré-Hopf theorem to the spin field, we identify stable skyrmionic phases with integer topological charge ($Q = 1$). These findings suggest that the recently reported canted phases in CrSBr/Fe_3GeTe_2 [1,2] naturally amplify Berry curvature in the magnonic spectrum, pointing toward new architectures for low-power, topologically protected spintronic memory.

†**Correspondence:** pe484939@uaeh.edu.mx, bp297224@ohio.edu, brandonrpce@gmail.com

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Leveraging Interactions for Efficient Swarm-Based Brownian Computing

Alessandro Pignedoli

Brownian particles naturally explore a system's configuration space through thermal fluctuations, requiring no external energy input. This intrinsic property makes them an energy-efficient basis for addressing optimisation problems [1].

Inspired by swarm intelligence [2], we show that short-range interactions between Brownian quasiparticles induce dynamic clustering around the global minimum of a complex temperature landscape [3,4]. By varying the interaction strength and particle density, we identify a broad range of physical conditions in which collective behaviour enhances optimization accuracy. Our results highlight that the emergent collective dynamics of interacting Brownian particles provide a scalable, energy-efficient framework for unconventional computing.

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Curvature-driven magnetic frustration and artificial ferrotoroidicity in nanomagnets

<u>O.V. Pylypovskyi</u>[1,2], E. Di Benedetto[3], C. Ortix[4], D. Makarov[1]

[1]Helmholtz-Zentrum Dresden-Rossendorf e.V., 01328 Dresden, Germany
[2] Kyiv Academic University, Kyiv 03142, Ukraine
[3] Dipartimento di Fisica e Chimica "E. Segrè", Università degli Studi di Palermo, 90123 Palermo, Italy
[4] Dipartimento di Fisica "E. R. Caianiello", Università di Salerno, IT-84084 Fisciano (SA), Italy

The geometry of low-dimensional magnets allows us to tune their local chiral and anisotropic responses [1]. The quantification of these responses is determined by intrinsic parameters of geometry: two principal curvatures in 2D shells, and curvature and torsion in nanowires. The last two parameters characterize local bends and twists of the sample. The spatial pattern of geometry and magnetic texture can break the spatial and time reversal symmetries of the sample, inducing magnetoelectric multipoles [2].

Here, we address quasi-1D ferro- and antiferromagnetic nanomagnets modeled as spin chains arranged along closed space curves with the constant torsion [3]. These geometries are characterized by a selected number of high-curvature knots along the curve without self-intersection and segments with the almost vanishing curvature in between. We found the ground states for these samples, including the case of the intrinsically frustrated system with antiferromagnetic coupling and an odd number of spins because of antiperiodicity of exchange bonds. The presence of high-curvature knots leads to a spatially inhomogeneous interplay between the geometry-driven Dzyaloshinskii-Moria interaction and local anisotropy. As a result, the ground state is dependent on the number of knots and can mimic the presence of intrinsic frustration in the chain for a non-frustrated sample and vice versa. We analyze the magnetoelectric multipoles present in these ferro- and antiferromagnetically coupled systems and find that the antiferromagnetic chains spontaneously develop toroidal domains pinned by the geometric knots.

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Quaternary probabilistic switching and current-induced domain wall motion in a chiral kagome antiferromagnet

Prajwal Rigvedi, Jae-Chun Jeon, Binoy Hazra, Andrea Migliorini, Banabir Pal, Stuart Parkin

Max-Planck-Institute of Microstructure Physics, Halle (Saale), Germany

Chiral kagome antiferromagnet, Mn_3Sn, is a promising candidate for spintronic applications due to its ultrafast spin dynamics and negligible stray field [1]. Its magnetic ground state exhibits six-fold degeneracy [2], and accessing these states would enable multistate switching, a key feature for unconventional computing schemes. In this work, we investigate ultra-thin W/Mn_3Sn bilayers and demonstrate spin-orbit torque-driven quaternary probabilistic switching by accessing multiple degenerate energy states of the system. When the applied current exceeds a threshold density, probabilistic fluctuations in the anomalous Hall resistance (R_{xy}) emerge [3, 4]. We show that these fluctuations can be tuned using either an external magnetic field or electrical pulses. The resulting sigmoidal response of R_{xy} on the applied dc current, reflecting tunable stochasticity [5], establishes the realization of antiferromagnetic probabilistic bits. By combining dc current with continuous nanosecond pulse excitations, we achieve true quaternary probabilistic switching.

Furthermore, we demonstrate current-induced domain wall motion in Mn_3Sn nano-conduits integrated with Hall bars by locally nucleating domain walls using nanosecond-long current pulses. Our results show that spin–orbit torques acting on octupole moments govern the nucleation process and enable deterministic domain wall motion. At room temperature, domain wall velocities up to 700 m/s are achieved with 2-ns-long current pulses, without an external magnetic field. These findings establish non-collinear antiferromagnets as a robust platform for ultrafast, multibit spintronics — including probabilistic bits and racetrack memory — paving the way for next-generation computing and memory technologies.

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Magnetization processes and spin-lattice coupling in the hexagonal easy-plane altermagnet *α*-MnTe

S. Rößler[1], V. Ginga[1], E. Uykur[2], Y. Skourski[3], J. Sourd[3], S. Zherlitsyn[3], M. Schmidt[4], Y. Prots[4], H. Rosner[4], U. Burkhardt[4], U. K. Rößler[5], A. A. Tsirlin[1]

[1]Felix Bloch Institute for Solid-State Physics, University of Leipzig, 04103 Leipzig, Germany
[2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, D-01328 Dresden, Germany
[3]Hochfeld-Magnetlabor Dresden, Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden, Germany
[4]Max-Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden
[5]Institute for Theoretical Solid-State Physics, Leibniz IFW Dresden, 01069 Dresden, Germany

We investigated the magnetization dynamics associated with domain behavior in *α*-MnTe using magnetization, magnetostriction, sound velocity, and attenuation measurements. Angle- and field-dependent magnetization data reveal complex magnetic responses with a distinct anomaly around 1 T, reflecting domain-related processes. Magnetostriction and elastic constant measurements indicate strong lattice effects at the field-induced reorientation transition. These features were analysed using a phenomenological micromagnetic model incorporating higher-order anisotropic exchange interactions that couple the weak ferromagnetic component to the antiferromagnetic order parameter. The model successfully reproduces the generic behaviour of the magnetic states and demonstrates that the observed uniaxial and unidirectional anisotropies arise from metastable domain configurations and irreversible magnetization processes [1].

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Magnetization dynamics in RMn_6Sn_6 crystals investigated by broadband ferromagnetic resonance spectroscopy

Philipp Schwenke[1], David Weffling[1*], Kyle Fruhling[2], Vitaliy Vasyuchka[1], Fazel Tafti[2] and Mathias Weiler[1]

[1] Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany

[2] Department of Physics, Boston College, Chestnut Hill, MA 02467, USA

[*] Present address: Department of Physics and Materials Science, University of Luxembourg, L-4362 Esch-sur-Alzette, Luxembourg

The RMn_6Sn_6-material family is known for hosting various magnetic orders, ranging from ferrimagnetic to antiferromagnetic, helical magnetic order and even skyrmions have been reported [1, 2]. They originate mainly from RKKY-exchange interactions between the rare-earth- and Mn atoms situated in triangular- and Kagome lattices, respectively [2]. This gives rise to an unconventional band structure forming flat bands and Dirac cones leading to significant anomalous Hall- and Nernst-effects [3,4]. In this study, we investigate the magnetization dynamics of three members of the RMn_6Sn_6-family (R=Yb, Er and Tb). We track characteristic phase transitions of the materials and the accompanying signatures in the magnetization dynamics over temperature. We find that the phase transitions are in agreement with previous results, while the spin dynamical signatures have not been discussed before. From analysis of our spin dynamics data, we observe a large uniaxial anisotropy in the Kagome plane of $YbMn_6Sn_6$. This study highlights the potential of using broadband ferromagnetic resonance spectroscopy to investigate the unconventional magnetic properties in RMn_6Sn_6.

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Engineering Spin Torque in Spin-Orbit Coupled Josephson Qubits Incorporating Chiral Ferromagnetic Superconductors with Unconventional Symmetries

Z. Shomali

Physics Department, Tarbiat Modares Univeristy, Tehran, Iran

In nano-electronics, thermal reliability depends on the temperature of the hottest region on the die, making material selection and heat-spreader design essential. Spin-transfer torque (STT) in unconventional ferromagnetic Josephson junctions enables the transfer of spin angular momentum to magnetization, and is important for future nano-devices such as MRAMs, oscillators, and spin-based transistors, especially as transistor scaling continues. Josephson-junction spintronic devices are also promising for quantum computing, where superconducting qubits already provide fast, scalable platforms used by leading companies. A spin transistor stores binary information through parallel or antiparallel magnetization states, making STT a key mechanism for switching magnetic configurations. Studying STT in unconventional Josephson structures is therefore essential. Spin–orbit coupling (SOC) is another important ingredient, as it can generate long-range triplet components that are useful for hybrid superconducting devices.

This work investigates STT in Josephson junctions with chiral p-wave ferromagnetic superconductor reservoirs of the form FS1|SOC1|N|SOC2|FS2. Two cases are studied: (1) a single SOC layer and (2) two SOC layers (symmetric or asymmetric). Using ballistic transport and the Bogoliubov–de Gennes formalism for thin-N junctions, we show that a single SOC layer produces nearly constant out-of-plane STT magnitude but reverses its direction at small relative magnetization angles. With two identical SOC layers, the out-of-plane STT is reduced due to opposite interface orientations, while asymmetric SOC strengths lead to partial cancellation only. Varying barrier strength modifies both the magnitude and sign of STT, and SOC also introduces in-plane torque components.

Chiral Molecule-Induced Magnetic Anisotropies

S. Sochiera[1], A. Hagenow[1], A. Moharana[1], Y. Kapon[2], D. Anthofer[1], F. Kammerbauer[1], A. Akashdeep[1], S. Yochelis[2], M. Kläui[1], Y. Paltiel[2], T. Marszalek[3], G. Lavarda[3], E. Rentschler[1], A. Wittmann[1]

[1]Johannes Gutenberg University, Mainz, Germany
[2]Hebrew University of Jerusalem, Jerusalem, Israel
[3]Max Planck Institute for Polymer Research, Mainz, Germany

The chiral-induced spin selectivity effect [1] is not only a promising candidate for the design of novel spintronic devices but also challenges our fundamental physical understanding of the interplay between spin and chirality. Despite a plethora of interdisciplinary experiments that illuminate the implications and trends of the effect, a theoretical understanding of the effect, especially the origin of the apparent time-reversal symmetry breaking, remains an open challenge [2, 3]. Here, we quantify the impact of the adsorption of chiral molecules on the magnetic anisotropy of thin films using electrical magneto-transport experiments. This serves as a platform for investigating a range of different molecular systems on many conductive or insulating magnetic systems. Correlating molecular properties, including structural chirality and atomic spin-orbit coupling, with the impact on the magnetic anisotropy of magnetic systems may be key in understanding the chiral-induced spin-selectivity effect on a more fundamental level and may facilitate the design of spintronic devices that highly depend on a fine-tuned magnetic anisotropy landscape.

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Capillary-based Soft X-ray Ptychography for Ultimate 4D Spectro-Microscopy with Versatile Sample Environment

<u>Boris V. Sorokin</u>[1], Marina Raboni Ferreira[2], Ruslan Khubbutdinov[3], Kai Litzius[1,4], Kai Bagschik[3], Moritz Hoesch[3], Claire Donnelly[2], Bastian Pfau[5], Felix Büttner[1,4]

[1]*Universität Augsburg, Augsburg, Germany*
[2]*Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany*
[3]*Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany*
[4]*Helmholtz-Zentrum für Materialien und Energie, Berlin, Germany*
[5]*Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Berlin, Germany*

X-ray imaging techniques enabled a significant advancement in the understanding of the physics driving magnetic systems, thanks to the possibility of combining element selectivity, sensitivity to the magnetic and antiferromagnetic ordering, and high spatial and temporal resolutions. Looking forward to the upcoming (fourth) generation of synchrotrons, new frontiers in spectroscopy and microscopy are emerging, most notably the combination of multiple cutting-edge detection schemes in the same experiment. Examples of such “multimodal” experiments are time-resolved nano-tomography and spectro-imaging with simultaneous sensitivity to chemical heterogeneity and vector-spin orientation. Such experiments would not average over any dimension, providing unprecedented insights into real, imperfect functional materials and elucidating how a material’s nanostructure generates functionality. As fourth-generation light sources also promise wavelength-limited spatial resolution, they are often referred to as “ultimate microscopes” (e.g., PETRA-IV). However, developing endstation instruments that realize this potential in practice remains an open challenge.

In this project we aim to create the first coherent, digital soft X-ray ptychography endstation with a highly versatile sample environment (temperature control down to 100 K, magnetic fields up to 1 T, 3D laminography, time-resolved imaging using GHz electrical and femtosecond optical excitation). To this end, we will employ capillary optics that extend the working distance compared to conventional zoneplates from sub-millimeter to several centimeters. The endstation is currently being built and will be located at the PETRA-III P04 beamline. Our scientific goal is to leverage this instrument to integrate chemical-spectroscopic and magnetic contrast with 3D resolution under uniform conditions and thereby examine the correlation between emergent textures and nanoscale material’s defects, for example, in permanent magnets and skyrmion materials.

Interaction and collision of skyrmions in chiral antiferromagnets

George Theodorou[1,2], **Bruno Barton Singer**[2] **and Stavros Komineas**[1,2]

[1] *Department of Mathematics and Applied Mathematics, University of Crete, 70013 Heraklion, Greece*

[2] *Institute of Applied and Computational Mathematics, Foundation for Research and Technology- Hellas (FORTH), Nikolaou Plastira 100, Vassilika Vouton, 70013 Heraklion, Greece*

Skyrmions in an antiferromagnet can travel as solitary waves in stark contrast to the situation in ferromagnets. Traveling skyrmion solutions have been found numerically in chiral antiferromagnets. We study head-on collision events between two skyrmions. We find that the result of the collision depends on the initial velocity of the skyrmions. For small velocities, the skyrmions shrink as they approach, then bounce back and eventually acquire almost their initial speed. For larger velocities, the skyrmions approach each other and shrink until they become singular points at some finite separation and are eventually annihilated. Considering skyrmion energetics, we can determine the regimes of the different dynamical behaviors. Using a collective co-ordinate approach, we reproduce the dynamics of the collisions including the variation of the size of the skyrmions and collapse above a critical velocity.

Theory of Magnetization Dynamics Control by Phonons

M. Valls Boix[1,2], A. Mook[1,2]

[1] Johannes-Gutenberg Universität, Mainz, Germany [2] Münster Universität, Münster, Germany

Spin-lattice coupling plays a crucial role in facilitating angular momentum exchange between the lattice and magnetic subsystems[1]. In this work, we explore how this coupling can be harnessed to enhance the lifetime of magnons in ferromagnetic materials. Specifically, we focus on the interaction between propagating surface acoustic waves and a proximate magnetic system, where these waves generate a torque on the spins. Using perturbation theory, we derive the effective field arising from the magneto-rotational and magneto-elastic couplings and subsequently define the resulting torque. In particular, we investigate whether a dampinglike component of the torque can emerge, which could act as an antidamping mechanism to counteract the intrinsic magnon damping.

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Spin band geometry drives intrinsic thermal spin magnetization and current

Sankar Sarkar, **Harsh Varshney**, Sayan Sarkar, and Amit Agarwal

Department of Physics, Indian Institute of Technology Kanpur, Kanpur-208016, India

Generating spin magnetization and spin currents without magnetic or electric fields is a key frontier in spin caloritronics. Spin responses driven by thermal gradients offer a promising route, though the band geometric origin of intrinsic mechanisms, especially in non-magnetic materials, remains poorly understood. Here, we develop a unified quantum theory of thermal spin magnetization (TSM) and thermal spin currents (TMC) in itinerant electrons, rooted in spin band geometry with both Fermi-surface and Fermi-sea contributions. We identify two key geometric quantities: the spin-velocity metric tensor, which governs thermal spin magnetization, and the spin geometric tensor, which combines spin Berry curvature and spin quantum metric, generating thermal spin currents. These intrinsic contributions persist and can even dominate in non-magnetic insulators. Numerical calculations for chiral metal RhGe and antiferromagnet CuMnAs demonstrate sizable thermal spin responses near band crossings. Our results establish the band geometric origin of thermal spin transport and provide guiding principles for discovering and engineering next-generation spin caloritronic materials.

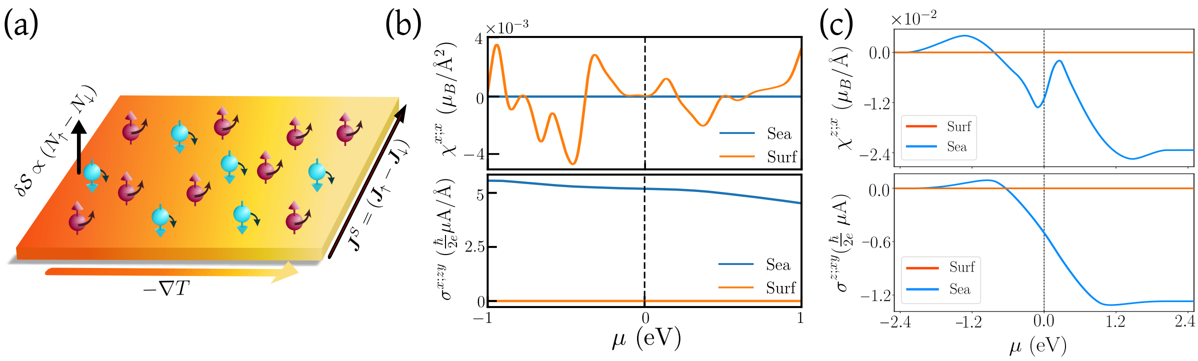

Figure 1: (a) Schematic of thermally driven spin responses due to a temperature gradient, which generates an imbalance between up and down spins of itinerant electrons due to spin-orbit coupling and leads to spin magnetization ($\delta\mathcal{S}$) and current (J^S). (b-c) Variation of TSM (χ) and TSC (σ) with chemical potential μ for time-reversal symmetric RhGe and time-reversal broken CuMnAs systems, respectively.

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Strain controlled *g* -to *d*-wave transition in altermagnetic CrSb

Bennet Karetta[1], Xanthe H. Verbeek[1], Rodrigo Jaeschke-Ubiergo[1], Libor Šmejkal[2,3,4] and Jairo Sinova[1,5]

[1]Insitut für Physik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

[2]Max-Planck-Institut für Physik Komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany

[3]Max-Planck-Institut für Chemische Physik Fester Stoffe, Nöthnitzer Str. 40, 01187 Dresden, Germany

[4]Institute of Physics, Academy of Sciences of the Czech Republic, Cukrovarnická 10, Prague 6, Czech Republic

[5]Department of Physics, Texas A&M University, College Station, Texas 77843-4242, USA

We demonstrate a strain-induced transition in the g-wave altermagnet CrSb, revealing how shear strain can tune spin symmetries and enable new responses [1]. Through symmetry analysis, we identify four specific strain directions that lower the symmetry and allow for a spin-splitter current—an effect forbidden in the unstrained phase. These strains induce three d-wave altermagnetic states and one uncompensated magnetic phase, each with distinct spin symmetries. Using both a minimal model and first-principles calculations, we confirm the emergence of these phases and show that their key features remain robust in the presence of spin-orbit coupling. Importantly, we predict a spin-splitter effect of up to 5% under just 1% strain, demonstrating that even small deformations can generate sizable spin-splitter currents. Our findings highlight strain as a precise and effective tool for controlling symmetry-driven spin phenomena in altermagnetic materials.

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Optical investigations of electron-doped $FeSb_2$

M. Wenzel[1], R. Mathew Roy[1], M. Povolotskiy[1], C. Prange[1], A. V. Pronin[1], Y. Xie[2], T. Zhang[2], V. Sundarmurthy[3], J. Kirschke[4], A. Kreyssig[4], A. E. Böhmer[4], and M. Dressel[1]

[1] 1. Physikalisches Institut, Universität Stuttgart, D-70569, Stuttgart, Germany
[2] Institute of Theoretical Physics, Chinese Academy of Science, 100190 Beijing, China
[3] Max-Planck-Institute for Solid State Research, 70569 Stuttgart, Germany
[4] Experimental Physics IV, Ruhr University Bochum, 44801 Bochum, Germany

While the maracasite-structured semiconductor $FeSb_2$ is nonmagnetic, theoretical predictions suggest that hole or electron doping can stabilize an altermagnetic order with a substantial non-relativistic spin splitting of approximately 0.2 eV [1].

Here, we investigate a series of Co-doped $FeSb_2$ samples using optical spectroscopic techniques including broadband infrared spectroscopy, Müller-matrix ellipsometry, and Raman scattering. Combined with density-functional theory calculations, we discuss the effects of electron doping and the consequent magnetic ordering on the electronic structure and optical phonon modes. In particular, we address the possibility of an emerging altermagnetic state for dopings above $x = 0.12$.

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Multi-Value Probabilistic Computing with Current-controlled Skyrmion Diffusion

Thomas B. Winkler (1), Yuean Zhou (2), Grischa Beneke (2), Fabian Kammerbauer (2), Sachin Krishnia (2), Mario Carpentieri (3), Davi R. Rodrigues (3), Mathias Kläui (2,4), Johan H. Mentnik (1)

(1) Radboud University, Institute for Molecules and Materials, Nijmegen 6525, the Netherlands
(2) Institut für Physik, Johannes Gutenberg-Universität Mainz, Mainz 55099, Germany
(3) Department of Electrical and Information Engineering, Politecnico di Bari, Bari, Italy
(4) Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, Trondheim 7491, Norway

Magnetic systems are highly promising for implementing probabilistic computing paradigms because of the fitting energy scales and conspicuous non-linearities. While conventional binary probabilistic computing has been achieved, the more advantageous multi-value probabilistic computing (MPC) has remained a challenge. Here, we report the successful realization of MPC by harnessing the thermally activated diffusion of magnetic skyrmions through a non-flat energy landscape defined by a discrete number of pinning sites. The time-averaged spatial distribution of the diffusing skyrmions directly realizes a discrete probability distribution, which is tunable by current-generated spin-orbit torques, and can be quantified by non-perturbative electrical measurements. Even a simple implementation with global tuning allows us to demonstrate the softmax computation - a core function in artificial intelligence. Moreover, we demonstrate invertible logic without the need to create a network of probabilistic devices, offering significant scalability advantages. Our proof of concept can be extended to multiple skyrmions and can accommodate multiple locally tunable inputs and outputs using magnetic tunnel junctions. This potentially enables the representation of highly complex distribution functions. Further, the stack recipe can in principle be adjusted to host skyrmions with length and time scales in the nanometer/nanoseconds regime.

Optical control of RKKY coupling and perpendicular magnetic anisotropy in a synthetic antiferromagnet

Meiyang Ma[1,2], Jing Wu[3,4], Bo Liu[1,2], Lei Wang[5], Zhuoyi Li[1,2], Xuezhong Ruan[1,2], Zehua Hu[2], Fengqiu Wang[2], Xianyang Lu[1,6], Tianyu Liu[1,6], Jun Du[7], Ke Xia[5] & Yongbing Xu[1,2,4,6]

1. National Key Laboratory of Spintronics, Nanjing University, Suzhou, China.
2. School of Electronic Science and Engineering, Nanjing University, Nanjing, China.
3. School of Integrated Circuits, Guangdong University of Technology, Guangzhou, China.
4. School of Physics, Electronics and Technology, University of York, York, UK.
5. Key Laboratory of Quantum Materials and Devices of Ministry of Education, School of Physics, Southeast University, Nanjing, China.
6. School of Integrated Circuits, Nanjing University, Suzhou, China.
7. Department of Physics, Nanjing University, Nanjing, China.

Synthetic antiferromagnetics (SAF) provide an excellent platform for anti-ferromagnetic spintronics. Recently, the voltage-control of the Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction in SAFs was studied experimentally. Optical control would offer unique opportunities for the ultrafast manipulation of spin states, however, it has yet to be demonstrated. Here, using femtosecond laser excitations in a [Co/Pt]-based perpendicular
magnetic anisotropy (PMA) synthetic antiferromagnet (p-SAF), we drive a reduction of the RKKY coupling and the PMA. We attribute the reduced RKKY interaction to the optically smeared Fermi wave vector of the Ru layer, which mediates the exchange coupling between the constituent ferromagnetic layers. The PMA exhibits the same amplitude of decrease as the RKKY coupling, which we associate with electron redistributions in the 3d orbitals caused by the optically smeared Fermi level. While the pump excitation process is shown to have an in uence on the modulations, thermal contributions are excluded. Our study establishes a link between the RKKY coupling and the PMA in a p-SAF structure and provides an approach to tune them in parallel.

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Probing unconventional spin materials with time and spin resolved ARPES

Y.B. Xu[1,2*], B. Liu[1], X. Y. Lu[1], L. He[1], Y. Li[1], X. Z. Ruan[1], X. Q. Zhang[1], and J. Wu[2]
[1]*National Key Laboratory of Spintronics, Nanjing University, Nanjing 210093, China*
[2]*York-Nanjing Joint Center of Spintronics, The University of York, YO10 3DD, United Kingdom*
*(*email: ybxu@nju.edu.cn)*

We have recently deleveopled a femtosecond TR-Spin-ARPES beamline for th study of spin ordered systems [Appl. Sci. 2019], integrated with various in-situ growth (MBE, Sputtering and PLD) and analysis (RHEED, in-situ MOKE) tools. Our current focus is the unconventional spin materials and structures such as centrosymmetric TMDC materials with hidden spin polarization, 2D magnets and altermagets etc. Our spin ARPES confirms the hidden spin polarization in 2H-MoTe2 with a large spin splitting of 236 meV and opposite spin polarizations up to 80% along out-of-plane direction in K valleys [Phys. Rev. B, 2020]. More recently with Tr-ARPES, we have revealed the distinct ultrafast recombination behaviors of spin-orbit splitting bands in 2H-MoTe2 [Phys. Rev. B 2025]. The long recovery time of 8.47 ps of upper valence band supports the existence of long-lived spin polarized electrons at the Σ valley. With 2D magnet $CrTe_2$, we have found that the bilayer graphene substrate can lead to room temperature intrinsic ferromagnetism with a Curie temperature (T_C) above 300 K [Nat. Commun. 2021]. With spin ARPES, the spin-resolved EDCs measurements reveal a significantly enhanced spin polarization in an atomically thin CrTe2 film [Adv. Mater. 2025], in contrasts with the typical decrease in magnetic order observed in conventinal ferromagnets. While we have achieved robust, 100% field-free SOT switching in a RuO2(101)/[Co/Pt]2/Ta structure [Adv. Mater. 2025], supporting a picture that the altermagnetic spin splitting effect (ASSE) in RuO2 promotes the generation of spin currents when the charge current flows along the [010] direction. However, our new spin-ARPES measurements of the RuO2 thin films suggest that the top surface layer exhibits ferrimagnetism with a significant magnetic moment of 0.48 μB resulting in spin splitting, while the bulk phase is non-magnetic. We are also investigating the spin dynamics of the RuO2 with Tr-MOKE and all these results will be presented in the conference.

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Néel-vector controlled Hall and Kerr responses in collinear altermagnetic α-Fe_2O_3

Min-Jae Yoo[1], **Guihyun Han[1]** and **S. H. Rhim[1*]**

[1]*Department of Physics, University of Ulsan, Ulsan 44610, Republic of Korea.*

Altermagnetism is a magnetic phase distinct from ferro- and antiferromagnetism by symmetry-induced spin splitting despite vanishing net magnetization [1,2]. In α-Fe_2O_3, we treat the Néel vector n as a control parameter and combine magnetic-space-group (MSG) analysis with first-principles calculations. For n ∥ [001] (MSG No. 167.103), the MSG permits band spin splitting but forbids the antisymmetric part of the conductivity tensor, leading to vanishing anomalous Hall conductivity (AHC) and magneto-optical Kerr effect (MOKE). We therefore examine other collinear alignments: n ∥ [010] (No. 15.89) and n ∥ [110] (No. 2.1). The derived MSGs predict where spin splitting occurs in k-space and whether the antisymmetric conductivity is symmetry-allowed, with AHC and MOKE calculations confirming these predictions.

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DFT-based investigation of spin dynamics in unconventional magnets

Hamid Nouri, Xiankang Tang, Hao Wang, and Hongbin Zhang

Institute of Materials Science, TU Darmstadt, Otto-Berndt-Str. 3, 64287 Darmstadt, Germany

The elementary magnetic excitations have attracted intensive attentions in emergent magnetic materials, such as Weyl semimetals, two-dimensional (2D) magnets, and altermagnets. For instance, the nonmonotonous temperature dependence of spin wave gaps in $SrRuO_3$ can be attributed to the presence of Weyl fermions [1], magnon-magnon interaction plays an essential role to normalize the magnetic ordering temperature in 2D magnets [2], whereas the chiral magnons is a benchmarking signature of altermagnetic ordering [3]. To elucidate such intriguing aspects of magnetic excitations, it is critical to perform accurate density functional theory calculations so that the experimental observations can be quantitatively validated. In this work, we demonstrate a workflow to perform systematic investigations on the spin dynamics in unconventional magnets. Based on symmetry analysis, pair-wise magnetic exchange parameters can be evaluated using appropriate approaches based on the nature of magnetism, *e.g.*, four-state mapping for insulators with well-defined local moments and linear response for metals. Furthermore, taking 2D CrX_3 (X = Cl, Br, I) as examples, we employed nonlinear spin-wave theory considering magnon–magnon interactions and evaluated their Curie temperatures and spin waves. We observed that the resulting Curie temperatures are generally lower than those predicted by mean-field and linear-response approaches, yet they more closely match results obtained from accurate quantum Monte Carlo and random phase approximation methods [4]. We are going to demonstrate how such a framework can be applied to obtain the chiral magnon splitting for altermagnets and the associated thermal Hall effects.

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Voltage-Triggered Emergent Dynamics in a Magnetic Neuron Network

Zhibo Zhao[1,2], Xinglong Ye[1], Horst Hahn[1,2], Oliver Gutfleisch[1]

[1] Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt, Germany

[2] Institute of Nanotechnology, Kaiserstraße. 12, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Emergent dynamics arises from local interactions among large population of simple elements, underpinning energy-efficient computation in the brain [1]. Arrays of non-interacting nanomagnets are widely used in magnetic storage, where dipole-dipole interactions are considered detrimental. Here, by embracing this physical interaction, we present a wafer-scale, self-assembled magnetic neural network composed of billions of $SmCo_5$ nanomagnets, where emergent dynamics can be triggered by electrochemical potentials of only ~1 V. The network combines three key ingredients: (1) voltage-responsive nanomagnets, which can be toggled between stable memory state and dynamic update regime, enabled by unprecedented nearly 1000-fold change of coercivity; (2) autonomous flipping of nanomagnet's state driven entirely by local dipolar interaction; and (3) self-assembled, disordered network architecture producing spin frustration and complex Ising-like energy landscape. At the network level, the system evolves under the Ising-type Hamiltonian, with asynchronous spin-state updates governed entirely by local interactions. Upon voltage stimulation, we observed a rich spectrum of emergent behaviors, including spontaneous self-demagnetization, large-scale reconfiguration of magnetic state, and convergence into stable state. These dynamics exhibit stochastic spin flipping and power-law evolution dictated by energy minimization, paralleling behaviors seen in spin-glass systems and energy-based models. Our work introduces a new class of physical substrate in which emergent dynamics —driven by native interactions and triggered by biologically-relevant inputs—opens a playground for implementing scalable, energy-efficient neuromorphic computing grounded in physical principles.

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