

TMAG 2026

BOOK OF ABSTRACTS

Trends in MAGnetism | Milan, Italy
7-11 September 2026



POLITECNICO
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Bonardi Campus

The act of “mending”



The work on the Bonardi campus was based on Renzo Piano's concept of “**mending**”, in line with several clear principles: to tackle the deterioration of historical buildings - notably the Trifoglio and the Nave, designed by Gio Ponti; to build three new non-invasive structures featuring large windows and capable of blending in with other existing structures; and to create a uniform context bringing the various parts together in a harmonious manner and putting the green and communal areas centre stage.

This is how the new **Architecture campus** was formed, integrating both history and modernity as part of a new narrative, and introducing new trees (as many as 127), green flowerbeds, two large terraces and equipped study areas. The lowered floor is presented as the true “ground floor”, the fulcrum of the area, the distribution plane and the feature capable of connecting the buildings with the open space of the city, and the ideal projection and functional addition of the patio of the central building designed by Vittoriano Viganò.



NV Sensing and Scanning Magnetometry

SPECSGROUP



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Trends in MAGnetism 2026
Milano, Italy, 7-11 September, 2026



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DI FISICA

Program at a glance

	Mon 7th		Tue 8th		Wed 9th	Thu 10th	Fri 11th									
8:00 - 9:00			REGISTRATION													
9:00 - 9:15	Opening		Jordi Sort Vinas, Universitat Autònoma de Barcelona		Peter Fischer, Lawrence Berkeley National Laboratory	Jagoda Slawinska, University of Groningen										
9:15 - 9:30	Tiffany Santos, Western Digital (keynote)		Pietro Gambardella, ETH Zurich		Valentin Alek Dediu, CNR-ISMN	Stephan Mangin, Université de Lorraine	D. Berkov, oral	A. Cataldo, oral								
E. Strambini, oral							G. Varvaro, oral									
9:30 - 9:45							R. Klingeler, oral	E. Van Meirvenne, oral								
9:45 - 10:00							N. Vijayan, oral	P. Mazalski, oral								
10:00 - 10:15	Philipp Pirro, Rheinland-Pfälzische Tech. Universität		Evgeny Tsymbal, University of Nebraska-Lincoln		Silvia Picozzi, University Milan-Bicocca	Rikako Yamamoto, Max Planck Institute	M. Fiorentino, oral	A.Chizhik, oral								
10:15 - 10:30																
10:30 - 11:00	COFFEE BREAK															
11:00 - 11:15	B. Brereton, oral	M. Titov, oral	F. Bottegoni, oral	S. Wang, oral	Shinji Yuasa, National Institute of Advanced Industrial Science and Technology (AIST)	Pedram Khalili Amiri, Northwestern University (keynote)	Can Avci, Institut de Ciència de Materials de Barcelona									
11:15 - 11:30	G.Gandini, oral	T. Karaman, oral	A. Bianco, oral	T. Blank, oral	Kai Liu, Georgetown University		Giovanni Finocchio, University of Messina									
11:30 - 11:45	C. Marrows, oral	H. Awano, oral	D. Dagur, oral	A. De Vita, oral			Mathias Klau, Johannes Gutenberg University, Mainz	Daoqian Zhu, Beihang University								
11:45 - 12:00	R. Tomasello, oral	A. Droghetti, oral	F. Al Ma'Mari, oral	A. Calloni, oral	Lukas Fischer, Max-Planck Ins. of Microstructure Physics	Hari Srikanth, University of South Florida	Award and closing ceremony									
12:00 - 12:15	S. Hait, oral	G.M. Vinai, oral	N. Biziere, oral	M. Costa, oral	Tour of Como/Bellagio	Social Activites - A guided tour of Milan's Cathedral										
12:15 - 12:30	S. Miyahara, oral	F. Camargo, oral	D. Rodrigues, oral	V. Scagnoli, oral												
12:30 - 12:45	LUNCH BREAK (Free time)						LUNCH BREAK (included)	LUNCH BREAK (Free time)								
12:30 - 13:30	Poster Session A						Poster Session B				Simone Finizio, Paul Scherrer Institut					
13:30 - 14:00													Andrea Meo, Politecnico di Bari			
14:00 - 14:15																
14:15 - 14:30																
14:30 - 14:45																
14:45 - 15:00																
15:00 - 15:30	COFFEE BREAK		COFFEE BREAK													
15:30 - 15:45																
15:45 - 16:00																
16:00 - 16:15	M. Kuepferling, oral	M.Bialek, oral	Carlos Rojas-Sánchez, Institut Jean Lamour, France													
16:15 - 16:30	C. Negrin, oral	P.Florio, oral														
16:30 - 16:45	N. Kulesh, oral	A. Frej, oral	Dmitry Berkov, General Numerics Research Lab e.V.													
16:45 - 17:00	G. Pradhan, oral	F. Maspero, oral														
17:00 - 17:15	S. Tacchi, oral	W. Piazzoli, oral	Hyunsoo Yang, National University of Singapore													
17:15 - 17:30	O.Koplak, oral	A. Shumilin, oral														
17:30 - 17:45	I. Rozhansky, oral	S. Wittrock, oral														
17:45 - 18:00	U. Enkhnarant, oral	G. Pransu, oral	Young research award													
18:00 - 18:30	Peter Rickhaus - sponsor Qnami															
18:30 - 19:00	WELCOME RECEPTION		Free time			Conference picture and social dinner at Como										
19:00 - 20:30																
20:30 - 23:00	Free time					Free time										



Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Monday, 7th September		
8:00-9:00	Registration	
ROOM A		
9:00-9:15	Opening	
	Session chair: Christian Rinaldi	
9:15-10:00	Tiffany Santos, Western Digital - "Spins and Flips: Advanced Studies with Tiny MRAM Bits" (keynote)	
10:00-10:30	Philipp Pirro, Rheinland-Pfälzische Technische Universität - "Microscaled tuneable spin-wave devices: influence of magnon-magnon interaction on the performance of standalone phase shifters"	
10:30-11:00	Coffee Break	
	ROOM A	ROOM B
	Session chair: Matteo Cantoni	Session chair: Daniela Petti
11:00-11:15	Benjamin Brereton - "Pulse-driven Spin Texture Manipulation in Perpendicularly Magnetized Topological Insulator/Magnetic Multilayer Heterostructures"	Mikhail Titov - "Boundary-Driven Orbital Kerr Effect from an Interband Coherence Drift"
11:15-11:30	Giovanni Gandini - "Ferroelectric control of chiral magnetic interactions in hafnia-based multiferroic heterostructures"	Tamer Karaman - "Discovery of imprinted faint domain patterns in amorphous ferrimagnets"
11:30-11:45	Christopher Marrows - "Structure and magnetism of co-sputtered epitaxial layered Fe-Sn kagome thin films"	Hiroyuki Awano - "Two-Dimensional Reversible Domain Control by Laser Scanning under In-Plane Field in GdFeCo/Pt Films"
11:45-12:00	Riccardo Tomasello - "A CMOS-compatible, scalable and compact magnetoelectric spin-torque microwave detector"	Andrea Droghetti - "Spin-polarized transport and correlation effects in van der Waals ferromagnets"
12:00 - 12:15	Soumyarup Hait - "Spin-orbit torque generation in topological insulator-magnetic multilayer heterostructures"	Giovanni Maria Vinai - "Strain-driven metastable magnetic domain stabilization in PMN-0.4PT/Ni heterostructures via mild annealing"
12:15 - 12:30	Shin Miyahara - "Magnetic excitations of frustrated spin systems: ferromagnetic AKLT model and Shastry-Sutherland model"	Franco Camargo - "Widefield femtosecond chiroptical imaging via multiplexed off-axis holography"
12:30 - 14:00	LUNCH BREAK (free time)	
ROOM C	Session chairs: Philipp Pirro, Carlos Rojas-Sánchez, Rikako Yamamoto	
14:00 - 15:15	Poster Session A	
15:15 - 16:00	Poster Session A / Coffee Break	
	Session chair: Alberto Brambilla	Session chair: Riccardo Bertacco
16:00 - 16:15	Michaela Kuepferling - "Decoupling Magnetoresistive effects in Spin Hall Magnetoresistance Sensors by Hysteresis Modeling"	Marcin Bialek - "Terahertz Magnon-Polariton Control Using a Tunable Liquid Crystal Cavity"
16:15 - 16:30	Christian Negrin - "Holographic imaging of ultrafast demagnetization dynamics in a Pt/CoFeB/MgO heterostructure"	Piero Florio - "Programmable Integrated Magnonic Meshes"
16:30 - 16:45	Nikita Kulesh - "Uncertainty-aware deep learning image analysis for data-driven FePt HAMR media optimization"	Antoni Frej - "Voltage control of magnonic Fabry-Pérot resonators"
16:45 - 17:00	Gajanan Pradhan - "Strain-Driven Electric Field Control of Magnetization in FeGa microstructures on PMN-PT"	Federico Maspero - "MEMS and magnonics technology platform: standalone and tunable RF systems"
17:00 - 17:15	Silvia Tacchi - "Interfacial Dzyaloshinskii-Moriya Interaction in epitaxial Graphene/Ferromagnetic Systems"	Walter Piazzai - "Multiferroic K0.27Na0.73NbO3/CoFeB heterostructure for magnonic devices"
17:15 - 17:30	Oksana Koplak - "Magnetic targeting of cubic CoFe2O4 nanoparticles in cells and in vivo"	Andrei Shumilin - "Multiscale modelling of magnonic devices"
17:30 - 17:45	Igor Rozhansky - "Interaction-enhanced spin-orbit splitting in monolayer MoS2 from magnetotransport"	Steffen Wittrock - "Nonlinear magnons revealed in reciprocal space: Magnon momentum microscopy"
17:45 - 18:00	Uyanga Enkhnarant - "Barium-magnesium ferrite nanocomposite for EMI shielding applications"	Gaurav Pransu - "Investigation of transport and magnetic properties of intercalated 2H-NbS2"
18:00 - 18:30	Peter Rickhaus, Sponsor Qnami - "Characterization of fragile magnetic states in 3D systems using Scanning NV microscopy"	
18:30 - 20:00	Welcome Reception	

Spins and flips: Advanced studies with tiny MRAM bits

Tiffany S. Santos

Western Digital Research Center, Western Digital, San Jose, California, USA

The magnetic tunnel junction is the key data storage element in magnetic random access memory (MRAM), first in toggle MRAM used in automotive applications and outer space, and now in the production of spin-transfer torque MRAM (STT-MRAM) as a replacement for embedded flash memory. As computing capabilities advance and drive demand for high-performance memory, innovation in MTJs continues to deliver faster, high-density MRAM that can support last-level cache, in-memory computing, and artificial intelligence. In Western Digital Research, we have the capability to fabricate and characterize MRAM devices that are smaller than 50 nm in diameter [1]. Along with enabling progress in MRAM technology, having such tiny bits at our fingertips gives us the opportunity to study magnetic properties and magnetization dynamics at the nanoscale, in both individual devices and arrays of devices. For example, in this talk I will describe our study of time-resolved free layer switching for small device sizes where the crossover between domain wall mediated switching and single-domain reversal occurs [2]. For a tight pitch patterned array of MRAM bits, I will show our MOKE characterization of mean coercive field and distribution for switching the large area array [3]. In addition, I will describe our characterization of device-level damping parameter by spin-torque ferromagnetic resonance [4], as well as determination of thermal stability parameter for devices down to 20 nm diameter [5]. For these studies, I will describe the importance of linking device-level performance to the optimized magnetic properties in the film level [6].

[1] L. Wan, T. Santos et al, *IEEE Trans Magn* **58**(5), 3400406 (2022)
[2] H.J. Richter, T.S. Santos, et al, *AIP Advances* **13**, 025013 (2023)
[3] Y. Fan, T.S. Santos et al, *IEEE Trans Magn*, submitted
[4] H.J. Richter, T.S. Santos et al, *J. Appl. Phys.* **136**, 113902 (2024)
[5] G. Mihajlovic, T.S. Santos et al, *J. Phys. D: Appl. Phys.* **59** 025002 (2025)
[6] T.S. Santos, J.A. Katine, B.D. Terris et al, *J. Appl. Phys.* **128**, 113904 (2020)



Tiffany Santos

Western Digital

Biography

Tiffany S. Santos received her S.B. and Ph.D. degrees in Materials Science and Engineering from MIT. Her Ph.D. thesis was on thin-film magnetism and spin-polarized tunneling in magnetic tunnel junctions under the supervision of Jagadeesh Moodera at the Francis Bitter Magnet Laboratory, MIT. She is the Director of Materials Research in the research division of Western Digital Corporation in San Jose, California where she leads a team and lab working on novel materials for information storage, sensors, spintronics, superconducting devices, non-volatile memory, and AI compute architectures. She first joined the company in 2011, when it was previously known as Hitachi Global Storage Technologies, to work on research of granular FePt media for heat-assisted magnetic recording. Prior to working in industry, she was a Distinguished Post-Doctoral Fellow, and later an Assistant Scientist, at the Center for Nanoscale Materials in Argonne National Laboratory, where she studied emergent phenomena at the interfaces of complex oxide heterostuctures. Dr. Santos has an active role in professional societies in the magnetism community. She was a Distinguished Lecturer of the IEEE Magnetism Society in 2022, and now she is Chair of the Distinguished Lecturer Program. She was General Chair of the 2025 Magnetism and Magnetic Materials (MMM) Conference in Palm Beach, Florida. In 2009, she was awarded the prestigious L'Oréal USA Fellowship for Women in Science. She is a Fellow of the American Physical Society.



Microscaled tuneable spin-wave devices: influence of magnon-magnon interaction on the performance of standalone phase shifters

J. Grei^a, A. Angotti^b, F. Kohl^c, A. Papp^d, M. Wagner^c, M. Cocconcelli^b, A. Del Giacco^b, D. Ferling^e, B. Heinz^c, F. Maspero^b, G. Csaba^d, R. Bertacco^b, M. Becherer^a, P. Pirro^c

^a Technical University of Munich, Germany

^b Department of Physics and Polifab, Politecnico di Milano, Italy

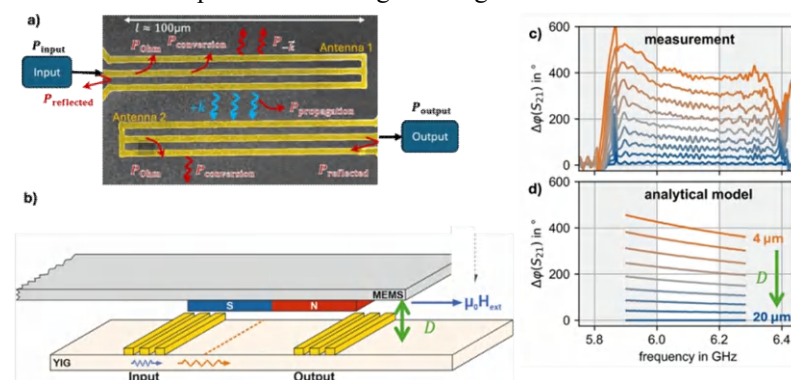
^c Department of Physics and Landesforschungs. OPTIMAS, RPTU, Kaiserslautern, Germany

^d Pazmany Peter Catholic University, Budapest, Hungary

^e Nokia Bell Labs, Nokia Corporation, Stuttgart, Germany

Coherent spin waves [1] are promising candidates both for radio-frequency (RF) signal processing since they offer properties like scalability, reconfigurability via magnetic fields. I will discuss the various challenges associated with the respective applications using a delay line-based magnonic phase-shifter as an example [2]. This hybrid magnonic-MEMS device is the joint development effort of the Horizon Europe project M&MEMS (www.mandmems.eu).

Fig. 1a shows a schematic of the delay line including the different loss channels. One main challenge is to reduce these losses and electromagnetic cross talk [3] to efficiently make use of the tunability of the working frequencies via magnetic fields. Fig. 1b schematically shows how tunability can be achieved with low power consumption by using voltage-driven piezo-MEMS instead of charge current-based methods. The MEMS is displacing a soft micromagnet whose stray field locally shifts the spin-wave dispersion between the input and output spin-wave antenna, but without significantly affecting the excitation and detection at the antennas themselves. As a result, the transmission band frequency is almost unaffected, but the phase accumulation of the spin waves strongly depends on the micromagnet distance D . I will first discuss the achieved integration of this device. Then, I will present a theoretical framework to address nonlinear effects like intermodulation and nonlinearity of the insertion loss, which constitute an important remaining challenge.

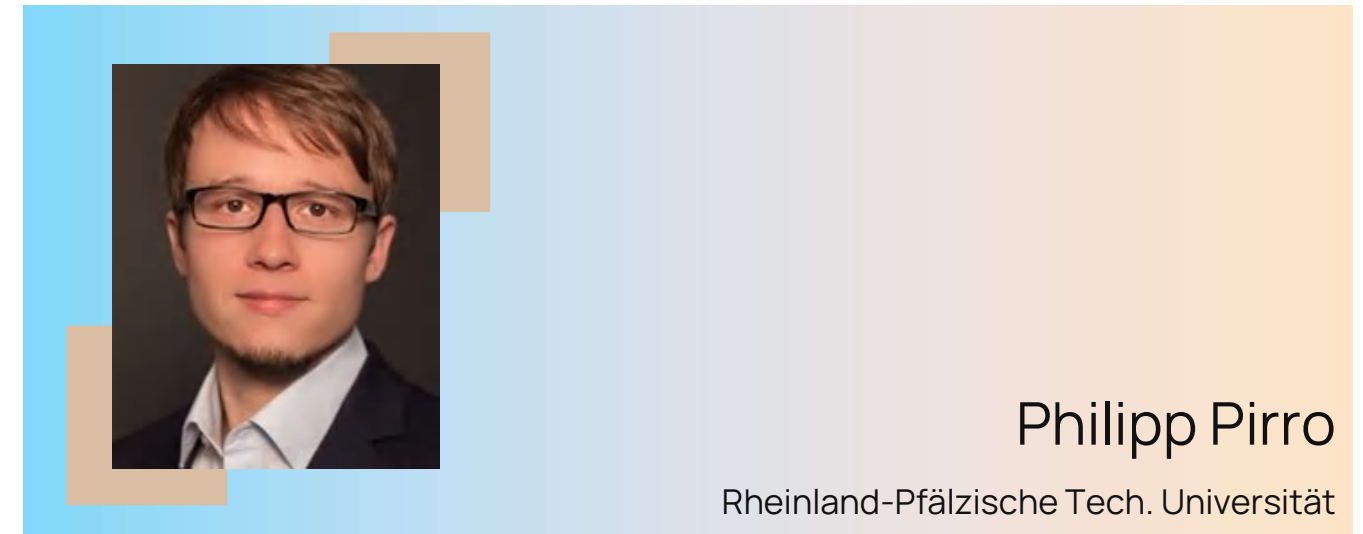


a) Magnonic delay line and its different loss channels. b) Sketch of a delay line whose phase-accumulation is tunable by the distance D of micromagnets on a vertically moving MEMS. c) experimentally measured and d) analytically calculated phase-shift of the RF signals as a function of D .

[1] P. Pirro, et al., Nat Rev Mater 6, 1114 (2021).

[2] J. Greil, PP, et al., arXiv:2606.14280 (2026)

[3] F. Kohl, PP, et al. Phys. Rev. Appl. 25, 054064 (2026)



Philipp Pirro

Rheinland-Pfälzische Tech. Universität

Biography

Philipp Pirro received his Diploma (2010) and PhD (2014) degree in experimental physics at the Technische Universität Kaiserslautern, Germany. In 2015, he was a Postdoctoral researcher at the Institut Jean Lamour in Nancy, France. Since 2016, he is a researcher at the Rheinland-Pfälzische Technische Universität (RPTU) Kaiserslautern-Landau. From 2019 on, he has been leading the junior research group “nanoscaled magnonics hybrids”. Since 2026, he is full professor and leader of the AG magnonics research group.

His main scientific aim is to explore and combine emerging physical phenomena related to spin waves which can be used to realize novel magnonic hybrid systems with superior characteristics. Specifically, he has a particular focus on nonlinear spin-wave phenomena in micro- and nanostructures, nanoscaled magnonic devices for unconventional data processing, hybrid systems combining magnonics with spintronic and phononic systems, and the amplification and control of coherent spin-waves in micro- and nanostructures using parametric processes.

Dr. Pirro has been awarded the ERC Starting grant “CoSpiN- Coherent Spintronic Networks for Neuromorphic Computing”. He is also the coordinator of the Horizon Europe Project “M&MEMS”.

Characterization of fragile magnetic states in 3D systems using
Scanning NV microscopy

Peter Rickhaus^a

^a Qnami

Scanning NV magnetometry (SNVM) is a sensitive and non-invasive characterization method that is especially well suited to image weakly magnetic or fragile states. However, its operational principle is based on rastering a surface, making it intrinsically challenging to characterize three-dimensional textures. Here, we discuss mitigation strategies that allow using the high spatial resolution, sensitivity and non-invasiveness of SNVM [1]. Motivated by the current interest in three-dimensional magnetic structures, we will demonstrate the investigation of magnetic monopoles in 3D artificial spin-ice structures [2]. Furthermore, we will take a broader look at opportunities and challenges of SNVM in 3D.

[1] P. Rickhaus et. al., Nano Lett. **24** (2024), 13172-13178.
[2] A. V.d. Berg, et. al., in review



Biography

Peter Rickhaus is scientist and R&D engineer at Qnami (Quantum Design). Within his PhD at Basel University and his Postdoc at the ETH Zurich on quantum transport in twisted bilayer graphene he acquired a deep understanding of quantum physics and nanofabrication. At Qnami, he worked on quantum sensing with NV centers on a wide range of engineered magnetic samples. He contributed to more than 30 research publications and hosts a rich hands-on knowledge for investigative and analytical techniques.



Pulse-driven Spin Texture Manipulation in Perpendicularly Magnetized Topological Insulator/Magnetic Multilayer Heterostructures

Benjamin A. Brereton^{1,2,3}, Soumyarup Hait¹, Ahmet Yagmur¹, Francesco Maccherozzi³, Christy J. Kinane², Michelle Conroy⁴, Thomas A. Moore¹, Sarnjeet S. Dhesi³, Sean Langridge² and Christopher H. Marrows¹

¹School of Physics and Astronomy, University of Leeds, Leeds, UK

²ISIS Neutron and Muon Source, STFC Rutherford Appleton Laboratory, Didcot, UK

³Diamond Light Source, Harwell Science and Innovation Campus, Didcot, UK

⁴Department of Materials, Imperial College London, Exhibition Road, London, UK

Magnetic skyrmions, due to their non-trivial topology, can be created and transported through spin-orbit torque (SOT) mechanisms in magnetic multilayers (MMLs). Traditionally the SOT source has been the spin-Hall effect of heavy metals, however in recent years topological insulators (TIs) have been of great interest due to offering far greater spin-to-charge conversion and lower required current densities arising from their topological surface states (TSS). Through optimization of TI and MML growth, we have characterized a combined TI-MML heterostructure (Fig 1) through polarized neutron reflectometry and standard magnetometry to be capable of hosting the perpendicularly magnetized domains required for skyrmion formation with the aim of utilizing the TSS for ultra-efficient skyrmion and spin texture control.

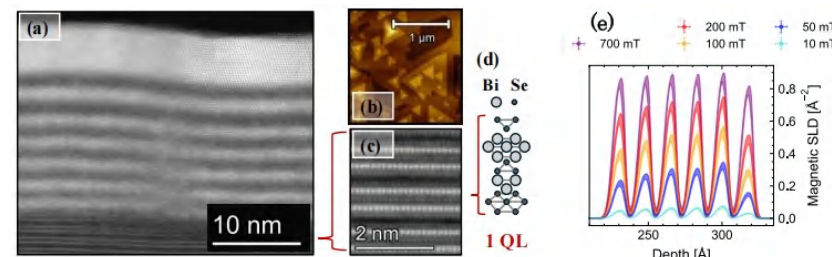


Fig 1: (a) HAADF-STEM imaging of combined TI-MML heterostructure with (b) topographic AFM showing terracing due to quintuple layering shown in (c-d); (e) shows fitted magnetic slab model from polarized neutron reflectometry (PNR) measurements under an increasing in-plane applied field affirming a uniform, hard-axis magnetic profile consistent with PMA.

We demonstrate using XMCD-PEEM imaging at room temperature, upon current pulsing of $J \sim 1.1 \times 10^{11}$ A/m², domains can be reoriented in the direction of current indicating directional torques as well as nucleate a skyrmion phase of varying density controlled by the external applied field (Fig 2). Samples without the TI layer could not be similarly manipulated suggesting the inclusion of the TI layer offers significant torque benefits and raises the possibility of TI-driven skyrmion motion in future experiments.

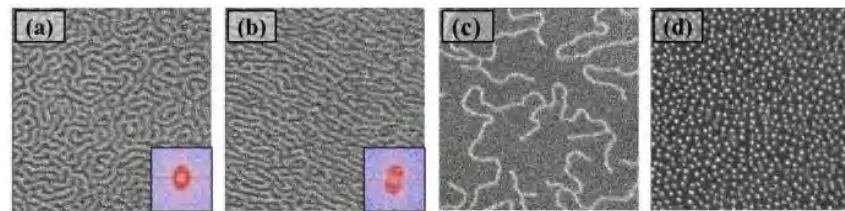


Fig 2: XMCD-PEEM images at the Co L₃ edge: zero field domains before (a) and after (b) current pulsing; 4 mT domains before (c) and after (d) pulsing leading to skyrmion nucleation.

Boundary-Driven Orbital Kerr Effect from an Interband Coherence Drift

Mikhail Titov^a, Ivan Iorsh^b

^a Radboud University, Nijmegen, the Netherlands

^b Queen's University, Kingston, Canada

We present a novel orbitronic mechanism for current-induced Kerr rotation in semiconductor slabs. In n-GaAs under a dc electric field, diffusive boundaries break translational symmetry and enable an anomalous interband coherence drift that generates a sizeable orbital magnetization. This boundary-induced coherence drift (BICD) can dominate the Kerr response over the contribution associated with spin accumulation from the spin Hall effect. In contrast to the conventional interpretation of the Kato et al. (2004) experiment, our theory shows that boundaries are indispensable: without edge scattering, both the SHE and BICD contributions are negligible. Our quantum-kinetic analysis, based on a generalization of Culcer et al.'s interband response theory [1], predicts a pronounced optical-frequency dependence of the Kerr angle, driven by resonant interband transitions, as well as a thermally driven Kerr effect under a heat current. We also outline experimentally testable predictions for orbital-driven Kerr signals in doped MoS₂ and WTe₂ slabs. Key results are as follows: (i) the orbital Kerr effect can arise not only from spin accumulation but also from an intrinsic orbital contribution linked to Berry curvature and interband coherence drift; (ii) its dependence on the band gap, split-off energy, and optical frequency provides clear signatures that distinguish it from spin-accumulation effects; and (iii) an in-plane magnetic field suppresses the BICD contribution in a manner similar to that seen experimentally [2].

These results point to a possible reinterpretation of spintronic Kerr signals in terms of orbitronics. Recent reviews show that electric fields can generate nonzero orbital angular momentum even in the absence of spin-orbit coupling. Our work connects directly to this emerging perspective and suggests that optical effects commonly described as spin-driven may, under realistic boundary conditions, be predominantly orbital in origin. In summary, our theory reveals a qualitatively different Kerr effect in biased GaAs and offers a framework for new experiments and for re-examining established spintronic phenomena.

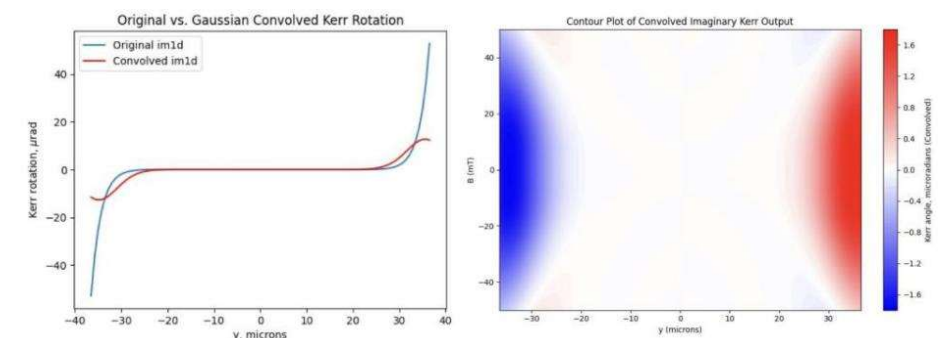


Figure 1. Calculated Kerr response after optical convolution: spatial profile (left) and magnetic-field dependence (right).

[1] D. Culcer, A. Sekine, and A.H. MacDonald, Phys. Rev. B 96, 035106 (2017)

[2] Ivan Iorsh and Mikhail Titov, unpublished (2026)

Ferroelectric control of chiral magnetic interactions in hafnia-based multiferroic heterostructures

Giovanni Gandini^a, Giacomo Spaccia^a, Johannes Hertel^b, Adriano Di Pietro^c, Alessandro Magni^c, Marco Madami^d, Silvia Tacchi^d, Armando Pezo^e, Davide Benettin^a, Federico Fagiani^a, Matteo Cantoni^a, Tatyana Guryeva^b, Christoph Durner^b, Maximilian Lederer^b, Federico Fagiani^a, Benjamin Lilienthal-Uhlig^b, Michaela Kuepferling^c, Rémi Arras^f, Aurélien Manchon^g, Christian Rinaldi^a

^a Politecnico di Milano, Milan, Italy

^b Fraunhofer IPMS (Center Nanoelectronic Technologies CNT), Dresden, Germany

^c Istituto Nazionale di Ricerca Metrologica (INRiM), Turin, Italy

^d Università di Perugia, Perugia, Italy

^e Université Paris-Saclay, CNRS, Thales, Palaiseau, France

^f Université de Toulouse, CNRS, UPS, Toulouse, France

^g Aix-Marseille Université, CNRS, CINaM, Marseille, France

The electric-field control of magnetism in magnetoelectric multiferroics is a promising route toward energy-efficient in-memory computing [1]. Hafnia-based ferroelectrics are particularly attractive due to their non-volatility and full CMOS compatibility, enabling scalable spin-orbitronic devices [2,3].

Here, we demonstrate robust magnetoelectric coupling and the emergence of chiral magnetic interactions in perpendicularly magnetized ultrathin Co films integrated with Zr-doped hafnia ($\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$, HZO) on Si. We identify processing conditions that simultaneously yield strong perpendicular magnetic anisotropy (PMA) and a magnetization comparable to bulk Co. The HZO layer exhibits high-quality ferroelectric behavior, with saturation polarization up to $20 \mu\text{C}/\text{cm}^2$ and long endurance.

The ferroelectric control of magnetism is investigated via in-operando magneto-optical Kerr microscopy, Brillouin light scattering, and anisotropic magnetic bubble expansion in micro-capacitors. We observe a significant modulation of magnetic coercivity and demonstrate non-volatile tuning of the antisymmetric exchange interaction, achieving a ~70% modulation of the Dzyaloshinskii-Moriya interaction (DMI). Density functional theory attributes this effect to the control of interfacial Rashba spin-orbit coupling, while micromagnetic simulations link the microscopic mechanisms to macroscopic observables such as domain size and nucleation probability. These results establish HZO/Co heterostructures as a versatile platform for voltage-driven, non-volatile control of magnetization and chiral spin textures. This approach opens new pathways for the manipulation of domain walls, skyrmions and spin-orbit torques, with strong potential for beyond-CMOS computing technologies [4].

The authors acknowledge the support through the National Recovery and Resilience Plan (NRRP), project “Spin-ORBit Effects in Two-dimensional magnets” (SORBET), ID 2022ZY8HJY – CUP D53D23002500006, funded by the European Union – Next Generation EU – “PNRR - M4C2, investimento 1.1”, fund PRIN 2022.

- [1] A. Fert *et al.*, Rev. Mod. Phys. **96** (2024), 015005.
- [2] S. Lancaster *et al.*, ACS Applied Materials and Interfaces **15** (2023), 16963.
- [3] B. Vermeulen *et al.*, ACS Applied Materials and Interfaces **11** (2019), 34385.
- [4] A. Pezo *et al.*, Phys. Rev. B **111** (2025), L140405.

Discovery of imprinted faint domain patterns in amorphous ferrimagnets

Tamer Karaman^{1*}, Daniel Metternich^{1,2,5}, Sabri Koraltan³, Aladin Ullrich¹, Timo Schmidt¹, Riccardo Battistelli^{1,2}, Manas Patra^{1,2}, Manuel Valvidares⁴, Daniel Pérez Salinas⁴, Christopher Klose⁵, Michael Schneider⁵, Bastian Pfau⁵, Emily Darwin⁶, Reshma Peremadathil Pradeep⁶, Sebastian Wintz², Konrad Samwer⁷, Kai Litzius¹, Manfred Albrecht¹, Hans Josef Hug⁶, Felix Büttner^{1,2}

¹Institute of Physics, University of Augsburg, Augsburg, Germany ²Helmholtz-Zentrum Berlin, Berlin, Germany

³Technical University of Vienna, Vienna, Austria ⁴ALBA Synchrotron Light Source, Barcelona, Spain

⁵Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany ⁶Empa, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland ⁷I. Physics Institute, University of Göttingen, Göttingen, Germany

A core assumption in magnetism is that magnetic saturation erases all magnetic textures, yielding a uniform, featureless state. Here we show that this assumption can break down in amorphous rare-earth-transition-metal (RE-TM) ferrimagnets—a material class that has been studied for decades, for example for bubble memories [1], all-optical switching [2], high-velocity domain wall motion [3], bulk chiral interactions [4], and room-temperature skyrmionics [3].

Using high sensitivity magnetic force microscopy, Lorentz transmission electron microscopy, and synchrotron-based magnetic X-ray imaging, we observe faint domain-wall patterns that remain embedded in the material even after conventional domains and skyrmions are fully suppressed by a magnetic field beyond saturation, persisting without any change even after 35 T field pulses. These “faint domains” coexist with, and guide, the nucleation and spatiotemporal evolution of magnetic domains under applied fields.

We show that the faint domains are imprints of the domain walls present during film growth. We hypothesize that the domain walls become permanently encoded into the material's anisotropy landscape due to magnetostriction. Micromagnetic simulations show that this model successfully explains the observed faint magnetic contrast and its field dependence.

The imprinting effect of faint domains is ubiquitous across RE-TM ferrimagnets, whether they are grown as alloys or multilayers, or exhibit square or sheared hysteresis loops. Our results show for the first time that magnetic textures can be permanently imprinted into solid-state materials, redefining the concept of magnetic saturation and opening exciting opportunities for persistent, field-resilient functionality in spintronic devices.

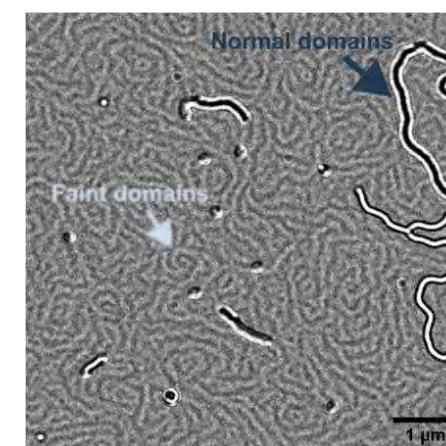


Figure 1: L-TEM image of a Dy/Co multilayer just below saturation, revealing normal domains (stripe domains, skyrmions, trivial bubbles, and antiskyrmion) above a maze-shaped background pattern of faint domain-type signal. These faint domains guide the expansion and contraction motion of magnetic spin textures when varying the applied field.

- [1] P. J. Grundy *et al.*, Contemp. Phys., **18**, 1, 1 (1977)
- [2] C. D. Stanciu *et al.*, Phys. Rev. Lett., **99**, 4, 047601 (2007)
- [3] L. Caretta *et al.*, Nat. Nanotechnol., **13**, 12, 12 (2018)
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Structure and magnetism of co-sputtered epitaxial layered Fe-Sn kagome thin films

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The intermetallic alloys of Fe and Sn display a rich interplay of electronic and magnetic properties [1]. The crystal Fe_3Sn_2 is a frustrated ferromagnet, while the crystallographically similar FeSn, which differs only by the stacking sequence of its Fe-containing kagome Fe_3Sn_2 and stanene Sn layers (Figure1), is an antiferromagnet. Here, we report the production of high quality epitaxial thin films of Fe_3Sn_2 and FeSn on sapphire [2], as well as a mixed phase film containing intergrowths of both crystal structures. We have characterized these films using both X-ray diffraction and four-dimensional scanning transmission electron microscopy (4D-STEM) methods. Phase maps based on the analysis of the 4D STEM are shown in Figure 2. The phase mixing is not easily made evident by XRD, despite this being the most common form of characterisation for films of this sort in the literature.

The resulting crystallographic phase content is compared to the results of magnetization measurements, with correspondence between the predicted ferromagnetic phase content and the resulting magnetization. Further magnetic properties of these films can then also be compared, leading to the discovery of a unusual non-monotonic behaviour in the temperature dependent coercivity within highly mixed phase alloys, a feature that is absent in either pure Fe_3Sn_2 and FeSn.

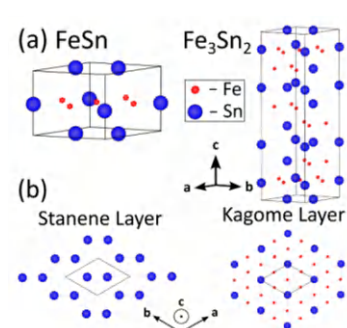


Figure 1: Crystal structures of FeSn and Fe_3Sn_2 . (a) Unit cells. (b) Schematics of the Sn₂ stanene layer and the Fe_3Sn_2 kagome layer.

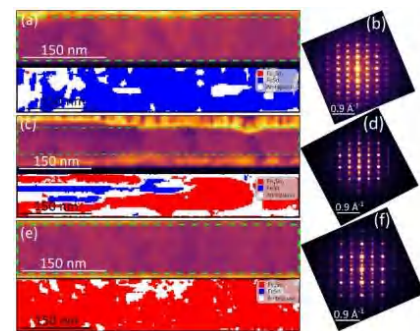


Figure 2: HAADF images and phase maps derived from 4D-STEM data for cross sections of: (a) the FeSn film, (c) the mixed phase film, and (e) the Fe_3Sn_2 film. (b,d,f) show the corresponding NBED patterns.

[1] L. Ye et al., *Nature* **555**, 638 (2018); Z. Hou et al., *Adv. Mater.* **29**, 1701144 (2017); M. Kang et al., *Nature Mater.* **19**, 163 (2020); S. A. Ekahana et al., *Nature* **627**, 67 (2024).

[2] C. Brennan-Rich et al., arXiv:2601.05735 [cond-mat.mtrl-sci] (2026).

Two-Dimensional Reversible Domain Control by Laser Scanning under In-Plane Field in GdFeCo/Pt Films

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We report reversible domain elongation and contraction driven by laser scanning under an in-plane magnetic field in ferrimagnetic GdFeCo/Pt planar films. The planar geometry allows arbitrary selection of the scanning direction, enabling two-dimensional control of domain propagation. When a focused continuous-wave laser beam is scanned across the film under an in-plane magnetic field H_x , a magnetic domain is continuously elongated along the scanning trajectory as shown in the Fig. 1 (a) - (b), forming a narrow stripe-like domain with a width comparable to the laser spot size and a length of several tens of micrometers.

When the laser irradiation is turned off as shown in the Fig.1 (c), the elongated domain smoothly contracts along the same trajectory and returns to its original domain-wall position without fragmentation. This reversible and path-preserving behavior indicates coherent domain-wall dynamics with low pinning. In contrast, no domain elongation is observed without H_x , demonstrating that the in-plane field is essential for activating the motion.

We attribute the observed dynamics to a cooperative mechanism between entropic torque and a weak thermally induced spin-orbit torque. The temperature gradient generates a free-energy gradient that drives the domain wall toward the hotter region [1], while heat diffusion produces a small charge flow converted into a spin current via spin Hall or spin Nernst effects in the Pt layer [2–4]. Although each contribution is weak, their combined effect enables domain-wall motion.

This research was supported in part by the Grant-in-Aid for Scientific Research (25K01273), (25K22102) and the Research Center of Smart Photon and Materials, Toyota Technological Institute.

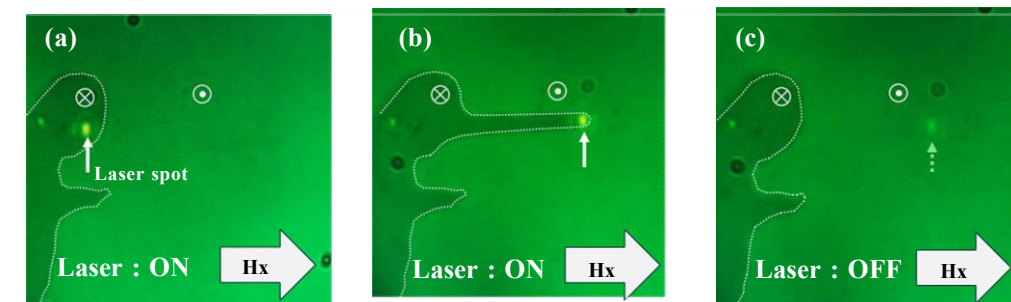


Figure 1 (a)-(b) when a focused continuous-wave laser beam is scanned across the film under an in-plane magnetic field H_x , a magnetic domain is continuously elongated along the scanning path, (c) when the laser irradiation is turned off, the elongated domain smoothly contracts along the same trajectory and returns to its original domain-wall position without fragmentation.

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- [2] A. Donges et al., *Phys. Rev. Research* **2**, 013293 (2020).
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- [4] S. Meyer et al., *Nat. Mater.* **16**, 977 (2017).

A CMOS-compatible, scalable and compact magnetoelectric spin-torque microwave detector

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The dimension reduction and scalability of microwave detection systems is fundamentally limited by the size and integration requirements of conventional antennas. Here, we report a compact and scalable magnetoelectric spin-torque microwave detector that eliminates the need for external antennas through monolithic integration of a magnetoelectric (ME) antenna with a magnetic tunnel junction (MTJ) [1]. The device directly converts incident electromagnetic waves into a rectified d.c. voltage VDC by exploiting nonlinear coupling between microwave-induced voltage, strain-mediated magnetoelectric effects, and incoherent magnetization dynamics driven by a bias current (Fig. 1a).

The detector operates in the 510–650 MHz range (Fig. 1b), and maintains robust performance even under zero magnetic bias field. In addition, it achieves high sensitivity S exceeding 90 kV/W (Fig. 1c) at sub-microwatt input power, with a noise-equivalent power of ~ 3 pW Hz^{-1/2} and a compact footprint of 0.4 mm². Furthermore, scalability is demonstrated through series integration of multiple MTJs, yielding sensitivities above 400 kV/W without increasing the device area (Fig. 1d).

These results [1] establish a pathway toward highly integrated, CMOS-compatible microwave detectors combining nanoscale spintronic devices with magnetoelectric antennas.

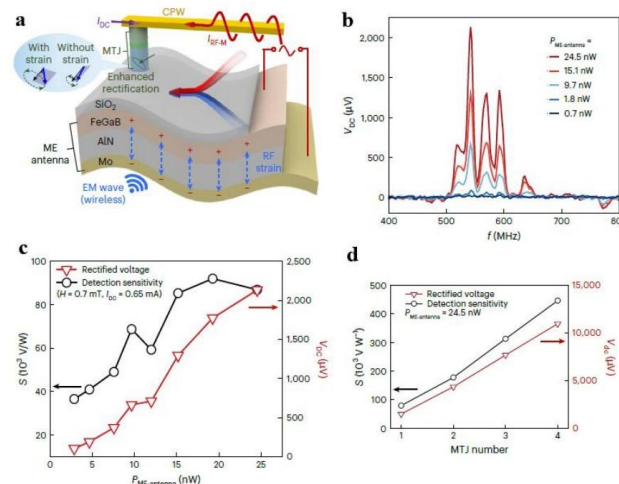


Figure 1: (a) sketch of device and working principle. (b) rectified voltage of the MTJ in the range 510 – 650 MHz. Sensitivity and rectified voltage of (c) 1 MTJ, and (d) as a function of the number of MTJs.

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Spin-polarized transport and correlation effects in van der Waals ferromagnets

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The van der Waals ferromagnets Fe_nGeTe₂ ($n = 3-5$) and Fe₃GaTe₂ are promising electrodes for two-dimensional spintronics due to their metallic ferromagnetism and high Curie temperatures down to the monolayer limit. Using density functional theory combined with non-equilibrium Green's functions, we investigate their spin-dependent electronic structure and quantum transport properties. In the linear-response regime, Fe₃GeTe₂, Fe₄GeTe₂, and Fe₅GaTe₂ exhibit nearly half-metallic out-of-plane transport with spin polarizations exceeding 90%, driven by Fermi surfaces dominated by spin-up states [1]. Among them, Fe₃GaTe₂ stands out, with the Fermi energy lying deep within the spin-down transmission gap.

We further study bilayer heterostructures as minimal magnetic tunnel junctions (MTJs). The high spin polarization is preserved, yielding tunneling magnetoresistance ratios of several hundred percent [1, 2]. Additionally, heterostructures combining different materials, such as Fe₃GaTe₂ and Fe₃GeTe₂, enable remarkable spin-diode functionality [3].

Finally, using our framework that extends and implements non-equilibrium layered dynamical mean-field theory for spin-dependent transport problems, we uncover a bias-induced crossover from coherent spin-polarized transport to a non-Fermi-liquid regime dominated by electron-magnon scattering, which we term “hot correlated electrons” [4]. This novel regime could potentially be probed by in-operando angle-resolved photoemission spectroscopy or scanning tunnelling spectroscopy.

Overall, our results highlight the fascinating fundamental physics that emerges in Fe-based van der Waals ferromagnets, emphasizing the importance of non-equilibrium electronic correlations, while also establishing these materials as strong candidates for next-generation spintronic devices.

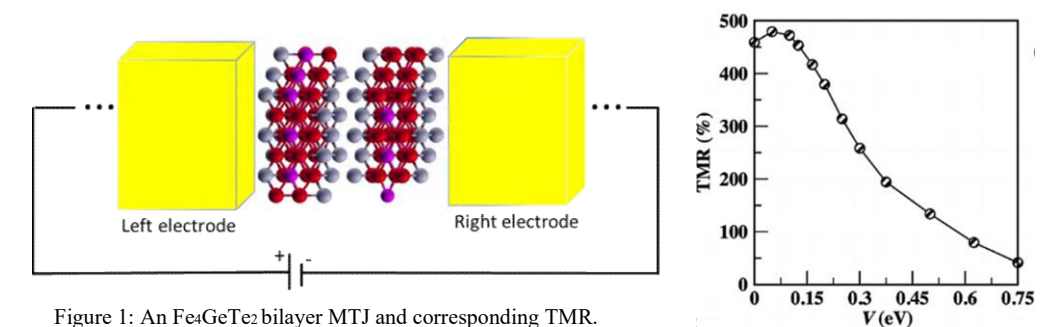


Figure 1: An Fe₄GeTe₂ bilayer MTJ and corresponding TMR.

[1] A. Halder, D. Nell, A. Sihi, A. Bajaj, S. Sanvito, and A. Droghetti, Nano Lett. **24** (2024), 9221 (2024).

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Spin-orbit torque generation in topological insulator-magnetic multilayer heterostructures

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Spin-orbit torques (SOTs) are a central topic in spintronic memory and unconventional computing, driving the search for material systems that combine efficient torque generation with stable magnetic storage [1]. In multilayer devices, interfacial effects and current shunting can significantly affect both the magnitude and sign of SOTs, making careful evaluation essential. Here, we investigate SOTs generated by the topological insulator Bi₂Se₃ acting on perpendicular magnetic anisotropy (PMA) magnetic multilayers (MMLs).

The samples comprise Bi₂Se₃ (20 nm) grown by molecular beam epitaxy on Al₂O₃ substrates, followed by Ta spacer layers of varying thickness and a dc-sputtered [Pt/Co₆₈B₃₂/Ru]₆ multilayer. Control samples without Bi₂Se₃ were deposited on oxidised Si substrates. Spin-orbit torques were measured using harmonic Hall techniques on microfabricated Hall bars, allowing separation of damping-like (DL) and field-like (FL) torques, as well as thermoelectric effects, through azimuthal-angle-dependent analysis [2].

The damping-like torque (B_{DL}) scales linearly with the applied current for all measured samples. In the reference structures, only a very small fraction of the current flows through the Ta layer, which results in highly noisy second-harmonic signals and prevents reliable quantitative analysis. Despite strong current shunting, samples incorporating Bi₂Se₃ exhibit substantial SOT magnitudes, while increasing the Ta thickness leads to a slight reduction in the torque strength. At room temperature, the Bi₂Se₃ (20 nm)/Ta (2 nm)/MML stack shows a DLT of ~ 0.08 mT per 10^{10} A m⁻², comparable to previously reported values for Bi₂Se₃-based systems [3], and this efficiency nearly doubles upon cooling to 25 K. In contrast, for samples with a thicker Ta spacer (10 nm), the SOT efficiency remains almost constant at ~ 0.04 mT per 10^{10} A m⁻² across the entire temperature range. These results emphasise the critical roles of multilayer design, spacer thickness, and current distribution in optimising SOT efficiency for future magnetic memory technologies.

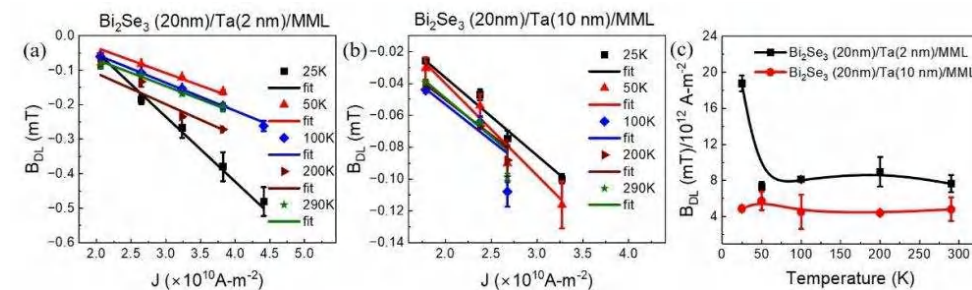


Figure 1: (a and b) Damping-like torque (B_{DL}) at current density at different temperatures for the samples with thin and thick Ta buffer layer, respectively. (c) Temperature evaluation for the B_{DL} for samples with different buffer thickness.

References:

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- [2] Y. Du et al., AIP Adv., vol. 11, p. 025033, 2021.
- [3] Q. Lu et al., Nature Commun., vol. 13, p. 1650, 2022.

Strain-driven metastable magnetic domain stabilization in PMN-_{0.4}PT/Ni heterostructures via mild annealing

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Multiferroic heterostructures, coupling ferroelectric/piezoelectric substrates with magnetic thin films via interfacial coupling, have gained increasing interest for both their fundamental properties and potential applications. Whereas the main coupling mechanisms, i.e. (strain, charge and ionic) are considered quite well established, [1] experimental proofs of the local microscopic correlation between structural properties of the functional substrate and the magnetic response of the interfacial layer are quite rare.

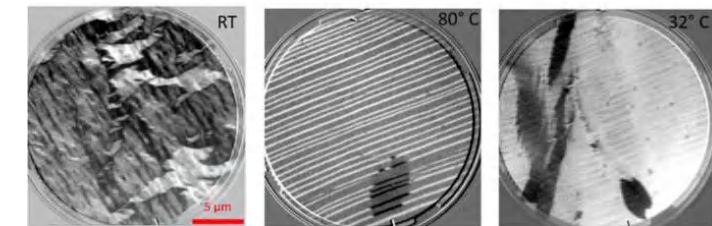


Figure 1: XMCD-PEEM at Ni L3 edge during mild thermal cycle. From left to right, room temperature, 80°C and 32°C.

In this context, here we present the stabilization of exotic magnetic domains in PMN-_{0.4}PT/Ni heterostructures upon mild annealing, a thermal regime up to now rarely explored. [2-4] The samples, preliminarily characterized at room temperature via magneto-optical (MOKE) and laboratory-based x-ray diffraction (XRD), were then demagnetized and measured via XMCD-PEEM at Circe, Alba synchrotron, where Ni domain contrast was measured while heating the heterostructure. Twin samples were structurally characterized in equivalent conditions at Diffabs, Soleil synchrotron, via XRD 3D maps. Structurally, PMN-PT showed the presence of an intermediate phase before reaching the tetragonal-to-cubic transition, around 80°C, with the stabilization of exotic orientations of the ferroelectric domains. At the same structural regime, a corresponding evolution of the interfacial magnetic properties was observed on the interfacial Ni layer, which presents highly ordered elongated domains through the whole sample (see Figure 1). Both structural and magnetic states are partially maintained once cooled to room temperature, and fully recoverable via mild heating. These results show how the intrinsic complexity of PMN-PT structural properties allow the stabilization, both locally and globally, of strain-driven exotic magnetic configurations, underlying the critical role of mild temperature regimes.

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Magnetic excitations of frustrated spin systems: ferromagnetic AKLT model and Shastry-Sutherland model

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Some of the magnetic excitations have an excitation energy corresponding to THz frequency range and the observation of anomalous magnetic excitations and the clarification of the mechanism of the excitation process are important.

Recently, we found a novel quantum state named “quatum ferromagnet” which is a coexistence of a classical ferromagnet and a quantum antiferromagnet. One of the examples, a spin- $S=3$ ferromagnetic Affleck-Kennedy-Lieb-Tasaki (AKLT) state, where ferromagnetic and Haldane state coexist [1], see Fig.1. Reflecting the coexistence of the two types of magnetic states, two types of quasiparticles, i.e., a gapless magnon and a gapped quasiparticle which corresponds to the Haldane gap, coexist and, thus, the magnetic chimera quasiparticles, i.e., one-magnon and Haldane-gap branches, are realized. We show that such chimera quasiparticles can be observed through the dynamical structure factor.

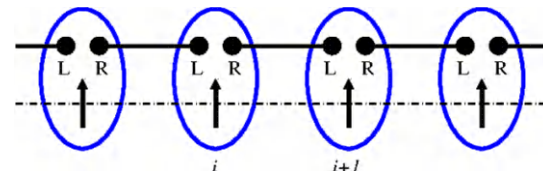


Figure 1: Ferromagnetic AKLT state. A spin-3 is separated to two spin-1/2s and spin-2.

In two-dimensional frustrated magnets $\text{SrCu}_2(\text{BO}_3)_2$, of which ground state is a product of dimer singlet states, spin excitations, one- and two-triplon excitation, were observed in THz region by ESR and far-infrared spectroscopy. However, usually the magnetic excitation from the singlet spin state cannot be excited through absorption processes. We introduce the magnetoelectric couplings to the Shastry-Sutherland model for $\text{SrCu}_2(\text{BO}_3)_2$ and show that most of the excitation processes are realized as electro-active process, i.e. the magnetic excitations are excited through the electric components of light through the dynamical electric susceptibility [2], see Fig. 2. Such an electro-active process can exist in various spin singlet states.

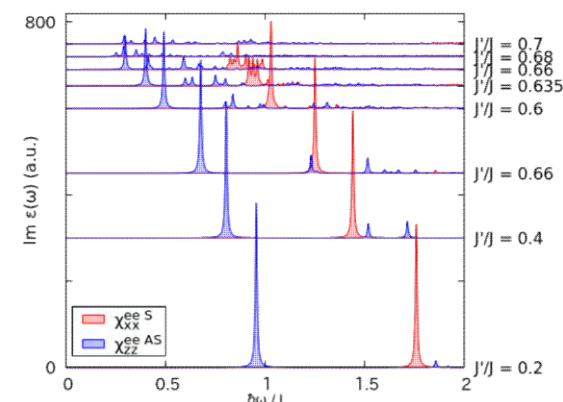


Figure 2: The imaginary parts of the dynamical electric susceptibility on the 32-site cluster in the Shastry-Sutherland model.

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[2] S. Miyahara, arXiv:2304.10823 [cond-mat.str-el].

Widefield femtosecond chiroptical imaging via multiplexed off-axis holography

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The chiroptical response of matter arises from the dependence of its complex refractive index on the handedness of circularly polarized light, which can be probed by its absorptive component, circular dichroism (CD), or its dispersive component, optical rotatory dispersion (ORD). These signals play a key role in magneto-optics, where measuring these properties on ultrafast timescales enables the investigation of spin and charge transport. In particular, time-resolved ORD is a popular technique to study spin dynamics, as an elegant detection scheme using a Wollaston prism and a pair of balanced photodiodes efficiently removes excess laser intensity noise and enables excellent sensitivity. However, there is no obvious way to extend this concept to a widefield imaging configuration. Here, we introduce an ultrafast chiroptical microscope with ~ 100 -fs temporal resolution and sub-micrometer spatial resolution that generalizes the optical bridge concept to widefield imaging by combining polarization-resolved multiplexed off-axis holography with femtosecond pulses in a pump-probe geometry (Fig. 1a) [1]. The sample is photoexcited with a circularly polarized pump pulse, while the probe pulse is linearly polarized. The probe polarization is measured by making it interfere on the camera sensor with two orthogonally polarized replicas, so that the cross-polarized components of the probe polarization are shifted to different areas of the spatial frequency domain (Fig. 1b). The holographic reconstruction enables pixel-resolved retrieval of the amplitude and phase information for the two cross-polarized components, which are then used to compute the ORD and CD (Fig. 1c) [2]. Comparing the state of polarization of the probe pulse in presence and absence of a modulated circularly polarized pump yields shot-noise-limited widefield transient ORD and CD images, alongside the conventional transient absorption and phase images, all in a single measurement. We validate this technique by imaging spatially resolved spin relaxation dynamics in hybrid organic-inorganic perovskite thin films (Fig 1d,e), and by directly tracking ultrafast spin transport, showing a carrier density-dependent spin diffusivity in the first 1.5 ps.

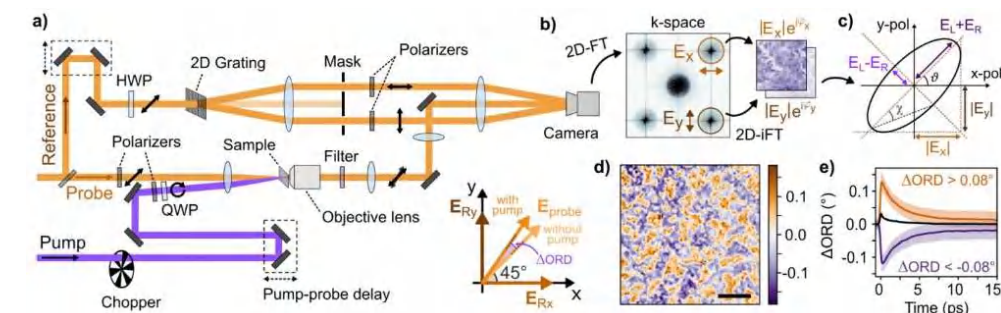


Figure 1: a) Setup. b) Hologram processing yields the c) probe polarization ellipse. d) Transient ORD imaging in $\text{MAPbBr}_{0.3}\text{I}_{0.7}$ (Scale: 10 μm). e) Spin relaxation dynamics of domains in (d).

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Decoupling Magnetoresistive effects in Spin Hall Magnetoresistance Sensors by Hysteresis Modeling

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The exploitation of Spin Hall Magnetoresistance (SMR) in heavy-metal/ferromagnetic (HM/FM) bilayer structures has emerged as a possible alternative to Hall or spintronic sensors, like TMR. They offer a simple architecture, good sensitivity, low power consumption, and intrinsic linearization of the sensor response through Spin-Orbit Torque (SOT). A challenge in optimizing these sensors is to model correctly the different magnetoresistive effects while taking into account SOT. Here we focus in particular on the coupled interplay between Anisotropic Magnetoresistance (AMR) and SMR. While these contributions can be separated experimentally via angle-dependent magnetoresistance (ADMR) measurements, the requirement for saturation by high magnetic fields and 3-axis rotation makes this measurement elaborative and time-consuming.

This study presents a comprehensive multiphysics modeling framework designed to facilitate the rapid evaluation and optimization of SMR sensors in Hall bar and Wheatstone bridge configurations. A key feature is the use of a modified Stoner-Wohlfarth approach that considers a statistical ensemble of single-domain particles described by "truncated astroids". This allows the model to account for the presence of domain walls and multidomain states at remanence, which are critical for describing generic, larger-scale devices. By comparing longitudinal magnetoresistance measurements and magneto-optic Kerr effect (MOKE) imaging with model predictions, we demonstrate the successful decoupling of AMR and SMR contributions.

This analytical tool may provide guidelines for optimizing signal amplitude and extending the linear field range of SMR sensors and so facilitate the development of high-sensitivity, low-power sensing solutions for automotive and biomedical applications.

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Terahertz Magnon-Polariton Control Using a Tunable Liquid Crystal Cavity

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In the regime of strong light-matter coupling, polariton modes emerge as hybrid light-matter excitations, combining properties of both an electrodynamic cavity mode and a matter mode. Over the past decade, magnon-polaritons in ferromagnets have been extensively studied in the microwave range, motivated by their potential applications in quantum technology and sensing [1]. Shifting to antiferromagnetic resonance elevates magnon-polariton frequencies to the terahertz (THz) range, where Fabry-Perot cavities have been shown to facilitate strong light-matter coupling [2]. However, while antiferromagnetic magnons can be tuned via temperature or high magnetic fields, they lack electric field tunability, limiting control over magnon-polariton states. In contrast, the refractive index of anisotropic nematic liquid crystals in the THz range can be electrically controlled.

Here [3], we demonstrate remote electrical control of magnon-polariton states resulting from the strong coupling between Fabry-Perot cavity modes and an antiferromagnetic crystal. Our cavity consists of a nickel oxide (NiO) slab placed adjacent to a liquid crystal cell, separated by a precisely controlled gap of approximately 2.5 mm. NiO is chosen for its low spin damping and temperature-dependent resonance frequency near 1.0 THz above room temperature. The magnon frequency is tuned via NiO crystal temperature, while an electric field applied to the liquid crystal cell alters the cavity modes—their frequencies and spatial field distributions—thereby modifying the photonic component of the magnon-polaritons.

Using a THz time-domain spectrometer, we measured reflection spectra as functions of NiO temperature and applied electric field. We observed avoided crossings of cavity modes and magnons as a function of voltage, as well as variations in magnon-photon coupling strength. These findings demonstrate remote electrical control of antiferromagnetic magnon-polariton states at room temperature, achieved without direct physical contact between the liquid crystal cell and the magnetic material.

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[2] M. Bialek, A. Magrez, J.-Ph. Ansermet, Physical Review B, 2020, 101, 024405.

[3] D. Yavorskiy et al, ACS Photonics 2025, 12, 6762–6769.



Holographic imaging of ultrafast demagnetization dynamics in a Pt/CoFeB/MgO heterostructure

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Ultrashort laser pulses are essential tools for probing magnetic order on ultrafast timescales [1]; however, the spatially resolved dynamics of demagnetization remain largely unexplored, due to the limitations of conventional ultrafast magneto-optical imaging. Here, we present a self-referenced ultrafast holographic microscope that enables direct imaging of the spatio-temporal evolution of laser-induced demagnetization in a Pt/CoFeB/MgO ferromagnetic heterostructure with 150-fs temporal and sub-micrometer spatial resolution.

The setup extends widefield ultrafast chiroptical imaging via multiplexed off-axis holography [2]. The scheme reconstructs the Jones vector at every pixel, giving access to circular dichroism (CD) and optical rotatory dispersion (ORD), alongside standard absorption and phase images. Photoexcitation with diffraction-limited pump spots, providing local energy deposition, gives access to transient images of these observables [3].

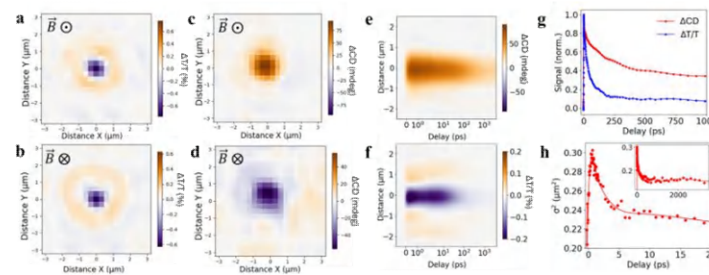


Figure 2: $\Delta T/T$ (a,b) and ΔCD (c,d) spatial profiles for opposite external field. Radially averaged ΔCD (e) and $\Delta T/T$ (f) vs. time. Normalized kinetics at the spot center (g). Time evolution of the ΔCD spatial width σ^2 (h).

We study a Pt/CoFeB/MgO heterostructure saturated out-of-plane by a 20 mT field, photoexcited at 400 nm. Reversing the magnetic field reverses the transient CD signal while leaving $\Delta T/T$ unaffected (Fig. 2a–d), confirming the chiral nature of the reconstructed signal. The transient CD rises within the 150-fs instrument response, indicating that demagnetization is established essentially instantaneously, and ~40% of the demagnetization persists beyond 1 ns at the spot center (Fig. 2e–g). Fitting the spatial profile with 2D Gaussians (Fig. 2h), we observe a fast broadening of the demagnetized region up to ~1.5 ps, consistent with hot-electron diffusion that heats spins and lattice at the spot edges, followed by a marked shrinking between 1.5 and 5 ps and a slower contraction over 100 ps, driven by re-magnetization from the surrounding magnetized region. These results demonstrate ultrafast holographic microscopy as a powerful tool for probing out-of-equilibrium spin processes.

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[2] M. Hörmann *et al.*, Nat. Photon., (2026), doi:10.1038/s41566-025-01824-9.

[3] M. Hörmann *et al.*, Opt. Express **32** (2024), 21230-21242.

Programmable Integrated Magnonic Meshes

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Integrated circuits are a cornerstone of modern information technology, and analog wave-based architectures could enable fast and efficient processing beyond conventional charge electronics. In magnonics, spin waves provide a highly tunable, compact and energy-efficient medium for on-chip microwave signal transport and processing [1]. However, progress has been limited to isolated elements or short devices, severely limiting the overall functional complexity and scalability [2]. We realize the key elements of universal magnonic circuitry, using a single-step direct laser writing process in yttrium iron garnet, and monolithically cascade them in multi-stage programmable devices and networks. Using magneto-optical Kerr effect microscopy, we show efficient spin-wave propagation and preserved phase coherence in waveguide structures for hundreds of wavelengths. In coupled waveguides, we observe complete and periodic power transfer over several coupling lengths (see Figure 1), and in phase shifters we achieve arbitrary, tunable phase delays.

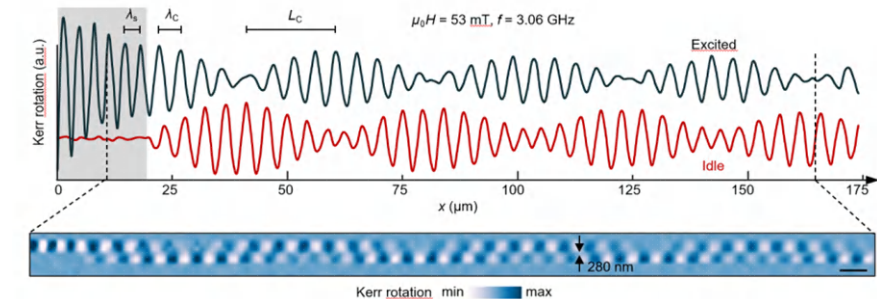


Figure 1: Spatial evolution of the spin-wave phase along the propagation direction of a directional coupler, extracted from the TR-MOKE measurement (Bottom row), showing periodic power transfer across several coupling lengths L_c between the two waveguides. The single-waveguide wavelength λ_s and coupled-waveguide wavelength λ_c are marked.

By cascading these elements, we realize programmable magnonic interferometric meshes for on-chip radio-frequency signal routing, with up to six magnonic inputs and outputs and seven cascaded stages. These direct-write cascaded networks bridge a long-standing gap in magnonic scalability, offering a viable pathway toward integrated, large-scale architectures for both classical and quantum processing.

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Uncertainty-aware deep learning image analysis for data-driven FePt HAMR media optimization

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Heat-assisted magnetic recording (HAMR) technology promises to increase hard disk storage capacity beyond conventional perpendicular magnetic recording (<1.5 Tbit/in²) toward 4 Tbit/in² for L1₀ FePt media and, theoretically, 10 Tbit/in² for bit-patterned media [1-2]. Achieving HAMR media with grain size around 4.3 nm, narrow size distribution ($<15\%$), and high switching field remains a major challenge that can potentially be solved by data-driven optimization [3]. One of the key limitations of existing databases is the lack of uncertainty information, including uncertainty introduced during TEM image analysis, which becomes increasingly important at smaller grain sizes and tighter tolerances. In this work, we compare state-of-the-art deep-learning segmentation models for analysis of plan-view TEM images of FePt granular media with different segregants and propose an inference-time method for propagating uncertainty to downstream microstructural descriptors. This method does not require uncertainty-aware training strategies or ensemble prediction, while providing uncertainty estimates for effective grain diameter, pitch and gap distance, grain density, etc.

Using in-house TEM image dataset, we show that segmentation models differ not only in standard metrics but also in the resulting microstructural descriptors, which can be traced to architectural differences. For detailed analysis, we selected Mask R-CNN and calibrated its detection scores to estimate grain detection probability. We then quantified uncertainty in each descriptor by Monte Carlo sampling based on uncertainty in contour detection and grain-detection probability (see fig. 1). This approach accounts for uncertain detections of small grains without imposing a hard cutoff, improving characterization of bimodal grain-size distribution and providing uncertainty intervals for grain density and packing fraction.

In this talk, the uncertainty-aware deep learning image analysis will be discussed in detail. Based on the obtained in-house dataset for FePt media with different segregants, multiobjective data-driven optimization will be demonstrated and discussed.

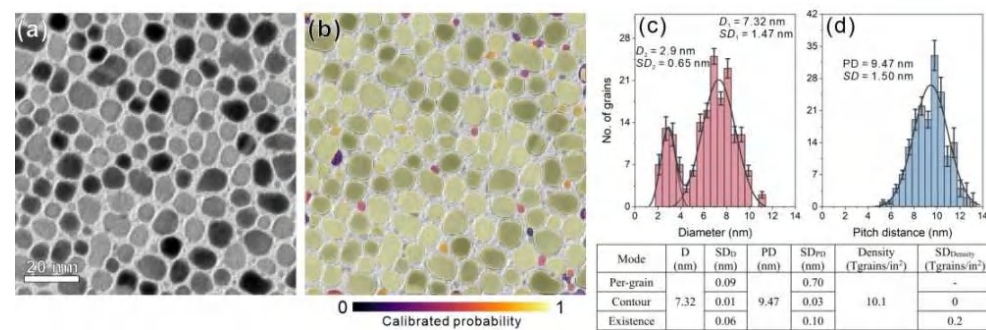


Figure 1: (a) Plan-view TEM image of FePt media. (b) Calibrated detection probability map. Distribution of grain diameters (c) and pitch distances (d) and table with analysis-level uncertainty.

- [1] D. Weller et al., IEEE Trans. Magn. **50** (2014), 1-8.
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Voltage control of magnonic Fabry-Pérot resonators

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We demonstrate voltage control of spin-wave transmission in magnonic Fabry-Pérot resonators consisting of a low-damping yttrium iron garnet (YIG) film coupled to a ferromagnetic CoFeB nanostripe. Dynamic dipolar coupling between the two magnetic layers forms a magnonic cavity with a modified spin-wave dispersion. The cavity resonances produce narrow transmission gaps in the spin-wave spectrum while maintaining a low insertion loss, enabling field-tunable control of the spin-wave amplitude [1] and phase [2]. The strong wavelength reduction within the resonator allows long-wavelength spin waves to be manipulated by elements just a few hundred nanometers wide.

Voltage control of the transmission spectrum is achieved by integrating a Pt/LiCoO₂/LiPON multilayer onto the CoFeB stripe. This stack functions as a solid-state magneto-ionic battery [3,4], in which LiPON serves as the solid-state electrolyte and LiCoO₂ acts as the Li⁺ ion reservoir. Applying a voltage to the Pt top electrode drives Li⁺ ions into or out of the CoFeB layer, modulating its magnetization and, through dipolar coupling with the underlying YIG film, shifting the spin-wave transmission spectrum. Device characterization is carried out using propagating spin-wave spectroscopy with two microwave antennas patterned on either side of the resonator for spin-wave excitation and detection. Figure 1 a) shows a representative measurement on a voltage-controlled Fabry-Pérot resonator alongside a reference spectrum recorded on a bare YIG film. Reversible Li⁺ ion migration driven by ± 3 V shifts the transmission gap frequencies by 20-30 MHz (fig. 1 b). This allows the transmitted intensity at a given frequency to be controlled (fig. 1 c), creating a solid-state programmable spin-wave filter.

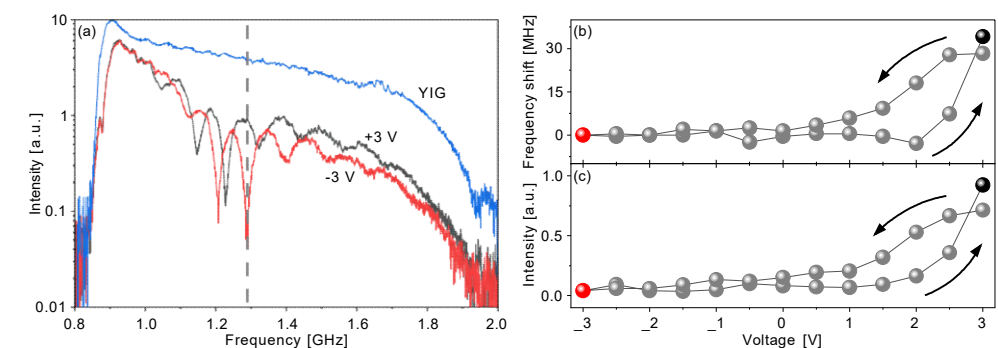


Figure 1: Voltage-controlled spin-wave transmission in a magnonic Fabry-Pérot resonator. a) Spin-wave transmission spectra of a 4-μm-wide resonator at +3 V (black) and -3 V (red) under an in-plane applied magnetic field of 7 mT (Damon-Eshbach geometry), with a reference bare YIG film spectrum (blue). b) Frequency shift of the transmission gap marked with a dashed line in a) during a +3 V → -3 V → +3 V voltage sweep, demonstrating reversible electrical tuning of the resonance condition. c) Signal intensity change at the selected frequency during the same voltage sweep.

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- [2] A. Lutsenko et al., Appl. Phys. Lett. **126**, 082406 (2025)
- [3] M. Ameziane et al., Adv. Funct. Mater. **32**, 2113118 (2022)
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Strain-Driven Electric Field Control of Magnetization in FeGa microstructures on PMN-PT

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The recent era of information technology and devices largely focusses on energy saving and cost efficiency. Manipulation of magnetic state of a micro element solely with the use of electric fields has attracted new attention in recent years due to its potential ability to be used in low-power magneto-electronics [1]. In the context, artificial magnetoelectric (ME) materials are suitable candidates to be used in these technologies due to its coupling between magnetization and electric-field induced strain, which therefore consumes less power and significantly reduces heat losses [2]. The application of voltage across the piezoelectric layer generates strain at the interface and this strain transfer to a soft magnetic layer from the piezoelectric layer induces change in magnetic anisotropy and domain structures [3].

We have investigated the properties of FeGa microstructures fabricated on PMN-PT (Figure 1a) using E-beam lithography under application of electric field across the piezoelectric layer. Due to the [011] crystallographic orientation of PMN-PT, the in-plane strains are anisotropic resulting in a significant difference in remnant strain values, as marked by the blue and pink dots in Fig. 1b. The magnetic hysteresis curves of elliptical disks ($5 \times 3 \mu\text{m}^2$) were recorded using MOKE as represented by the 0- and 0+ states in Fig. 1c (remanent strain states at zero electric field after polarization switching). A difference in the shape of the hysteresis is observed which marks the rotation of magnetic anisotropy in the system (vortex state in 0- state and S-shaped multidomain in 0+ state). Further, electrical pulses were applied to the elliptical disks without any magnetic history where an application of positive and negative pulses modifies the magnetic domains as shown in Fig. 1d.

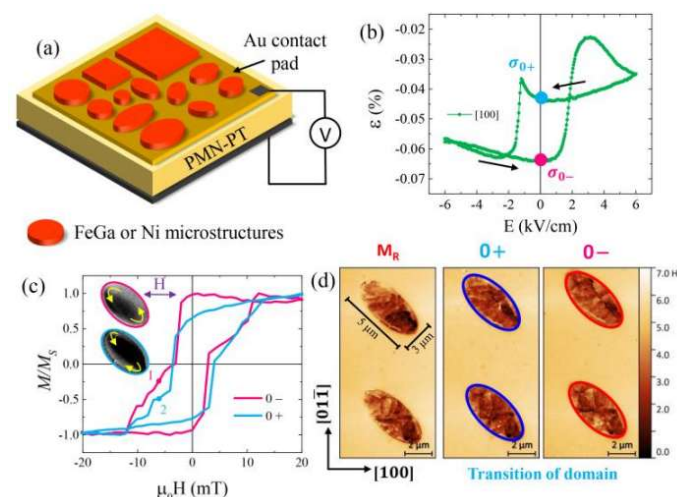


Figure 1: (a) Schematic of FeGa/PMN-PT heterostructure for voltage application. (b) Effective strain measured in PMN-PT. (c) Magnetic hysteresis and domain structures recorded at remnant strain states. (d) Magnetic states at remnant polarization states.

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[3] G. Pradhan, et al. Advanced Electronic Materials (2025): e00558.

MEMS and magnonics technology platform: standalone and tunable RF systems

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Magnonics is an emerging and promising technological platform for radio-frequency (RF) signal-processing components such as filters, phase shifters, and delay lines [1]. The small wavelength of spin waves in the GHz range enables the processing of RF signals in compact and integrated devices. Despite the potential of magnonics, several challenges remain unsolved, including the need for standalone operation (i.e., no external bias field), tunability, and reduced insertion losses/power consumption. Within the European-funded project MandMEMS [2], we have addressed current limitations of magnonics and proposed a new technological platform that could overcome these challenges. In particular, we have demonstrated the integration of magnonic systems with permanent micro-magnets (SmCo), enabling a zero-power bias field in an integrated system, thus achieving standalone operation with bias fields up to tens of mT [3][4]. Moreover, we have demonstrated the tunability of spin-wave (SW) devices using micro-electro-mechanical systems (MEMS), which act as microscale mechanical actuators to reshape the magnetic field landscape. By combining piezoelectric MEMS with magnonic elements, it is possible to realize phase shifters, delay lines, and filters for telecommunications by locally modifying the SW dispersion relation, either through strain or magnetic stray fields [5]. In this work, we provide an overview of the main achievements, potential, and limitations of the current MandMEMS technology, and outline the path toward the next generation of radio-frequency devices.

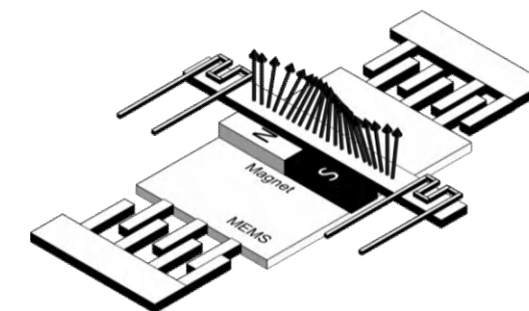


Figure 1: Schematic view of the MandMEMS concept. A magnet is displaced by a MEMS to tune the propagation of spin waves.

[1] K. Levchenko et al., arXiv: arXiv:2411.19212 (2024),

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[3] O. Koplak et al., JMMM vol. 605, p. 172323, (2024)

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Interfacial Dzyaloshinskii-Moriya Interaction in epitaxial**Graphene/Ferromagnetic Systems**S.Tacchi^a, F.Ajejas^b, M.Madami^c, I.García-Manuz^b, A.Guio^b, A.Gudin^b, P.Perna^b^a Istituto Officina dei Materiali del CNR (CNR-IOM), Sede Secondaria di Perugia, Perugia, Italy^b IMDEA Nanociencia, Madrid, Spain, and Universidad Autonoma de Madrid, Madrid, Spain^c Dipartimento di Fisica e Geologia, Università di Perugia, Perugia, Italy

In the research field of spintronics, Graphene (Gr) is regarded as an ideal material thanks to its unique and intrinsically tunable electronic properties. Moreover, the observation of a noticeable interfacial Dzyaloshinskii-Moriya Interaction (DMI) at the Graphene/Ferromagnetic interface, represents a crucial step to develop a technology which enables the electrical control of the transport and manipulation of topologically protected magnetic structures [1].

In this work we investigated the magnetic properties of Ta(2nm)/Pt(10nm)/Co(2nm)/Gr/M(3 nm) multilayers (with M= Ta, Ir, Cu, Al), epitaxially grown on an Al₂O₃(0001) substrate following a well-established growth methodology [1-3]. Such systems display enhanced out-of-plane anisotropy (PMA) due to orbital hybridization [2], Rashba-type spin texture [3] and giant spin charge conversion (SCC) due to the IREE effect [4]. Using Brillouin Light Scattering (BLS) technique, we studied the dependence of both the PMA and the DMI as a function of the stack composition. We find that the presence of Gr strongly affects both the PMA and the DMI. In particular, the sign and the strength of the total DMI, resulting from the competition between the Pt/Co and the Co/Gr/M interfaces, is observed to change on varying the metal M on top of the Gr sheet. Indeed, we found that DMI assumes a negative (positive) value for the samples with a Cu (Ta and Ir) capping layer, while becomes almost zero in the sample with the Al one. This behaviour can be explained in terms of the work function (WF) difference between the FM and the capping layer, which indeed is determined not only by the SOC strength, but also by the surface potential (i.e., the electroaffinity, captured by the WF of the materials involved at the interface) [5]. As result, we found that the effective DMI amplitude of the trilayer scales linear with $\Delta\phi$ between Co and M.

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Multiferroic K_{0.27}Na_{0.73}NbO₃/CoFeB heterostructure for magnonic devicesWalter Piazza^{*a}, Alberto Toniato^a, Edoardo Galimberti^a, Matteo Poli^a, Giulia Pavese^a, Maria Cocconcelli^a, Antonio Angotti^a, Miguel Badillo^a, Federico Maspero^a, Riccardo Bertacco^a^aPolitecnico di Milano, Piazza Leonardo Da Vinci 32, Milano, Italia.

Strain-mediated magnetoelectric (ME) heterostructures offer a promising route for voltage-controlled spin-wave devices with ultra-low power consumption. In this work, we investigate CoFeB/Na_xK_{1-x}NbO₃ (KNN) multiferroic waveguides subject to a lateral strain to exploit inverse magnetoelectric coupling for the realization of voltage-tunable, magnonics based, RF components.

The devices studied consist of a CoFeB magnetic waveguide integrated on a lead-free KNN piezoelectric film [1], flanked by Pt electrodes, as can be seen in Fig. 1a). The application of an electric field between the top and bottom electrodes translates into an out-of-plane expansion and in-plane contraction of the piezoelectric film below the electrodes, which in turn transfers a tensile strain to the waveguide region, changing its effective field [2]. This voltage-controlled strain is used to modulate the spin-waves dispersion, and with that the phase of the output signal. Spin waves are excited and detected using RF antennas with a vector network analyzer (VNA), enabling the characterization of the magnetoelastic response over a wide frequency range.

In this work a voltage-induced phase-shift of $\Delta\phi \approx 4^\circ/\text{V}$ has been proven over a 3 GHz wide frequency band via propagating-spin-waves spectroscopy [3]. Next-generation devices based on KNN suspended membranes are currently under development to enhance phase-shift and to increase the transmitted signal. Overall, this work establishes a solid experimental basis for the development of energy-efficient, lead-free magnetoelectric magnonic devices.

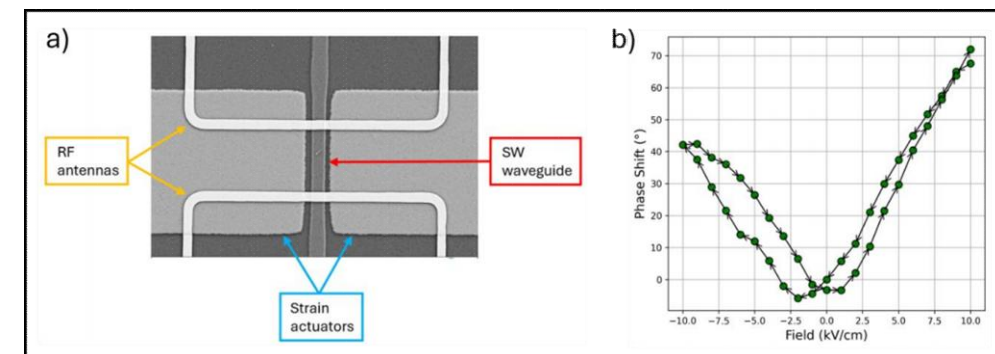


Figure 1: (a) SEM image of one of the studied devices, where its most important components are highlighted with different colors. (b) Phase shift obtained on one of the studied devices, calculated with respect to the signal acquired at $V_{\text{app}} = 0$ V and $\mu_0 H_{\text{ext}} = 110$ mT, as a function of the voltage applied to the strain actuators. The butterfly-like phase shift strongly suggests that the SW shifting effect is strain induced.

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Magnetic targeting of cubic CoFe₂O₄ nanoparticles in cells and *in vivo*

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Cubic CoFe₂O₄ nanoparticles (NPs) are promising multifunctional magnetic agents for biomedical applications, combining tunable magnetic properties with the ability to interact with biological membranes. Interaction of these NPs with diphtanoylphosphatidylcholine bilayer membranes induces metastable conductive pores, resulting in an increase in membrane ionic conductivity [1,2]. In addition, the magnetic moment of individual NPs is sufficient to be measured using magnetoresistive sensors [3]. Deposition on a CoFeB/Ta/CoFeB ferromagnetic platform modifies the blocking temperature due to dipolar interactions, demonstrating a back-action of the sensor on nanoparticle magnetism [4]. These properties highlight the potential of CoFe₂O₄ NPs for applications requiring precise magnetic control and biological interface functionality.

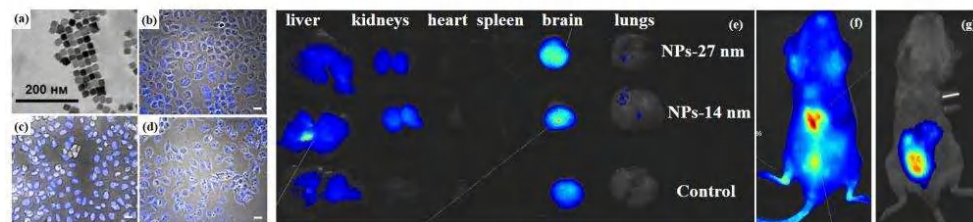


Figure 1: (a) TEM image of CoFe₂O₄ nanoparticles. (b–d) Confocal fluorescence images of HeLa cells following 24 h incubation with BDP-TR-functionalized CoFe₂O₄ nanoparticles: (b) 14 nm particles in the absence of an applied magnetic field; (c) 14 nm particles in the presence of an external magnetic field; (d) 27 nm particles in the presence of an external magnetic field (1.2 T). (e) *Ex vivo* fluorescence imaging of harvested organs with 14 and 27 nm nanoparticles. (f),(g) *In vivo* fluorescence imaging of mice following injection of 14 nm nanoparticles in the absence (f) and presence (g) of an external magnetic field.

In this study, we investigate size-dependent magnetic targeting, cellular uptake, and *in vivo* biodistribution of PEG-coated cubic CoFe₂O₄ NPs under a 1.2 T static magnetic field. Confocal microscopy confirmed efficient cellular internalization, with 14 nm NPs predominantly localized inside cells, while 27 nm NPs were distributed both intra- and extracellularly, demonstrating clear size-dependent intracellular localization (Fig. 1). *In vivo* experiments in BALB/c mice revealed gradual NP accumulation in the liver, kidneys, and brain, indicating that nanoparticles can cross the blood–brain barrier. Application of an external magnetic field *in vivo* enabled controlled redistribution of NPs, confirming their potential for magnetically guided targeting. Importantly, the CoFe₂O₄ NPs were non-toxic and efficiently cleared, with complete elimination within three days, highlighting their suitability for magnetic hyperthermia, targeted therapy, and imaging applications.

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Multiscale modelling of magnonic devices

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Magnonics provides a promising platform for information processing, ranging from wave-based logic to neuromorphic and quantum devices. However, its development is limited by the lack of predictive frameworks connecting material chemistry to device-scale functionality, particularly beyond conventional systems such as yttrium iron garnet (YIG).

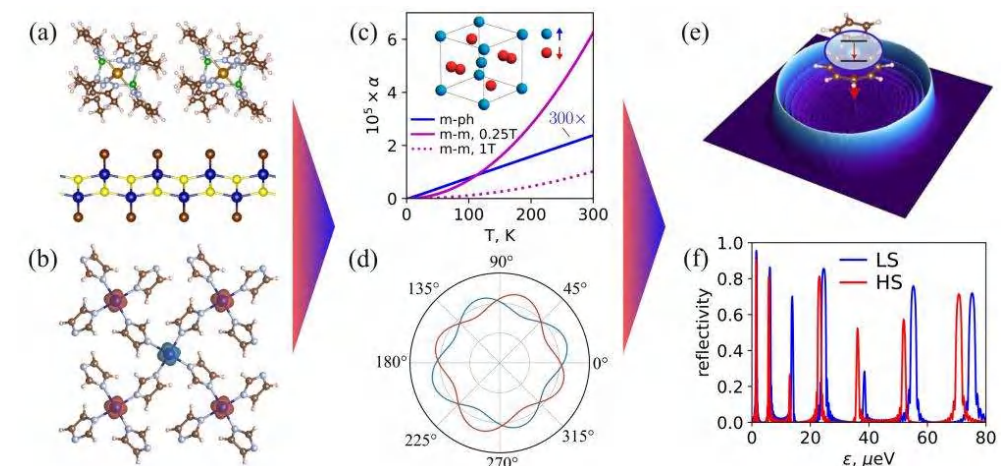


Figure 1: (a) Fe–pz molecules adsorbed on CrSBr [2]; (b) g-wave antiferromagnetic metal–organic framework Cr(imz)₂ [3]; (c) temperature dependence of intrinsic magnon damping in YIG [4]; (d) third-order spin-splitting effect in Cr(imz)₂ [3]; (e) coherent magnon pulse emitted from a CpTi(cot) qubit adsorbed on CrSBr [1]; (f) reflectivity spectrum of Fe–pz/CrSBr magnonic crystals, modified by the spin transition of Fe–pz [2].

We present a multiscale modeling framework that begins with density functional simulations of novel materials and systematically bridges to higher-level theories, enabling the description of complex device architectures. These include systems such as molecular qubits CpTi(cot) coupled to a monolayer van der Waals magnet CrSBr [1], as well as tunable magnonic Bragg mirrors controlled via light-induced switching of spin-crossover molecules Fe–pz [2] adsorbed on the CrSBr surface.

As an intermediate stage within this multiscale paradigm, we investigate transport phenomena in magnetic materials, including nonlinear spin-splitting effects in antiferromagnetic metal–organic frameworks (MOF) [3], and magnon damping in magnetic insulators arising from magnon–magnon and magnon–phonon scatterings [4].

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- [2] A. Shumilin, S. Dey, D. Coltuneac, et al, [arXiv:2512.17003](https://arxiv.org/abs/2512.17003), under revision in *Adv. Mat.* (2nd round)
- [3] D. López-Alcalá, A.M. Ruiz, A. Shumilin, J.J. Baldoví, [arXiv:2512.14623](https://arxiv.org/abs/2512.14623), under revision in *JACS*
- [4] A. Shumilin, D. López-Alcalá, N. Benchtaber, A. M. Ruiz, J.J. Baldoví, [arXiv:2602.21885](https://arxiv.org/abs/2602.21885), under revision in *Phys. Rev. Lett.*



Interaction-enhanced spin-orbit splitting in monolayer MoS₂ from magnetotransport

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The conduction-band spin-orbit splitting in monolayer MoS₂ is a key parameter for spin and valley transport, yet its value remains controversial. Conventional density functional theory (DFT) typically predicts only a few meV, whereas experiment points to a substantially larger value. We determine this splitting from magnetotransport measurements on high-mobility hBN-encapsulated monolayer MoS₂. Shubnikov-de Haas oscillations and their Fourier spectra identify the threshold density for occupation of the upper spin-split conduction subband, $n \approx 4 \times 10^{12} \text{ cm}^{-2}$. This value is far above that expected from commonly used DFT parameters and provides a direct experimental constraint on the conduction-band splitting.

We show that the observed scale arises from two contributions. First, exchange interactions in the finite-density two-dimensional electron gas enhance the spin-orbit splitting and produce a strong density dependence. Second, the remaining discrepancy comes from the bare single-particle band structure, whose conduction-band splitting is highly sensitive to orbital hybridisation. Using a refined DFT approach with account for inter-site Hubbard interaction constrained by the transport data, we obtain a bare splitting of about 8 meV while many-body effects account for a substantial additional enhancement [1].

These results reconcile magnetotransport and theory for monolayer MoS₂ and show that interaction effects are essential for a realistic description of spin-split bands in two-dimensional semiconductors.

- [1] I. Rozhansky, M. Masseroni, R. Pisoni, S. Alshammari, X. Li, T. Ihn, K. Ensslin, J. McHugh, V. Fal'ko, accepted to Nano Letters DOI 10.1021/acs.nanolett.6c00725 (2026).

Nonlinear magnons revealed in reciprocal space: Magnon momentum microscopy

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Next-generation magnonic devices for beyond-CMOS computing demand spin-wave control in the exchange-dominated regime, where relevant wavelengths reach the nanometer scale. Detecting such short-wavelength magnons has remained a central experimental challenge. Here, we introduce X-ray Magnon Momentum Microscopy (MMM) [1] to address this problem. MMM bridges a critical methodological gap: it surpasses the resolution limits of optical methods, typically confined to sub-micrometer wavelengths, while complementing inelastic scattering approaches, which resolve sub-10 nm features but lack sensitivity in the intermediate-wavelength regime. Unlike real-space probes such as scanning transmission X-ray microscopy, MMM grants direct access to magnon dispersion relations and dynamics across the full 2D momentum plane. Its inherent sensitivity uncovers deep nonlinear magnon-magnon interactions across large regions of the dispersion curve, as we demonstrate in prototypical yttrium iron garnet (YIG) thin films (fig. 1). With no frequency limitation and full element selectivity, MMM establishes a versatile new technique for exploring short-wavelength and nonlinear magnonics.

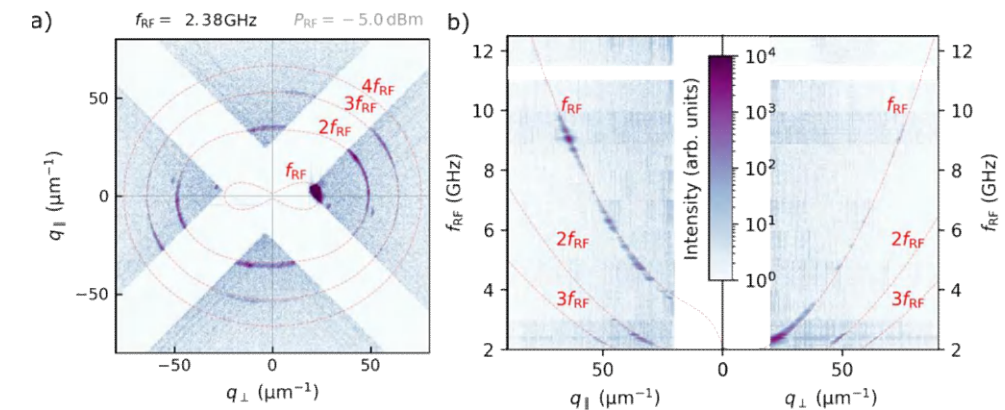


Figure 1: (a) Detector image of nonlinear magnon dynamics. MMM directly captures the 2D anisotropic characteristics of the magnons in a single measurement. Here, $q_{\perp}$ reflects the wave vectors corresponding to the backward volume (BWV) spin waves and $q_{\parallel}$ the Damon-Eshbach (DE) modes. (b) Extracted dispersion relation of BWV and DE modes. Red curves represent theory.

- [1] S. Wittrock et al., Nat. Phys. (in press), arXiv:2504.20958.

Barium-magnesium ferrite nanocomposite for EMI shielding applications

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High-performance electromagnetic interference (EMI) shielding materials based on magnetic-carbon nanocomposites have attracted increasing attention due to their combined dielectric and magnetic loss mechanisms [1]. In this work, a ternary $\text{BaFe}_{12}\text{O}_{19}/\text{Mg}_{0.6}\text{Ni}_{0.4}\text{Fe}_2\text{O}_4/\text{C}$ nanocomposite was synthesized via a sol-gel route followed by ball milling to improve interfacial coupling and phase dispersion. The structural and molecular characteristics were investigated using X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR), confirming the coexistence of hexagonal $\text{BaFe}_{12}\text{O}_{19}$ and spinel $\text{Mg}_{0.6}\text{Ni}_{0.4}\text{Fe}_2\text{O}_4$ phases within a conductive carbon matrix. Magnetic properties were examined using SQUID magnetometry, revealing enhanced magnetic behavior due to the combination of hard and soft magnetic phases (see e.g. fig. 1).

Electrochemical and charge transport properties were analyzed using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). The pristine $\text{BaFe}_{12}\text{O}_{19}$ exhibited a specific capacitance of 0.70 F g^{-1} , whereas incorporation of carbon nanostructures significantly enhanced the electrochemical performance. In particular, the addition of multi-walled carbon nanotubes (MWCNTs) increased the specific capacitance to 0.88 F g^{-1} . Furthermore, the MWCNTs markedly reduced the charge-transfer resistance (R_{ct}) from 22Ω to 10.5Ω , indicating improved interfacial conductivity and enhanced electron transport pathways (see e.g. fig. 1).

The synergistic interaction between hard magnetic $\text{BaFe}_{12}\text{O}_{19}$, soft magnetic $\text{Mg}_{0.6}\text{Ni}_{0.4}\text{Fe}_2\text{O}_4$ and conductive carbon components promotes enhanced dielectric polarization, magnetic loss, and interfacial charge transfer, making the $\text{BaFe}_{12}\text{O}_{19}/\text{Mg}_{0.6}\text{Ni}_{0.4}\text{Fe}_2\text{O}_4/\text{C}$ nanocomposite a promising candidate for advanced EMI shielding applications.

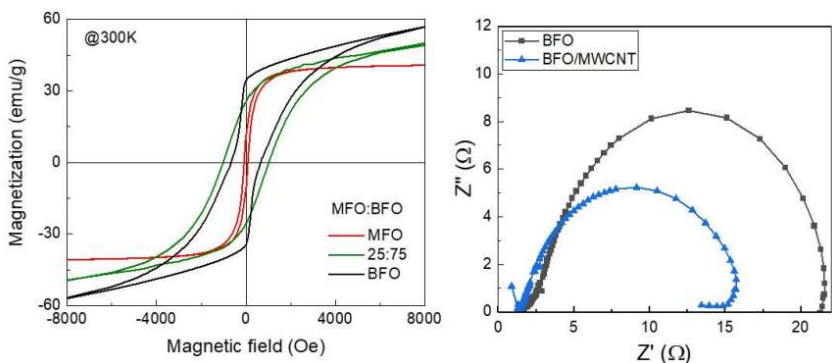


Figure 1: Left: hysteresis loops of $\text{BaFe}_{12}\text{O}_{19}/\text{Mg}_{0.4}\text{Ni}_{0.6}\text{Fe}_2\text{O}_4$ (BFO/MFO). Right: EIS spectra of BFO and BFO/C.

[1] R. Manogaran, M. Murugesan, Mater. Today Commun. 44 (2025), 111879.

Investigation of transport and magnetic properties of intercalated 2H-NbS₂

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Transition metal dichalcogenides (TMDs) are a layered class of materials known for their rich physical properties, including charge density waves (CDWs) and superconductivity. Their layered crystal structure allows for the intercalation of first-row transition metals into the van der Waals gaps, which significantly modifies the electronic states of the host material, suppressing CDW order and superconductivity while inducing magnetic order with potential applications in spintronics and novel electronics [1].

We synthesized Ni_xNbS_2 single crystals over a broad intercalation range ($0.01 < x < 0.6$) using the chemical vapor transport method. X-ray diffraction (XRD) confirmed high crystal quality, while energy-dispersive X-ray spectroscopy (EDX) determined the Ni stoichiometry of the synthesized crystals. A systematic evolution of the lattice parameters with increasing intercalation is observed. Magnetic susceptibility measurements reveal a gradual weakening of antiferromagnetic coupling between Ni magnetic moments with increasing Ni content. The Néel temperature (T_N) exhibits a dome-like dependence on x , with a maximum at $x = 0.33$.

Notably, the composition range $x = 0.25 - 0.33$, where ordered Ni superstructures form, shows distinct behavior compared to the broader intercalation regime. Within this narrow range, both magnetic and transport properties differ qualitatively: the electrical resistivity exhibits a pronounced concave curvature with relatively low residual resistivity, while the magnetic moment extracted from Curie-Weiss analysis is enhanced, suggesting stronger charge transfer compared to the rest of the investigated range, which is dominated by disorder. These results highlight the sensitivity of the electronic structure to disorder and the formation of superstructures, underscoring the importance of understanding the interplay between crystal and electronic structure in the development of new functional devices.

[1] R. H. Friend et al., Adv. Phys. 36 (1987) 1–94.



Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Tuesday, 8th September	
8:00 - 9:00	Registration
ROOM A	Session chair: Paola Tiberto, Silvia Picozzi
9:00 - 9:30	Jordi Sort Vinas, Universitat Autònoma de Barcelona - "Merging voltage-iontronics with magnetism: fundamentals and applications in data security and advanced memory concepts"
9:30 - 10:00	Pietro Gambardella, ETH Zurich - "Orbital transport and relaxation in metal layers and insulating antiferromagnets"
10:00 - 10:30	Evgeny Tsymbal, University of Nebraska-Lincoln - "Spin Transport in Noncollinear Antiferromagnetic Tunnel Junctions"
10:30 - 11:00	Coffee Break
	ROOM A
	Session chair: Riccardo Tomasello
11:00 - 11:15	Federico Bottegoni - "Non-local architectures for spin current manipulation in group-IV semiconductor platforms"
11:15 - 11:30	Antonio Bianco - "Field-Free Switching via Current-Induced Torque in a MoS2-Based Device"
11:30 - 11:45	Deepak Dagur - "X-ray detection of current-induced orbital accumulation in 3d metals"
11:45 - 12:00	Fatma Al Ma'Mari - "Coexistence of Rod-Like Domains and Skyrmions in Ta- and W Based Asymmetric Multilayers"
12:00 - 12:15	Nicolas Biziere- "Imaging spin waves by electron holography "
12:15 - 12:30	Davi Rodrigues - "Spintronic Architectures for Edge Computing and Communication"
12:30 - 14:00	LUNCH BREAK (free time)
ROOM C	Session chair: Michaela Kuepferling, Jordi Sort Vinas, Kai Liu
14:00 - 15:15	Poster Session B
15:15 - 16:00	Poster Session B / Coffee Break
ROOM A	Session chair: Evgeny Tsymbal
16:00 - 16:30	Carlos Rojas-Sánchez, Institut Jean Lamour, France - "Interfacial Orbital Signal Conversion and Long-Range Propagation Enabled by Spin Current"
16:30 - 17:00	Dmitry Berkov, General Numerics Research Lab e.V. - "Design optimization of spin-torque-based RF energy harvesters: from resonant nanoelements to oscillating domain walls"
17:00 - 17:30	Hyunsoo Yang, National University of Singapore - "Ultrafast and energy-efficient spin dynamics in exchange-coupled systems"
	Young research award - Session chair: Jagoda Slawinska, Pietro Gambardella, Evgeny Tsymbal
17:30 - 17:45	Award Finalist: Emily Darwin - "Bias-engineered synthetic antiferromagnets hosting sub-20 nm zero-field skyrmions at room temperature"
17:45 - 18:00	Award Finalist: Adriano Di Pietro - "Reconciling Dzyaloshinskii-Moriya interaction measurements via spectroscopy methods and asymmetric bubble expansion in the creep regime"
18:00 - 18:15	Award Finalist: Esteban Garzón - "STT-MRAM-based Content-Addressable Memory for In-Memory and Neuromorphic Computing"

Merging voltage-iontronics with magnetism: fundamentals and applications in data security and advanced memory concepts

J. Sort^{a,b,c}, I. Spasojević^a, Z. Ma^a, A. Arredondo^a, L. Martínez-Armesto, M. Peda^a, A. Quintana^a, E. Pellicer^a, N. López-Pintó^a, E. Menéndez^a

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In the same way spintronics revolutionized electronics by introducing spin as a new degree of freedom for device functionality, merging iontronics with magnetism promises a new paradigm for computing technologies. Voltage-driven ion motion coupled to magnetic order (i.e., magneto-ionics) enables energy-efficient, analog, and highly reconfigurable device operation, opening pathways toward neuromorphic architectures. Many features of neuromorphic materials (non-linearity, multi-level memory, threshold voltage, energy efficiency and actuation in ms or faster) can be achieved via magneto-ionics.

While most reported magneto-ionic systems exploit oxygen, hydrogen, or lithium ion migration, our recent work has established nitrogen magneto-ionics as a powerful complementary approach [1–5]. While being faster than oxygen, a distinguishing feature of nitrogen magneto-ionics is the emergence of a uniform, plane-wave-like N³⁻ migration front, in contrast to clustering or filamentary behavior often observed in other systems. This spatially homogeneous transport is advantageous for multilayer memory architectures.

Voltage-driven ion transport enables modulation of a broad range of neuromorphic behaviors, including potentiation, depression, spike-timing and spike-rate-dependent plasticity, amplitude-dependent plasticity, and multilevel memory states. Cumulative effects arising from pulsed voltage actuation (typically 1–100 Hz) allow emulation of higher-order learning rules, such as learning by maturity or learning under deep sleep. Remarkably, in certain configurations, these responses can be triggered even without direct electrical contacts on the sample, through bipolar electrochemistry (wireless magneto-ionics). At the nanoscale, magneto-ionics gives rise to additional physical phenomena. Patterned arrays of FeCoN sub-micron disks exhibit reversible and voltage-controlled transitions between paramagnetic, coherent-rotation, and vortex states. These behaviors stem from precise control of the planar nitrogen migration front and the locally generated FeCo magnetic layer. In certain conditions, magneto-ionic vortices can act as probabilistic bits offering prospects for probabilistic computing and device authentication. In turn, oxygen magneto-ionics can be used to engineer coupling effects in synthetic antiferromagnetic/ferrimagnetic multilayers [6]. Overall, magneto-ionic systems position as strong candidates for configuring spintronic and brain-inspired memory technologies, where networks of interconnected synaptic elements hold potential for scalable in-memory computing and secure analog data storage.

[1] J. de Rojas et al., Nat. Commun. **11** (2020), 5871.
[2] Z. Tan et al., Mater. Horiz. **10** (2023) 88.
[3] Z. Ma et al., Nat. Commun. **14** (2023), 6486.
[4] N. López-Pintó et al, Adv. Funct. Mater. **15** (2024), 2404487.
[5] I. Spasojevic et al., Nat. Commun. **16** (2025), 1990.
[6] Z. Ma et al., Adv. Mater. **37** (2025), 2415393.



Jordi Sort Vinas

Universitat Autònoma de Barcelona (UAB)

Biography

Prof. Jordi Sort received his PhD Degree in Materials Science from Universitat Autònoma de Barcelona (UAB) in 2002 (Extraordinary Award). The topic of his PhD dissertation was the study of magnetic exchange interactions in ferromagnetic-antiferromagnetic systems. He worked for two years as Postdoctoral Researcher at the SPINTEC Laboratory (Grenoble) and subsequently stayed six months at Argonne National Laboratory (USA). At present, Prof. Sort leads the “Group of Smart Nanoengineered Materials, Nanomechanics and Nanomagnetism (Gnm3)” at UAB, which focuses its research activities on the synthesis of a wide variety of functional materials (electrodeposited films, lithographed structures, porous materials, bulk metallic glasses, nanocomposites) and the study of their structural, magnetic, magnetoelectric, mechanical and thermal properties. This research aims at enhancing the performance of these materials in new technological applications that go beyond the state-of-the-art. Prof. Sort’s research activity was awarded by the Catalan Physical Society (Jordi Porta i Jué’s Prize, 2000), as well as by the Spanish Royal Physical Society (Young Researcher Award in Experimental Physics, 2003), the Federation of Materials Societies (FEMS Prize in Materials Science & Technology, 2015) and UPC/Naturgy (Duran Farell Award for Technological Research, 2020). Prof. Sort has supervised 20 PhD Theses and is currently co-supervising the work of 6 more PhD students. So far, Prof. Sort has published more than 375 articles that have received above 13000 citations (h=58) in ISI Web of Science. Prof. Sort has been personally appointed as Invited/Plenary Speaker in more than 100 conferences. In 2014 Prof. Jordi Sort was awarded a Consolidator Grant from the European Research Council (ERC). His project, entitled "Merging Nanoporous Materials with Energy-Efficient Spintronics (SPIN-PORICS)", aimed to integrate engineered nanoporous materials into novel spintronic applications. He was also the Coordinator of the “BeMAGIC” Marie Skłodowska-Curie Innovative Training Network (ITN-ETN), whose aim was to use magnetoelectric effects for memory and biomedical applications. In 2022 he has been awarded an Advanced Grant from the ERC with title “Voltage-Reconfigurable Magnetic Invisibility: A New Concept for Data Security Based on Engineered Magnetoelectric Materials (REMINDS)”, which focuses on the use of magnetoelectric materials for data security applications.



Orbital transport and relaxation in nonmagnetic metals and insulating antiferromagnets

Pietro Gambardella

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Electric-field-induced orbital angular momentum (OAM) has emerged as a fundamental electronic degree of freedom in solid-state devices, complementing spintronic functionalities to sense and manipulate magnetic states. Yet, how OAM evolves and relaxes in materials with variable degrees of structural, magnetic, and thermal order remains poorly understood. Here, we demonstrate that the orbital Hall effect and orbital relaxation are robust and quantifiable in strongly disordered up to single-crystalline metallic thin films [1]. Using orbital Hanle magnetoresistance as a probe, we find that the orbital Hall conductivity of Mn scales linearly with electrical conductivity in the hopping-dominated regime from amorphous to polycrystalline films, revealing a scaling behavior analogous to the anomalous and spin Hall effect in bad metals. The orbital relaxation time decreases with increasing crystalline order. Temperature-dependent measurements unravel different orbital relaxation channels, namely on-site orbital dephasing, hopping, and Elliott-Yafet-type scattering in disordered and crystalline systems. In the second part of the talk, we report a large orbital torque and enhanced orbital-to-spin conversion by an antiferromagnetic insulating CoO layer [2]. Measurements in CuOx/CoO/Co trilayers show that inserting CoO reverses the torque's sign and triples its magnitude compared to CuOx/Co. This behavior stems from the inverted oxygen gradient at the CuOx/CoO interface and CoO's high orbital multiplicity, which favors the transmission of orbital momenta and efficient orbital-to-spin conversion via spin-orbit excitons. Comparative measurements of the torque mediated by CoO, NiO, and MnO show that the torque efficiency scales with the orbital momentum of the Co^{2+} , Ni^{2+} , and Mn^{2+} ions in the antiferromagnet. Our findings establish OAM as a structurally resilient degree of freedom and elucidate its transport and relaxation dynamics across crystalline and disordered systems, enabling orbital control in different classes of materials.

[1] *Orbital Hall conductivity and relaxation in thinfilms with variable disorder*, M.-G. Kang, F. Nasr, G. Sala, R. Schlitz, S. Ding, S. Bartsch, M. D. Rossell, S. F. Alvarado, and P. Gambardella, Nat. Phys. **22**, 1238 (2026).

[2] *Generation, transmission, and conversion of orbital torque by an antiferromagnetic insulator*, S. Ding, P. Noël, G. K. Krishnaswamy, N. Davitti, G. Sala, M. Fantauzzi, A. Rossi, P. Gambardella, Nat. Comm. **16**, 9239 (2025).

**Biography**

Pietro Gambardella is a Professor and Chair of Magnetism and Interface Physics at the Department of Materials, ETH Zurich. He graduated in Physics summa cum laude at the University of Genova in Italy, and received his PhD from the Ecole Polytechnique Fédérale de Lausanne in Switzerland. He worked at the Max Planck Institut for Solid State Physics in Stuttgart in Germany, and the Catalan Institute of Nanotechnology in Barcelona, in Spain, before joining ETH Zurich. Prof. Gambardella's research focuses on the development of spintronic devices and thin film heterostructures with tailored magneto-electronic properties, single atom and molecular magnets, and on developing experimental techniques for probing magnetic phenomena with high temporal and spatial resolution.



Spin transport in noncollinear antiferromagnetic tunnel junctions

Evgeny Y. Tsymbal

Department of Physics and Astronomy, University of Nebraska-Lincoln, USA

Recently, antiferromagnets have emerged as promising materials for next-generation spintronic devices owing to their robustness against magnetic perturbations, absence of stray fields, and ultrafast spin dynamics. Among the broad family of antiferromagnetic materials, non-collinear antiferromagnets are particularly interesting, as most of them break the combined space-inversion and time-reversal symmetry. This symmetry breaking leads to spin splitting of their electronic bands even in the absence of both net magnetization and spin-orbit coupling. As a result, non-collinear antiferromagnets exhibit momentum-dependent spin polarization, enabling the realization of antiferromagnetic tunnel junctions (AFMTJs).

This talk will highlight key properties of non-collinear AFMTJs relevant to applications in antiferromagnetic spintronics. [1] An effective momentum-dependent spin polarization is introduced, revealing an unexpected characteristic of many non-collinear antiferromagnets: nearly perfect spin polarization over large portions of their Fermi surface. When employed as electrodes in AFMTJs, this property gives rise to an extraordinary tunneling magnetoresistance (ETMR) effect. [2] Factors governing TMR in AFMTJs are considered, including the symmetry matching of propagating states in the electrodes and evanescent states in the tunnel barrier. [3] Finally, the underlying physics of spin-transfer torque is addressed, demonstrating how it can be exploited to efficiently switch the antiferromagnetic order parameter—an effect recently demonstrated experimentally in AFMTJs based on non-collinear Mn₃Pt (111) electrodes. [4] These findings reveal hidden functionalities of non-collinear spin systems and open new avenues for antiferromagnetic spintronics.

[1] D.-F. Shao and E. Y. Tsymbal, Antiferromagnetic tunnel junctions for spintronics, *npj Spintronics* **2** (2024), 13.

[2] G. Gurung, M. Elekhitar, Q. Q. Luo, D.-F. Shao, and E. Y. Tsymbal, Nearly perfect spin polarization of noncollinear antiferromagnets, *Nat. Commun.* **15** (2024), 10242.

[3] M. Elekhitar, D.-F. Shao, and E. Y. Tsymbal, Effects of band symmetry on spin-dependent transport in noncollinear antiferromagnetic tunnel junctions,” arXiv:2605.25369 (2026).

[4] J. Kang *et al.*, Octupole-driven spin-transfer torque switching of all-antiferromagnetic tunnel junctions, arXiv:2509.03026 (2025).



Evgeny Tsymbal

University of Nebraska-Lincoln

Biography

Evgeny Tsymbal is George Holmes University Distinguished Professor in the Department of Physics and Astronomy at the University of Nebraska-Lincoln (UNL). Before joining UNL in 2002, he held research positions at the University of Oxford, Forschungszentrum Jülich, and the Kurchatov Institute in Moscow. He directed UNL’s NSF-supported Materials Research Science and Engineering Center from 2007 to 2021 and the Center for NanoFerroic Devices from 2013 to 2017. His research focuses on predictive modeling of functional materials for nanoelectronics and spintronics. He has co-authored more than 350 publications, co-edited the three-volume Spintronics Handbook: Spin Transport and Magnetism (2019), and has a Google Scholar h-index of 104. He is a Fellow of the American Physical Society and the Institute of Physics and a recipient of UNL’s Outstanding Research and Creative Activity Award.



Interfacial Orbital Signal Conversion and Long-Range Propagation Enabled by Spin Current

Melissa Yactayo^{1,2,6}, A. Pezo^{3,4}, J. L. Ampuero¹, J. Quispe-Marcatoma^{2,5}, C. V. Landauro^{2,5}, Y. Xu⁶, S. Petit-Watelot¹, M. Hehn¹, A. Fert³, and J.-C. Rojas-Sánchez¹

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³Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, France

⁴Institute for Solid State Physics, University of Tokyo, Kashiwa, 277-8581, Japan

⁵Centro de Investigaciones Tecnológicas, Biomédicas y Medioambientales, CITBM, Peru

⁶MIT Key Lab. of Spintronics, School of ICSE, Beihang University, China

The field of orbitronics explores the manipulation of orbital angular momentum (OAM) for low-power devices, yet the characteristic length of orbital transport remains a central, unresolved debate. While initial reports suggested that orbital currents propagate over long distances in light metals (LM) like Ti (47 nm) [1], recent theoretical work argues that orbital accumulation relaxes within just a few atomic layers [2]. Using Spin-Orbital pumping at ferromagnetic resonance (S/OP-FMR), accounting for rectification effects [3], and thermal gradient experiments on Ni/Ti/Au based heterostructures, we find that the resulting signals are independent of Ti thickness – evidence that spin-orbital-to-charge conversion is a purely interfacial phenomenon rather than bulk-mediated. Our results, supported by DFT calculations, show that the signal is dominated by the Ti/Au top interface. We propose a multistep interfacial mechanism involving spin-to-orbital interconversion at the bottom and top interfaces of the LM [4]: OAM is "loaded" via spin accumulation at the ferromagnet/LM interface, diffuses through the LM as a spin current, and is then "unloaded" back into OAM at the top interface before conversion into a detectable charge current. This loading-unloading process reconciles the apparent discrepancy between short-range orbital transport and the observed long-range signals [4], shifting the focus of the field toward interfacial engineering for future orbital-based electronics.

Supported by ERC CoG MAGNETALLIEN (101086807), EU-H2020-RISE ULTIMATE-I (101007825), and ANR (LUE ANR-15-IDEX-04, EM-COM ANR-22-PEEL-0009, PEPR SPIN ANR-22-EXSP-0007/0009). M. Yactayo also: CONCYTEC/PROCIENCIA (PE501098380-2025).

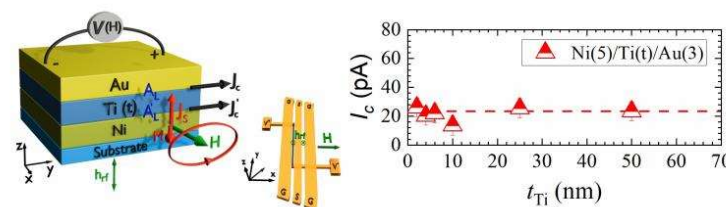


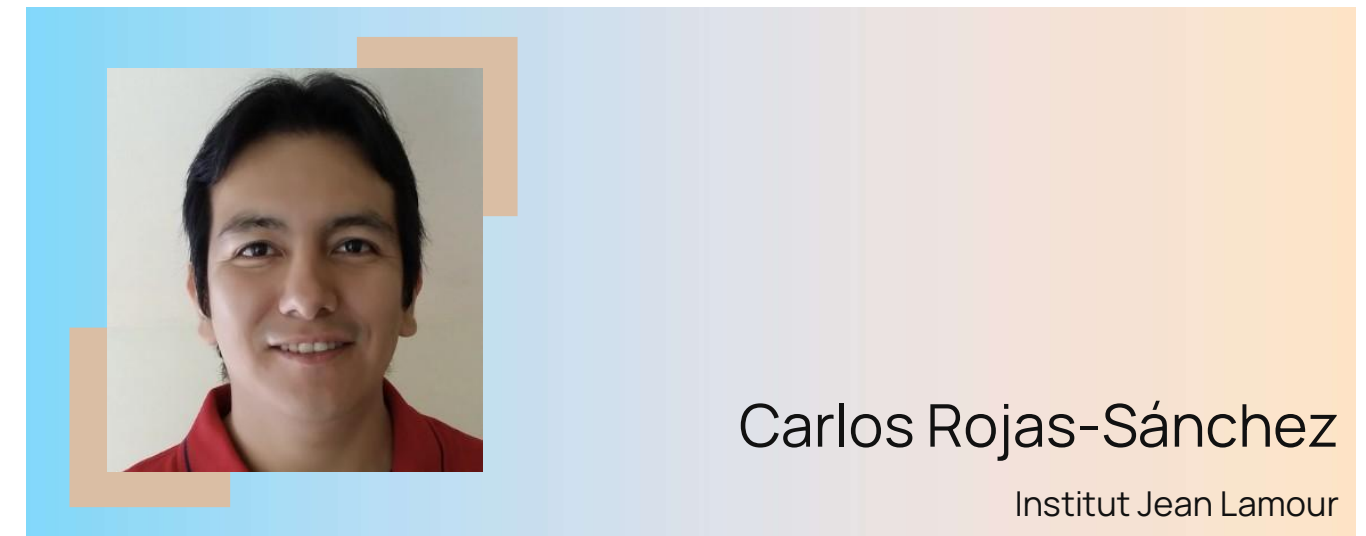
Figure 1: Left: Schematic of spin/orbital injection from Ni into Ti under S/OP-FMR and microwave antenna. Right: Charge current production I_c for Ni/Ti(t)/Au series. Its independence from t_{Ti} indicates an interface-dominated mechanism.

[1] Hayashi, et al., Commun Phys 6, 32 (2023).

[2] M. Rang and P. J. Kelly, Phys. Rev. B, 109, 214427 (2024).

[3] M. Yactayo et al. Phys. Rev. Applied 25, 064051 (2026)

[4] M. Yactayo, et. al, arXiv:2603.28075 (2026).



Biography

J. Carlos Rojas-Sánchez received his BS from Universidad Nacional de Ingeniería (Lima, Peru) in 1999, and his MS and PhD from Instituto Balseiro (Bariloche, Argentina) in 2004 and 2011, respectively. After four years as a postdoc in Grenoble (CEA, Spintec, and Néel Institute) and Palaiseau (Albert Fert Laboratory), he obtained a permanent position as a CNRS researcher in France. He has been working at the Jean Lamour Institute in Nancy, France, since October 2015, and served as head of IJL's clean room facilities from 2018 to 2023.

He currently leads a multidisciplinary team at the intersection of condensed matter physics, materials science, and spintronics, working on systems such as novel quantum materials based on intercalated graphene, ferrimagnets, topological insulators, and Rashba interfaces. His main research interests span spintronics, spin-caloritronics, and spin-orbitronics, with an emphasis on spin-charge and orbital conversion.

He is also the organizer of the International Workshops in Spintronics held in Latin America, including Spin Peru (2019), Spin Argentina (2022), Spin Galapagos (2025, Ecuador), and the upcoming Spin Peru 2027.

In 2020, he received the CNRS Bronze Medal (for young researchers), and in 2023, he was awarded an ERC Consolidator Grant for his MAGNETALLIEN project.

Design optimization of spin-torque-based RF energy harvesters: from resonant nanoelements to oscillating domain walls

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Ambient radiofrequency radiation emitted by mobile, Wi-Fi, Bluetooth and IoT devices (power density up to $\sim 1 \mu\text{W}/\text{cm}^2$) is an attractive energy source for self-powered nanoelectronics. An on-chip rectifier well suited for this purpose is the spin-torque diode (STD): a magnetic tunnel junction (MTJ) in which a microwave current resonantly excites the magnetization of the free layer and, via the TMR effect, generates a dc voltage. For an in-plane geometry with realistic TMR asymmetry $\delta_{\text{TMR}} = 0.9$, the theoretical maximum of the reduced dc voltage is $v_{\text{dc}}^{\text{max}} \approx -0.27$. The central design question is how close to this fundamental limit a realistic STD can be driven. We compare four distinct STD designs by full-scale micromagnetic simulations and identify the best possibility to approach the ideal rectifier.

(1) Single resonant in-plane MTJ [1]. Placing the working point near the switching field of an elliptical free layer enlarges the resonant precession amplitude. However, thermal stability demands an energy barrier $\Delta E > 30\text{--}50 kT$, which limits the allowed ac-current amplitude; consequently the achievable voltage saturates at $|v_{\text{dc}}| \approx 5\text{--}7\%$ of $v_{\text{dc}}^{\text{max}}$.

(2) Array of resonant-type STDs [2]. We have shown that the peak voltage does not depend on the axes ratio of the free elliptical layer. Hence stacking several ellipses of equal area but different axes ratios (with spacing between them) yields a nearly flat $v_{\text{dc}}(f)$ characteristic over 2-4 GHz, producing a broadband rectifier with efficiency close to the resonant one.

(3) Transition regime between in-plane and out-of-plane (OOP) precession. Tuning a uniaxial OOP-anisotropy K_1 across the spin-reorientation transition (Fig. 1) of an elliptical free layer produces canted equilibria with complex butterfly- and dome-shaped energy landscapes. This canted state raises the rectified voltage to $|v_{\text{dc}}| \approx 20\%$ of $v_{\text{dc}}^{\text{max}}$.

(4) Oscillating out-of-plane domain wall (DW) in a notched nanostripe [3]. A thin magnetic stripe containing a long rectangular notch pins an out-of-plane DW, driven by a spin-polarized current can produce due to DW oscillation (Fig. 1) a rectified voltage $|v_{\text{dc}}|$ up to 75% of $v_{\text{dc}}^{\text{max}}$ – nearly an order of magnitude above any single-MTJ design (Fig. 2).

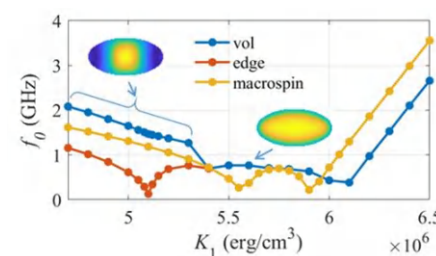


Fig. 1: Dependence of the resonance frequency on the OOP-anisotropy K_1 (design (3)).

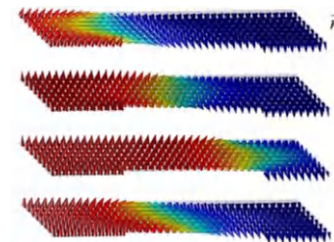


Fig. 2: Snapshots of the oscillating DW in a notched magnetic nanostripe (design (4)).

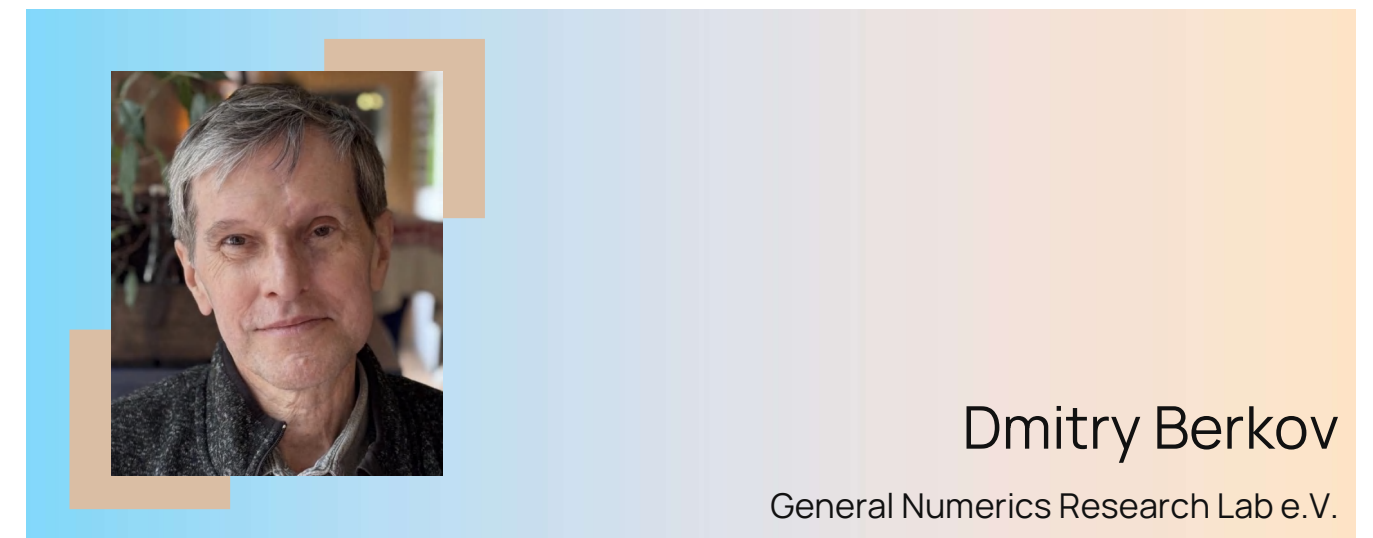
Our systematic comparison shows that replacing the classical resonant-precession paradigm by the oscillation of an out-of-plane domain wall in a notched nanostripe pushes the rectification efficiency from a few percent up to $\sim 75\%$ of the fundamental limit, thereby opening a particularly promising route for nanoscale spintronic RF energy harvesters.

Support of the Deutsche Forschungsgemeinschaft (German Research Society) in frames of the project BE 2464/21-1 is greatly acknowledged.

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Biography

Dr. habil. Dmitry Berkov is Director and Leading Research Scientist at General Numerics Research Lab e.V. (GNRL) in Jena, Germany. He received his PhD from the Institute of Radioengineering and Electronics in Moscow in 1989, his Doctor of Science degree from Lomonosov Moscow State University in 1995, and his German habilitation from Friedrich Schiller University Jena in 2003. From 1997 to 2014, he was Senior Research Scientist and Head of the Theory Group at INNOVENT Technology Development in Jena.

His research focuses on magnetization dynamics, micromagnetic and mesoscopic modeling of magnetic nanoparticles, thin films and nanocomposites, spintronics, and thermally activated processes. He also works on dislocations and point defects in semiconductor crystals, irreversible processes in disordered systems, ill-conditioned inverse problems, and numerical modeling of coupled thermal and mechanical processes. Dr. Berkov has authored numerous scientific publications and book chapters and serves as a referee for leading journals in magnetism, materials science, and computational physics. He is also a member of the European Materials Modelling Council.

Ultrafast and energy-efficient spin dynamics in exchange-coupled systems

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Ultrafast spin dynamics and efficient control of magnetic order are central to the development of next-generation spintronic technologies operating at high frequencies and low energy. This work explores diverse magnetic platforms and excitation schemes to advance the generation, propagation, manipulation, and detection of ultrafast spin dynamics. First, we demonstrate nonreciprocal magnon propagation in the canted antiferromagnet α -Fe₂O₃ at sub-terahertz frequencies using ultrafast optical excitation and Bragg-selective magneto-optical Kerr detection [1]. We reveal distinct propagation dynamics of quasi-ferromagnetic and quasi-antiferromagnetic magnons, with the quasi-ferromagnetic mode exhibiting pronounced nonreciprocity and a record-high group velocity of 33 km/s. The observed amplitude nonreciprocity originates primarily from asymmetric dipolar interactions enhanced by the Dzyaloshinskii–Moriya interaction.

We further establish electrical control of perpendicular altermagnetic order in a PtTe₂/CrSb heterostructure, where the altermagnetic proximity effect enables anomalous Hall readout and efficient spin–orbit torque switching of the Néel vector [2]. This approach provides a pathway toward electrically addressable and scalable altermagnetic memory. To enable ultrafast electrical manipulation, we develop an all-electric on-chip nanoplasma pulse generator capable of producing pulses as short as 6.4 ps, with amplitudes exceeding 100 V and a switching speed of 21 V/ps [3]. Using these pulses, we demonstrate field-free picosecond spin–orbit torque switching in Co/Pt/Co trilayers and achieve a four-order-of-magnitude reduction in writing energy compared with microsecond pulses, highlighting the role of ultrafast Joule heating in enhancing switching efficiency.

Finally, we demonstrate energy-efficient spin-wave generation using rare-earth–transition-metal ferrimagnetic CoGd spin Hall nano-oscillators [4]. Near magnetization compensation, the optimized device simultaneously achieves a low current density, a small magnetic field, and a narrow linewidth, enabled by enhanced spin–orbit torque efficiency, reduced effective magnetization, and suppressed nonlinearities. The above results establish versatile strategies for high-speed, directional, and energy-efficient control of magnetic dynamics across antiferromagnetic, altermagnetic, and ferrimagnetic systems.

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Biography

Hyunsoo Yang earned his bachelor’s degree in electrical engineering from the Seoul National University in 1998 and M.S. and Ph.D. degrees in the electrical engineering department of Stanford University in 2003 and 2006, respectively. From 1988 he worked at a circuit and system design company, earning a patent award, until 2001, when he enrolled in Stanford’s graduate school on a scholarship from the Korean Ministry of Information and Communications. He had been working on long-wavelength photonic devices at Stanford university. Since 2004, he had been at IBM-Stanford Spintronic Science and Applications Center. His doctoral research focused on the metal spintronics, especially magnetic tunnel junctions for the magnetic random access memory application. He was awarded the fellowship in the conference on Magnetism and Magnetic Materials for 2005 and the American Physical Society (GMAG) outstanding dissertation award for 2006. He joined the National University of Singapore in the department of Electrical and Computer Engineering in 2007 and is working on various nanomaterials and devices for future electronic applications.



Non-local architectures for spin current manipulation in group-IV semiconductor platforms

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A fundamental aim for spintronics is the development of spin-based devices in bulk group-IV platforms to enhance the functionalities of CMOS-compatible circuits without altering the electronics supply chain. However, the manipulation of the spin degree of freedom of carriers in Si and Ge by means of Rashba fields is a difficult task if one excludes the application of magnetic fields [1]. Here, we present an alternative method that takes advantage of the group-IV semiconductor spin-transport features to accomplish the electrical control of spin-dependent output signals by modulating the spin current rather than the spin itself.



Fig. 1

Fig. 2

We realized a non-local architecture for spin current generation, modulation and detection in lightly n -doped bulk Si and Ge at room temperature. Spin-polarized electrons are injected in the conduction band of the semiconductor by means of optical orientation technique (see Fig. 1) and then detected by means of the Inverse Spin Hall Effect inside a Pt bar (see Fig. 2) which acts as a spin detector. We demonstrate that the spin current can be driven by an in-plane electric field that fosters or hinders spin diffusion, applying voltage lower than 10 V. As a result, we verify that the ISHE signal can be electrically manipulated to have high or low output values.

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- [2] C. Zucchetti *et al.*, *APL Mater.* **10** (2022), 011102.
- [3] C. Zucchetti *et al.*, *APL Mater.* **11** (2023), 021102.
- [4] F. Bottegoni *et al.*, *Nat. Mater.* **13** (2014), 790.
- [5] C. Zucchetti *et al.*, *Phys. Rev. B* **96** (2017), 014403.
- [6] Z. G. Yu and M. E. Flatté, *Phys. Rev. B* **66** (2002), 2012021.

Emergent inductance in antiferromagnetic systems with spin-orbit coupling

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Emergent inductance, with its magnitude L inversely proportional to the device cross-sectional area S_c , offers substantial advantages for device scaling [1-3]. In this work, we investigate emergent inductance in antiferromagnetic (AFM) systems with spin-orbit coupling (SOC), as shown in fig. 1(a) [4]. The opposite sublattice SOC configuration is found to be crucial for the observation of emergent inductance because the staggered SOC effective field can drive highly efficient AFM precession and promote the generation of sizable spin motive force (SMF), which can be realized in prototype AFMs with locally inversion symmetry breaking, such as Mn_2Au [5]. We derive the analytic formulas of the AFM emergent inductance in a two-port nanodevice, which is robust up to sub-THz frequency range due to the ultrafast spin dynamics in AFMs, as shown in fig. 1(b). Besides, we find that careful design of material parameters, such as magnetic anisotropy and Gilbert damping, may satisfy large inductance and quality factor simultaneously in low frequency region with the trade-off of operating bandwidth sacrifice. The accuracy of our inductance formulas are verified by numerical simulations. A transition from linear to nonlinear inductance model is also found and quantitatively evaluated under large current density and high frequency region. Our work provides renewed insights into the Néel spin-orbit torque (SOT)-driven AFM ultrafast electrical response, and offers promises for the development of spintronic inductor device for high-density and sub-THz applications.

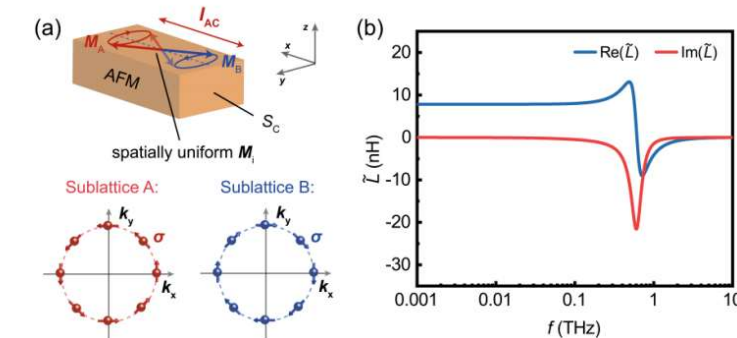


Figure 1: (a) Emergent inductor based on AFM systems with spatially uniform magnetic structures and opposite sublattice SOC configuration. (b) Frequency characteristics of AFM emergent inductance.

- [1] T. Yokouchi, *et al.*, *Nature (London)* **586** (2020), 232.
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- [3] R. Yamada, *et al.*, *Nat. Phys.* **22** (2026), 239-244.
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Highly efficient field-free switching by current-induced torque in a MoS₂-based device operating at room temperature

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Charge-to-spin and spin-to-charge conversion mechanisms in high spin-orbit materials are the new frontier of memory devices. They operate via spin-orbit torque (SOT) switching of a magnetic electrode, driven by an applied charge current. In this work, we propose a novel memory device based on the semiconducting two-dimensional centrosymmetric transition metal dichalcogenide (TMD) MoS₂, that operates as a SOT device in the writing process and a spin valve in the reading process. We demonstrate that stable voltage states at room temperature can be deterministically controlled by a switching current density as low as 3.2×10^4 A/cm² even in zero field, owed to a tilted geometry and a differential voltage architecture. An applied field ~ 50 -100 Oe can be used as a characterizing control parameter for the state switching. Ab initio calculations of spin Hall effect (SHE) and orbital Hall effect (OHE) point to the latter as the most likely responsible for the generation of the SOT in the magnetic electrode. Our device is competitive in terms of energetic efficiency and could be integrated in TMD heterostructures to design memory devices with multiple magnetization states for non-Boolean computation.

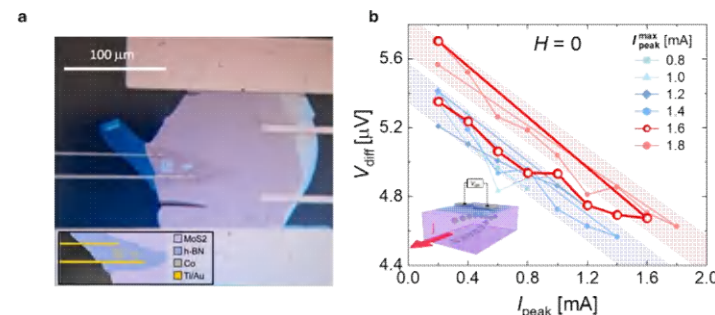


Figure 1: Optical image of the final device (a), based on an hBN/MoS₂ van der Waals heterostructure. The measurement in (b) is performed by driving an electrical current through the MoS₂ layer and recording the voltage drop between the Co pads. When the current density exceeds the threshold value (1.8 mA), the system deterministically switches from the “0 state” (blue bar) to the “1 state” (red bar).

Fermi-arc dichroism in the topological altermagnet CrSb

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Angle-resolved photoemission spectroscopy (ARPES) is the primary experimental technique for directly probing the microscopic electronic and spin degrees of freedom in momentum space. Since altermagnets are characterized by symmetry-enforced alternating spin textures in momentum space, ARPES provides a natural platform for their investigation. However, the interpretation of ARPES data remains nontrivial. This complexity arises primarily from two factors: (i) the intrinsic surface sensitivity of ARPES, whereby surface states, particularly in topological materials, can dominate the measured signal, and (ii) the multi-component nature of the photoemission intensity I , which includes contributions from the Fermi-Dirac function, the spectral function, and photoemission matrix elements:

$$I(k_x, k_y, E) = f(E) \cdot A(k_x, k_y, E) \cdot |\langle \psi_i | \mathbf{p} \cdot \mathbf{A} | \psi_f \rangle|^2 \quad (1)$$

Here, the matrix element term hides detailed information about the orbital and spin texture of the electronic states. By varying the polarization of the incident light (ARPES dichroism) or by spin-filtering the emitted electrons (spin-ARPES), this information can, in principle, be extracted. A prominent example is the direct observation of helical spin-momentum texture in topological insulators such as Bi₂Se₃ [1,2]. At the same time, interference effects between initial (ψ_i) and final (ψ_f) states can produce complex intensity patterns, making interpretations of the data without theoretical support prone to error.

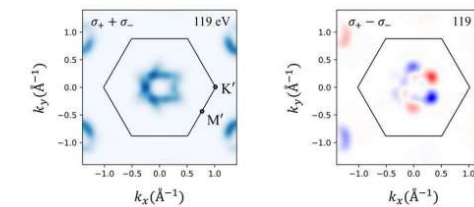


Figure 1: Simulated ARPES-intensity of the bulk Fermi-surface (left) and dichroism (right) in CrSb.

Recently, the introduction of a matrix-element calculation software package *chinook* has enabled systematic quantitative calculations of ARPES matrix elements (see Fig. 1), including their polarization and spin dependence, based on ab initio-derived tight-binding models [3]. In this work, we apply this approach to interpret our low-energy ARPES dichroism measurements in CrSb, a *g*-wave bulk altermagnet and Weyl semimetal exhibiting one of the largest

experimentally confirmed non-relativistic altermagnetic band splittings. We demonstrate that topological surface-state Fermi arcs connecting distinct Weyl nodes dominate the ARPES response and give rise to dichroic patterns that reflect the underlying altermagnetic symmetry. Not only does this provide more insights into the intricate details of the topological Weyl Fermi arcs in altermagnetic systems, the findings also provide a framework for interpreting ARPES measurements in other altermagnetic systems and for identifying signatures of altermagnetism. Finally, using time-resolved ARPES on the same material, we show that circularly polarized pump pulses can selectively excite specific regions in momentum space. This selective excitation opens a pathway toward optical control of altermagnetic order.

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X-ray detection of current-induced orbital accumulation in 3d metals

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Electric currents can manipulate and read magnetization in nanoscale devices by transferring angular momentum from electron spins to magnetic moments, a principle widely used in modern memory technologies. Over the past decades, research has focused on generating spin currents via spin-orbit coupling (SOC), but more recently, orbital angular momentum has emerged as an alternative carrier, originating from a current-induced imbalance in the occupation of electronic Bloch states. [1] Notably, its generation does not require SOC and is often more efficient than spin-based mechanisms. [2] However, direct experimental detection of orbital currents remains challenging, as they typically need to be converted into spin currents to interact with magnetic systems. [3] Techniques such as MOKE [4] and EELS [5] have provided initial evidence, but reported discrepancies suggest strong sensitivity to material microstructure and measurement conditions. Further experimental work is required to conclusively establish orbital effects and clarify the mechanisms governing their magnitude.

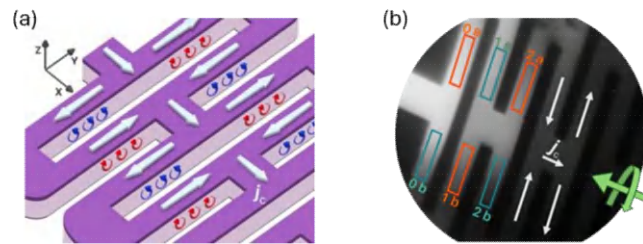


Figure 1: (a) Schematic of the device, indicating current flow (white arrows) and the directionality of accumulated orbital angular momentum (red and blue), and (b) PEEM image illustrating the surface potential variation from the driving voltage, causing an intensity variation from left to right.

Adopting a strategy and sample design similar to previous measurements of the Spin Hall Effect, [6] we investigated the accumulation of orbital moments generated by charge currents in 3d non-magnetic transition metals (P. Pradeep et al., *in preparation*). [7] The accumulated orbital moment is selectively detected at the upper surface of a patterned electrode under applied current using surface-sensitive XMCD-PEEM imaging at the $L_{3,2}$ absorption edges, making use of the element-specific nature of synchrotron radiation. The electrode geometry is optimized to enhance sensitivity and minimize artifacts related to beam footprint inhomogeneity, enabling detection of signals on the order of 10^{-4} . We observed that the XMCD-PEEM signal reverses sign upon inversion of the current polarity and exhibits the same sign at both the L_3 and L_2 edges. This behaviour is consistent with an orbital origin (in contrast, spin contributions would yield opposite signs), [6] demonstrating that the signal is current-driven and of orbital nature.

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- [3] S. Ding et al., Phys. Rev. Lett. **125** (2020), 177201.
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- [6] S. Ruiz-Gómez et al., Phys. Rev. X **12** (2022), 031032.
- [7] P. Pradeep et al., in preparation.

Robust spin splitting and fermiology in a layered altermagnet

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Altermagnetism defies conventional classifications of collinear magnetic phases, with its unique combination of spin-dependent symmetries, net-zero magnetization, and anomalous Hall transport. Although altermagnetic states have been realized experimentally, their integration into functional devices has been hindered by the structural rigidity and poor tunability of existing materials. First, through cobalt intercalation of the superconducting 2H-NbSe₂ polymorph [1], we induce and stabilize a robust altermagnetic phase and, via angle- and spin-resolved photoemission spectroscopy (spin-ARPES), we directly observe the lifting of Kramers degeneracy (Fig. 1) [2]. Then, using laser pulses, we study the ultrafast dynamics of the electronic states in the two magnetic phases. While shedding light on overlooked aspects of altermagnetism, our findings open pathways to spin-based technologies and lay a foundation for advancing the emerging field of altertronics.

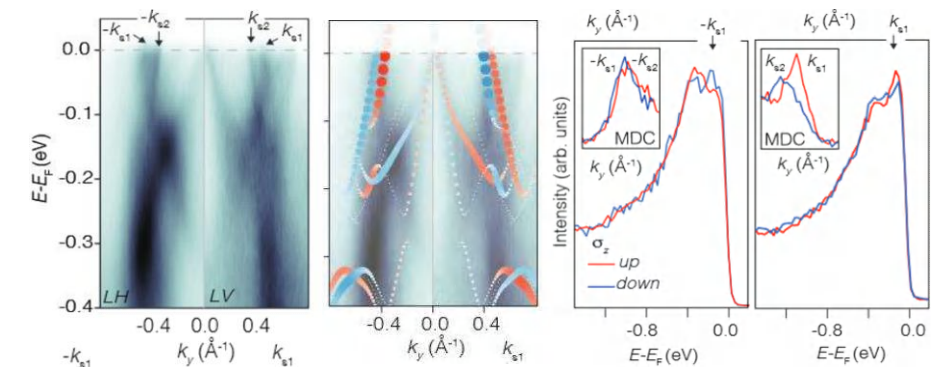


Figure 1: Left: (E, k) ARPES spectra of CoNb₄Se₈, without and with overlaid spin-resolved DFT calculations. Right: corresponding spin-ARPES measurements showing lifted Kramers degeneracy and spin-polarization reversal at opposite k -points.

[1] R.B. Regmi et al., Nat. Commun. 2024, 16 4399.

[2] A. De Vita et al., arXiv:2502.20010 (2025).

Coexistence of Rod-Like Domains and Skyrmions in Ta- and W Based Asymmetric Multilayers

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Magnetic skyrmions are of significant interest for next-generation spintronic applications due to their small size, efficient energy use, and thermal stability [1, 2]. In this work, we demonstrate the coexistence and field-driven evolution of distinct magnetic textures in asymmetric Pt/Co/X multilayers (X = Ta, W), governed by interfacial Dzyaloshinskii–Moriya interaction (DMI) and perpendicular magnetic anisotropy (PMA). Both structures showed a tailed hysteresis loop indicating the existence of skyrmions. Brillouin light scattering measurements reveal a significantly enhanced interfacial Dzyaloshinskii-Moriya Interaction (iDMI) in W-based structures (-0.52 mJ/m²), approximately 2.5 times larger than in Ta-based multilayers. In addition to iDMI, the perpendicular magnetic anisotropy is also stronger for W case due to the orbital hybridization at the interface. Magnetic force microscopy imaging demonstrates the coexistence of distinct magnetic textures, including unusual rod-like domains and skyrmions, under applied magnetic fields. Notably, W-based multilayers exhibit the formation of unusual rod-like domains that evolve into skyrmions, whereas Ta-based systems show a conventional transition from labyrinth domains to skyrmions [3]. These findings highlight the critical role of interface engineering in tuning DMI and controlling spin texture evolution pathways, providing new insights for the design of skyrmion-based devices.

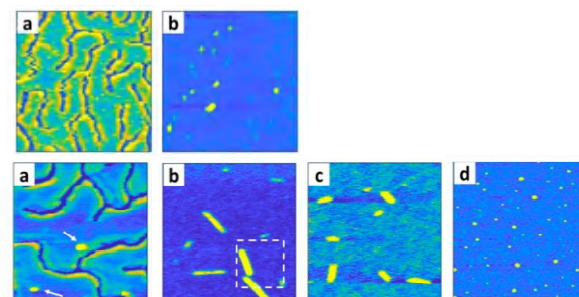


Figure 1: Top row: MFM images of the Pt/Co/Ta multilayer under magnetic fields of (a) 20 mT and (b) 40 mT exhibiting conventional labyrinth-to-skyrmion transition. Bottom row: MFM images of Pt/Co/W asymmetric multilayer under varying magnetic field strengths of (a) 25 mT (b) at 50 mT (c) at 60 mT and (d) at 70 mT showing unusual rod-like magnetic domains that coexist with and transform into skyrmions. The size of each image $2.5 \times 2.5 \mu\text{m}^2$.

- [1] S. Mühlbauer, et al., Science. **323**, 915 (2009).
- [2] A. Fert, et al., Nat. Rev. Mater. **2**, 17031 (2017).
- [3] S. Al Shukaili et al., Appl. Phys. Lett. **125**, 222401 (2024).

Tuning Spin–Substrate Coupling via Vertical Chemical Engineering in Molecular Superstructures

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We have recently proposed a novel bottom-up approach for the realization of complex molecular superstructures composed of regular arrays of magnetically active molecules. The system consists of alternating layers of metal tetraphenyl porphyrins (MTPP) and ditopic ligands (DPNDI), grown by sequential sublimation under vacuum. [1,2] Molecular ordering is achieved by starting from a 2D MTPP wetting layer and exploiting the directionality of coordination bonds between the porphyrin metal centers and the ligand anchoring groups. The magnetic response arises from the localized moments of the porphyrin metal ions. [3,4]

Here, we focus on a superstructure fabricated on oxygen-passivated iron, embedding ZnTPP and magnetic CoTPP molecules within its architecture. To probe the magnetic behavior of both the substrate and the molecular layers, we combine *in situ* growth, ensuring a high degree of control over the assembly, with advanced X-ray spectroscopies. In particular, X-ray magnetic circular dichroism (XMCD) measurements were performed under high magnetic fields and over a wide temperature range, down to cryogenic conditions. [5]

Our results indicate that the magnetic behavior of CoTPP units depends sensitively on their position within the structure, with clear differences between molecules in direct contact with the substrate and those embedded within the stack. A viable strategy to tune the CoTPP response via vertical chemical engineering is thus demonstrated: this approach opens perspectives for the controlled design of magnetic interfaces, potentially relevant for molecular spintronic devices.

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- [2] Orbelli-Biroli, A. et al. Adv. Funct. Mater. **31** (2021), 2011008
- [3] Gottfried, J. M. Surf. Sci. Rep. **70** (2015), 259–379
- [4] Jagadeesh, M. S. et al. Appl. Phys. Lett. **115** (2019), 082404
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Imaging spin waves by electron holography

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Imaging spin waves in magnetic nano-objects is an essential step in the development of gigahertz magnonic devices. However, only a limited number of techniques provide sufficient spatial resolution of a few nanometres. In this context, we present the concept of an innovative experimental approach using electron holography to image spin waves in nano-objects with nanometer spatial resolution, allowing the mapping of local magnetization precession to be correlated with structural and chemical information, thus improving the modelling of spin dynamics at the nanoscale.

Off-axis Electron Holography is an imaging technique that relies on the formation of an interference pattern from which it is possible to measure the phase shift of the electron beam induced by the object's magnetic potential, thereby mapping the associated magnetic field. To

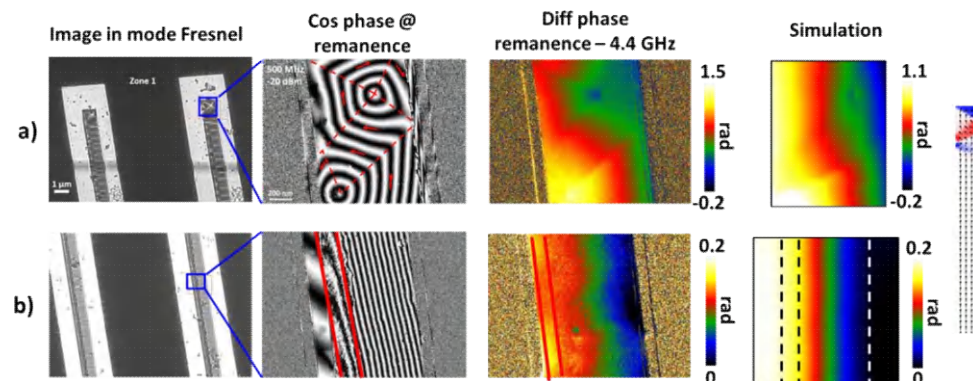


Figure 1: Fresnel-mode images, holographic phases images and micromagnetic simulations of a 1 μm wide, 100 μm length, 40 nm thick permalloy stripe for the stripe head (a) and center (b). The magnetic phase images (colored image third column) correspond to the difference of phase images obtained experimentally at remanence and under a microwave of 4.4 GHz. The simulated phase images (fourth column) have been calculated for 10 μm x 1 μm x 40 nm stripe showing a double vortex state at the end and step shape profile on one side as observed experimentally. The phase images have been calculated after simulations of the dynamic modes (not shown here).

map the precessing magnetization, one can take advantage of the small variations in the magnetization component along the equilibrium direction when exposed to a microwave field [1]. The spatial variations of magnetization induced by the precession can be measured as small variations in the time-averaged electron phase shift image relative to the equilibrium state (fig 1.).

We demonstrate the potential of this approach by conducting microwave excitation of a 1 μm wide, 40 nm thick Py stripe. We demonstrate the quasi-uniform precession ($n=1$ mode) of the magnetization in the part of the stripe where the magnetization lies parallel to its length at remanence, while a complex local precession is observed at the head of the stripe showing a flux closure domain with two vortices. Our experiments are shown to be in very good agreement with micromagnetic simulations of the dynamic states and their corresponding phase shift calculations, demonstrating the sensitivity of the technique to precession angles of only few degrees.

[1] M. Resano et al. Appl. Phys. Lett. 127, 212404 (2025); doi: 10.1063/5.0294261

Ab initio effective exchange Hamiltonian, magnetostriction and magnetic excitations in altermagnetic α -MnTeMatteo Costa^{a,b}, Dario Fiore Mosca^c, Cesare Franchini^{c,d}, Leonid V. Pourovskii^{a,b}^a CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France^b Collège de France, Université PSL, 11 place Marcelin Berthelot, 75005 Paris, France^c University of Vienna, Faculty of Physics, Center for Computational Materials Science, Kolingasse 14-16, 1090, Vienna, Austria^d Department of Physics and Astronomy, University of Bologna, Bologna, 40127 Italy

Hexagonal α -MnTe has recently attracted growing interest as a prototypical altermagnetic system. Here we calculate its effective exchange Hamiltonian and characterize its magnetic excitation spectra from first-principles. To that end, we calculate its paramagnetic electronic structure using density functional theory + dynamical mean field theory [1,2] within the quasi-atomic Hubbard-I approximation for the strongly correlated Mn 3d shell. The target intersite exchange interactions (IEI), including anisotropic and multipolar contributions, are then obtained via the so called force theorem in Hubbard-I method [3]. Solving this IEI Hamiltonian within mean-field approximation, we find a layered antiferromagnetic order that agrees with experiment. The easy-plane anisotropy of MnTe turns out to be induced by the two-site anisotropic exchange interactions, especially the 3rd nearest-neighbour Dzyaloshinskii-Moriya interaction [4,5]. We calculate magnetic excitations for this ordered phase in the random-phase approximation. The resulting dispersions (Fig. 1) reproduce the spin splitting off the altermagnetic nodal planes and the splitting at the Γ point in line with experimental inelastic neutron scattering (INS) measurements [6]. We find that the Γ -point splitting is induced by small and highly anisotropic classical dipole-dipole interactions.

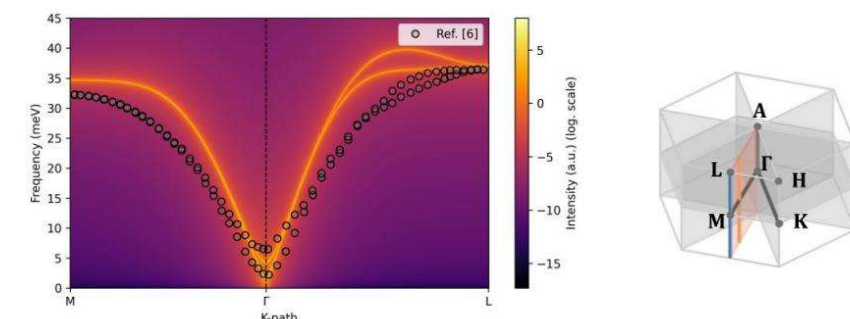


Figure 1: (left) Magnon branches of α -MnTe along the M- Γ -L path. Dots are extracted from the INS data in Ref. [6]. (right) 1st Brillouin zone of α -MnTe with the altermagnetic nodal planes.

From the pressure dependence of the calculated IEI, we evaluate the MnTe magnetostriction contraction in the ordered phase in good agreement with X-ray diffraction experiments [7].

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- [6] Z. Liu *et al.*, Phys. Rev. Lett. **133**, 156702 (2024).
- [7] R. Baral *et al.*, Adv. Funct. Mater. **33**, 2305247 (2023).

Spintronic Architectures for Edge Computing and CommunicationDavi Rodrigues^a^a Politecnico di Bari, Bari, Italy

Edge computing is becoming central to modern communication and inference because it reduces latency, lowers bandwidth demand, and improves data privacy [1]. These gains come with strict constraints on energy, memory traffic, and silicon area. The challenge is particularly acute for workloads such as neuromorphic inference, probabilistic generative models, and post-quantum cryptography, which rely on nonlinear dynamics, stochastic sampling, or non-Boolean logic that are costly to implement efficiently with conventional CMOS circuits. Spintronic devices provide a promising alternative because they combine non-volatility, intrinsic stochasticity, nonlinear response, and nanoscale scalability within a hardware platform compatible with established fabrication routes [2].

In this talk, I will show how several computational primitives relevant to modern edge computing and communication can be implemented directly in compact spintronic systems. I will discuss hardware-native Gaussian sampling for probabilistic inference and cryptographic acceleration, nonlinear activation and gradient generation for trainable neuromorphic hardware [3,4], and multi-level logic based on stochastic magnetic dynamics [5]. These functions are realized in different spintronic platforms, including magnetic tunnel junctions, spin-wave systems, and topological magnetic textures, each chosen to exploit its native physical response. The resulting devices combine competitive silicon footprint with large energy gains, reaching up to two orders of magnitude improvement at the device level and about one order of magnitude at system level in representative tasks.

These results support a broader view of spintronics as a hardware platform for edge intelligence, where key operations emerge directly from device physics rather than from digital emulation. This approach provides a practical route toward scalable and energy-efficient computing architectures for communication, inference, and security beyond conventional digital design.

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- [1] Shi, Weisong, et al. "Edge computing: Vision and challenges." *IEEE Internet of Things Journal* 3.5 (2016): 637-646.
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 - [3] Pereira, Catarina, et al. "Trainable Neuromorphic Spintronic Hardware Via Analog Finite-Difference Gradient Methods." *arXiv preprint arXiv:2603.03947* (2026).
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**Ultrafast laser driven ground state in artificial spin ices**D. Pecchio^{a,b}, S. Sahoo^{a,b}, O. Chubykalo-Fesenko^c, S. Koraltan^d, G. M. Macauley^{a,b}, T. Thomson^e, D. Suess^d, V. Scagnoli^{a,b} and L. J. Heyderman^{a,b}^a Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland.^b PSI Center for Neutron and Muon Sciences, 5232 Villigen PSI, Switzerland.^c Instituto de Ciencia de Materiales de Madrid, CSIC, Cantoblanco, 28049 Madrid, Spain.^d Physik funktioneller Materialien, Universität Wien, Kolingasse 14–16, Wien 1090, Austria.^e NEST Research Group, Department of Computer Science, The University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom.

Artificial spin ices (ASIs) are arrays of dipolar-coupled single-domain nanomagnets, arranged in suitable lattice geometries. These systems have played a pivotal role in exploring frustration, emergent magnetic monopoles and phase transitions [1]. In addition, their use is envisioned for memory applications, logic operations and reprogrammable magnonic crystals. To this goal, ultrafast optical control provides a powerful route to reconfigure the magnetic microstates of artificial spin ices (ASIs).

We demonstrate how the magnetic configuration of nanomagnets relaxes to a low-energy state within a few nanoseconds on exposure to a femtosecond laser pulse [2, 3]. The samples are made of densely-packed stadium-shaped permalloy nanomagnets placed on square and kagome lattices. Following ultrafast demagnetization, the magnetic moments of nanomagnets try to reconfigure themselves to minimize their total energy, striving to satisfy the dipolar interactions.

With results from ultrafast laser-induced magnetic relaxation in square ASI and site-selective ultrafast annealing in kagome ASI, we demonstrate that femtosecond excitation enables access to low-energy ordered states on sub-nanosecond timescales. In square ASI, single-pulse demagnetisation followed by rapid remagnetization, permits dipolar-driven collective relaxation, achieving almost complete ground-state ordering under a decreasing-fluence protocol. In kagome ASI, implementing engineered sublattice-dependent absorption enables deterministic single-step switching into the spin-crystal ground state. These results reveal ultrafast laser excitation as a powerful tool for writing ordered magnetic states in frustrated nanomagnet arrays.

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 - [2] D. Pecchio et al., [Phys. Rev. B 113 \(2026\), 054434](#)
 - [3] D. Pecchio et al., [Phys. Rev. B 113 \(2026\), 064404](#)



**Bias-engineered synthetic antiferromagnets hosting
sub-20 nm zero-field skyrmions at room temperature**

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Magnetic skyrmions are topologically protected nanoscale spin textures with strong potential for high-density, low-power spintronic technologies. However, stabilizing small skyrmions at zero external magnetic field, particularly in synthetic antiferromagnets (SAFs), remains a central challenge [1].

We demonstrate layer-selective skyrmion formation in a compensated synthetic antiferromagnet with chemically distinct magnetic sublattices [2]. Competition between the external magnetic field and RKKY-mediated interlayer exchange produces two skyrmion families with opposite polarities, confined exclusively to one sublattice. This highlights effective-field and sublattice engineering as routes to control the polarity and three-dimensional structure of skyrmions.

Building on this, introduce a bias-engineered SAF architecture that enables robust zero-field stabilization of both ferromagnetic (FM) and SAF skyrmions with deterministic polarity control. The approach employs a compensated SAF bias layer that generates a uniform internal exchange field while suppressing domain formation. Ferromagnetic and fully compensated SAF multilayers were characterized using high-sensitivity quantitative magnetic force microscopy combined with micromagnetic simulations [3].

Quantitative reconstruction of the measured spin textures reveals SAF skyrmions that have diameters as small as 12 nm, representing the smallest experimentally observed SAF skyrmions to date. Together, these results demonstrate how exchange-field engineering in SAFs can provide control over skyrmion localization, polarity, size, and zero-field stability, providing a scalable route to energy-efficient spintronic devices.

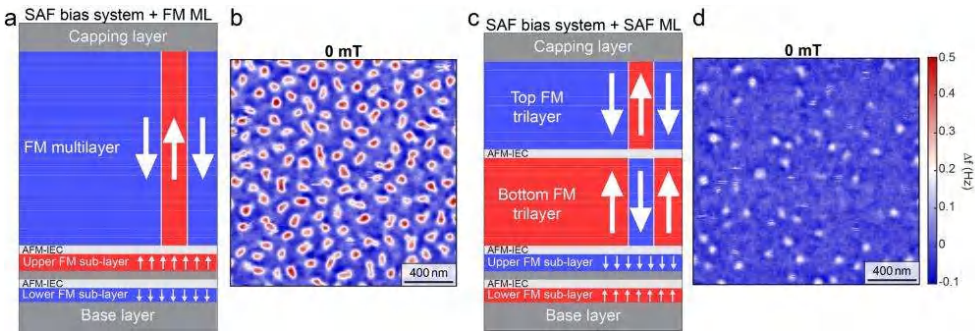


Figure 1. Schematic of FM ML (a) with SAF bias layer and SAF multilayer (c) with SAF bias layer with the corresponding zero-field MFM data (b and d, respectively).

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- [2] Fallon et al., Nat. Mat., 1-8 (2026).
- [3] E.Darwin et al., Adv. Sci., e75825 (2026).

Reconciling Dzyaloshinskii-Moriya interaction measurements via spectroscopy methods and asymmetric bubble expansion in the creep regime

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G. Carlotti^f, G. Durin^a, S. Pizzini^g, A. J. Huxtable^h, E. Darwinⁱ, V. Puliafito^l, C.
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The interfacial Dzyaloshinskii-Moriya interaction (iDMI) [1] plays a central role in stabilizing chiral magnetic textures in heavy-metal/ferromagnet thin films and is therefore crucial for spintronic applications. Although asymmetric bubble domain expansion (ABE) measurements in the creep regime are attractive because they can be performed at room temperature and under low magnetic fields, extracting reliable iDMI values from them remains problematic, often disagreeing with Brillouin light scattering (BLS) and flow-regime measurements [2]. We hypothesize that this fundamental discrepancy arises because BLS natively disentangles chiral damping from chiral energy (iDMI) contributions [3-4], whereas ABE measurements mix them in a non-trivial way. To investigate this issue, we developed a semi-analytical model that incorporates both domain wall stiffness and chiral damping. Using symmetry decomposition [5], we derive a modified creep-velocity expression that allows these two contributions to be separated directly from Kerr microscopy creep curves. We validate the model through a comparative study combining BLS, creep, and flow measurements in perpendicular magnetic anisotropy thin films. We pay special attention to the samples that we identify as devoid of any chiral damping, providing additional insights on the possible origins of the mechanism. The extracted DMI strengths are found to be in quantitative agreement with BLS and flow-regime results across all considered samples. Our results provide a consistent framework for accurate iDMI quantification in the creep regime and help resolve a discrepancy in the spintronics literature.

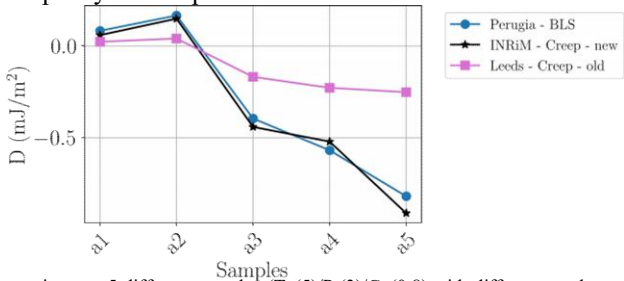


Fig. 1. DMI measurement comparison on 5 different samples (Ta(5)/Pt(3)/Co(0.8) with different overlayer combinations) with 3 different measurement techniques. The different markers represent: blue) BLS measurements, pink) measurements via asymmetric bubble expansion in the creep regime fitted with standard creep models, black) measurements via asymmetric bubble expansion in the creep regime fitted with the new hybrid model of this work.

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[3] E. Jué, et al. Nature Mater 15, 272–277 (2016)

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STT-MRAM-based Content-Addressable Memory for In-Memory and Neuromorphic Computing

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^b ICAR, CNR, Rende, Italy

The data movement bottleneck in conventional von Neumann architectures, where processor-memory communication increasingly dominates both energy consumption and execution time, has driven the exploration of non-von Neumann computing paradigms such as in-memory computing (IMC) and neuromorphic computing (NC). Both paradigms address this limitation by embedding computation within or near the memory array, reducing reliance on centralized arithmetic units. Among the memory technologies proposed for IMC, spin-transfer-torque magnetic RAM (STT-MRAM) has been used in analog crossbar arrays for neural network inference [1] and fully digital bit-serial macros [2].

This work explores the NAND-type content-addressable memory (CAM) scheme for IMC and NC. The scheme is based on a perpendicular-anisotropy double-barrier magnetic tunnel junctions (DMTJs) and a 28 nm CMOS process. It features massively parallel associative comparison in-memory across all rows (referred to as processing units, PUs) in parallel. Mapping a full-adder truth table onto this associative operation enables bit-serial vector addition. The full adder can also be carried out through majority (MAJ)-logic operations executed as: carry-out via MAJ3 and sum via MAJ5. Finally, the architecture can be used to perform binary neural network, where dot-product accumulation reduces to XNOR+POPCOUNT, establishing a path from simple associative logic to acceleration of neural networks.

Fig.1 (a)-(b) shows the top-level view of the architecture and their data allocation strategy. Fig.1 also shows the different computing modes and the circuit-level Monte Carlo simulations for the basic primitives. For associative-based addition, the correct-operation rate ranges from ~63% to ~95% across a PU. For majority-logic operations, yields of 97% and 94% are obtained for MAJ3 and MAJ5, respectively.

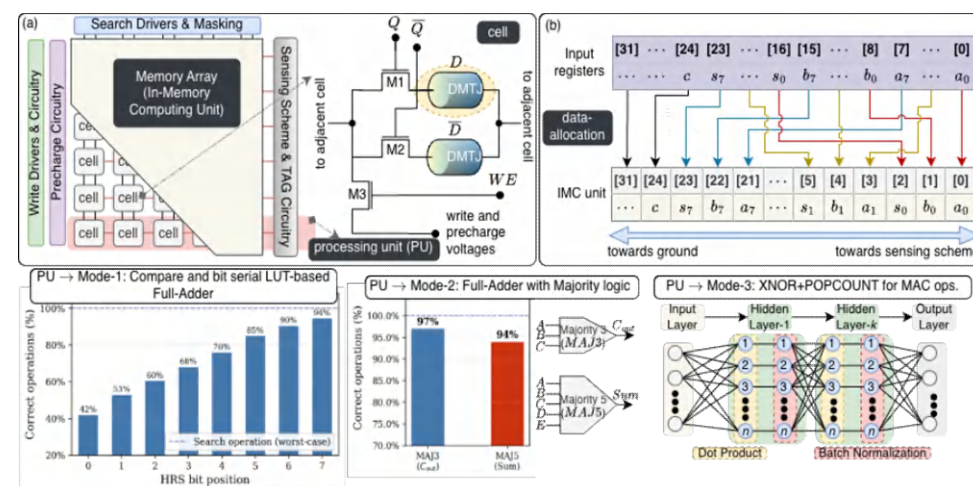


Figure 1: (a) NAND-based in-memory/neuromorphic computing unit. (b) Data allocation. Below: Computing modes of each PU.

[1] S. Jung et al., *Nature Electronics*, 601, 211–216 (2022).

[2] H. Li et al., *Nature Electronics*, 1–13 (2025).



Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Wednesday, 9th September	
8:00 - 9:00	Registration
ROOM A	Session chair: Hyunsoo Yang
9:00 - 9:30	Peter Fischer , Lawrence Berkeley National Laboratory - <i>"Trends in magnetic X-ray spectromicroscopy towards spintronics"</i>
9:30 - 10:00	Valentin Alek Dediu , CNR-ISMN - <i>"New ferromagnetic phase induced by proximity effects in hybrid Ferromagnetic/Molecule systems"</i>
10:00 - 10:30	Silvia Picozzi , University Milan-Bicocca - <i>"Non-reciprocity in multiferroics"</i>
10:30 - 11:00	Coffee Break
ROOM A	Session chair: Giovanni Finocchio
11:00 -11:30	Shinji Yuasa , National Institute of Advanced Industrial Science and Technology (AIST) - <i>"Highly reliable voltage-induced magnetization switching for voltage-controlled MRAM"</i>
11:30 - 12:00	Kai Liu , Georgetown University - <i>" 3D magnetic nanostructures and effects of curvature "</i>
12:00 - 12:30	Lukas Fischer , Max-Planck Institute of Microstructure Physics - <i>"Driving magnetic domain walls with microwaves: from rectification to sustained motion"</i>
12:30 - 13:30	LUNCH co-sponsoder QNAMI
13:30 - 23:00	Social Activites: Tour Bellagio/ Como/ Social Dinner

Trends in magnetic X-ray spectromicroscopy towards spintronicsPeter Fischer^{a,b}^a Materials Sciences Division, Lawrence Berkeley National Lab, Berkeley, CA USA^b Physics Department, UC Santa Cruz, CA USA*pjfisher@lbl.gov

The scientific and technological exploration of three-dimensional magnetic nanoscale systems is a rapidly emerging research field that opens the path to exciting novel physical phenomena, originating from the increased complexity in spin textures, topology, and frustration in three dimensions. Tailored three-dimensional nanomagnetic structures, including in artificial spin ice systems or magnonics will enable novel applications in magnetic sensor and information processing technologies with improved energy efficiency, processing speed, functionalities, and miniaturization of future spintronic devices. Given the amount of data, the complexity and the often non-linear behaviour of problems in three-dimensional nanomagnetism, this field of research seems to be a perfect match for a rapid integration of AI/ML concepts.

Another approach to explore and harness the full three-dimensional space is to use curvature as a design parameter, where the local curvature impacts physical properties across multiple length scales, ranging from the macroscopic to the nanoscale at interfaces and inhomogeneities in materials with structural, chemical, electronic, and magnetic short-range order. In quantum materials, where correlations, entanglement, and topology dominate, the local curvature opens the path to novel phenomena that have recently emerged and could have a dramatic impact on future fundamental and applied studies of materials. Particularly, magnetic systems hosting non-collinear and topological states and 3D magnetic nanostructures strongly benefit from treating curvature as a new design parameter to explore prospective applications in the magnetic field and stress sensing, micro-robotics, and information processing and storage.

Exploring 3d nanomagnetism requires advances in modelling/theory, synthesis/fabrication, and state-of-the-art nanoscale characterization techniques to understand, realize and control the properties, behavior, and functionalities of these novel 3d magnetic nanostructures.

I will summarize and review recent breakthroughs, but also challenges and opportunities ahead of us in the future exploration of nanomagnetism in three dimensions.

This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences and Engineering Division under Contract No. DE-AC02-05-CH11231 within the Non-equilibrium Magnetic Materials Program (MSMAG).

- [1] A. Fernández-Pacheco, R. Streubel, O. Fruchart, R. Hertel, P. Fischer, R. P. Cowburn, Three-dimensional nanomagnetism, *Nature Comm* 8:15756 (2017)
- [2] R. Streubel, E. Tsybal, P. Fischer, Perspective: Magnetism in Curved Geometries, *JAP* 129 210902 (2021)
- [3] S. Ladak, A. Fernandez-Pacheco, P. Fischer, Science and Technology of 3D Magnetic Nanostructures (Editorial), *APL Materials* 10 120401 (2022)
- [4] 2025 Roadmap on 3DNano-magnetism, Gianluca Gubbiotti et al 2025 *J. Phys.: Condens. Matter* 37 143502

**Biography**

Dr. Peter Fischer received his PhD in Physics (Dr.rer.nat.) from the Technical University in Munich, Germany in 1993 on pioneering work with X-ray magnetic circular dichroism in rare earth systems and his Habilitation from the University in Würzburg, Germany in 2000 based on his pioneering work on Magnetic Soft X-ray microscopy.

He is the Division Director of the Material Sciences Division (MSD) at Lawrence Berkeley National Laboratory in Berkeley CA. His research program is focused on the use of polarized synchrotron radiation for the study of fundamental problems in magnetism. He also holds the positions of Adjunct Professor for Physics at the University of California in Santa Cruz. He is very active within the IEEE Magnetics Society as Chapter Chair for the Oakland East Bay Section, and member of AdCom and the Technical Committee. He is also the current Vice Chair of the Topical Group on Magnetism (GMAG) within APS.

Dr. Fischer has published so far over 245 peer reviewed papers and has given close to 380 invited presentations at national and international conferences. He was nominated as Distinguished Lecturer of the IEEE Magnetics Society in 2011. For his achievements of “hitting the 10nm resolution milestone with soft X-ray microscopy” he received the Klaus Halbach Award at the Advanced Light Source in 2010.

Dr. Fischer is Fellow of the APS and IEEE.



New ferromagnetic phase induced by proximity effects in hybrid Ferromagnetic/Molecule systems

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The interplay between Hund's coupling, exchange interaction and magnetic anisotropy is responsible for a multitude of magnetic phases, ranging from conventional ferromagnetism to exotic spin textures. Yet, engineering and finetuning a magnetic state remains a major challenge in modern magnetism. I will show that the chemisorption of organic molecules over 3d ferromagnetic thin films offers a tool to transform the films from ferromagnetic to a glassy-type state. This emerges when the correlation length of the random anisotropy field, induced by the π -d molecule/metal hybridization, is comparable to the characteristic exchange length.

This state is characterized by the collapse of the conventional domain structure and the emergence of blurred pseudo-domains, intertwined with diffuse and irregular domain walls [1]. Magnetization reversal also gives rise to topological vortex-like structures, as predicted and subsequently confirmed by magnetic-force microscopy. At the macroscopic level, this novel glassy ferromagnetic state is characterized by an extraordinary magnetic hardening and a breakdown of Rayleigh law in low-field (minor loops) magnetization reversal.

Intriguingly, these properties—induced through interfacial engineering—extend several nanometers into the bulk of ferromagnetic films, thereby enabling a versatile approach for tailoring key magnetic parameters on demand across a range of magnetic and spintronic applications. Moreover, the resulting magnetic hardening can be tuned, or even reversibly switched on and off, by external stimuli such as light and electric fields. This behavior, demonstrated in ultrafast magnetization dynamics experiments [2], opens promising pathways toward novel device paradigms [3].

[1] Benini *et al.* Nature Communications 16 (1), 5807 (2025)

[2] Benini *et al.* Nature Communications 16 (1), 7297 (2025)

[3] Cinchetti, Dediu, Hueso. Nature Materials 16 (5), 507 (2017)



Valentin Alek Dediu

CNR-ISMN

Biography

Over the past decades V. Alek Dediu has pioneered several influential research directions in magnetism and spintronics. Since 2000, he has been among the key contributors to the development of molecular spintronics, a field that has grown into a major area of research worldwide. His work has significantly advanced the understanding of spin-dependent phenomena in hybrid organic–inorganic systems. In 2010 he contributed to the discovery of the “spinterface,” a concept describing spin-dependent effects at organic–inorganic interfaces, which has since become central to research on beyond-CMOS architectures and hybrid materials.

Dediu's research has also led to the proposal and development of novel device concepts. These include magnetically modulated memristors based on hybrid materials, relevant for neuromorphic computing, and “active spinterface” devices, in which information is encoded directly at interfaces, enabling reduced energy consumption and faster operation. These concepts have been experimentally explored in recent projects, leading to the observation of new magnetic behaviors, including unconventional ferromagnetic states. In the coming years, VAD will continue to focus on advancing the understanding and control of magnetic phenomena in complex materials, with particular attention to interfacial physics.



Non-reciprocity in multiferroics

Silvia Picozzi

Department of Materials Science, University of Milan-Bicocca, Milan, Italy

Multiferroic materials, which simultaneously exhibit coupled ferroelectric and ferromagnetic orders, provide a fertile playground for hosting exotic quantum and complex band phenomena. In this talk, we demonstrate how the coexisting breaking of space-inversion and time-reversal symmetries in these systems can be exploited to engineer highly nonreciprocal electronic states. Using first-principles density functional theory (DFT) combined with rigorous magnetic symmetry analysis, we identify the multiferroic phase of Europium Oxide (EuO) as a prototypical platform hosting a giant, switchable nonreciprocal band structure effect (NRBE).[1] This effect manifests as a striking asymmetry in the electronic dispersion and is enabled by spin-orbit coupling. Crucially, our results highlight that understanding this behavior requires looking beyond simple inversion and time-reversal breaking, emphasizing instead the deterministic role of specific magnetic space groups and the relevance of realistic ab-initio modelling of NRBE. Ultimately, we show that this engineered nonreciprocity leads to a colossal bulk photovoltaic response, yielding shift and injection currents that far exceed those observed in more conventional materials. These findings not only deepen our understanding of symmetry-protected band engineering but also open new avenues for switchable, high-efficiency optoelectronic and spintronic cross-functionalities.

[1] S. Stavric et al. Phys. Rev. Lett. 135, 206401 (2025)



Silvia Picozzi

University Milan-Bicocca

Biography

Silvia Picozzi received her BSc in Physics at Univ. L'Aquila, Italy (1994) and her PhD in Materials Science from Univ. Camerino, Italy (1998). She is currently Full Professor of Condensed Matter Theory at the Materials Science Department of University Milan Bicocca (Milan, Italy), after being Director of Research at Consiglio Nazionale delle Ricerche (CNR) at the Institute for Superconducting and Innovative Materials and Devices (SPIN) in Chieti (Italy). She is a Fellow of the American Physical Society (2019, Division of Materials Physics). She coordinated a Starting Grant from the European Research Council (2008–2012) and was involved (as coordinator or responsible of the CNR-Unit) in 3 PRIN national projects, one H2020-Marie Curie ITN, 1 FIRB project, 2 Next Generation-EU PNRR initiatives. Since 2006 she coordinates a small scientific group and she has supervised 25 post-docs in the entire career. She's coauthor of > 230 publications in peer-reviewed journals. Her activity is centered on High-Performance Computing simulations based on density functional theory for solid-state materials (including surfaces, nanostructures, interfaces). Her focus is on spin degrees of freedom in both magnetic and non-magnetic materials and on their interplay with other types of cooperative phenomena (ferroelectricity, charge-ordering, multiferroicity).



Highly reliable voltage-induced magnetization switching for voltage-controlled MRAM

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Voltage-controlled magnetic anisotropy (VCMA) in magnetic tunnel junctions (MTJs) is the basis of voltage-controlled MRAM (VC-MRAM), an emerging MRAM technology that uses “dynamic” (precessional) magnetization switching induced by ultrafast voltage pulses for writing. The main advantage of VC-MRAM is its ultra-low write energy consumption of less than 10 fJ per bit. However, VC-MRAM remains in the research and development stage due to several unresolved technical challenges. The most important of these challenges is the high rate of write error rate inherent in precessional switching mechanism and the device-to-device variability in the optimal write pulse duration. In this paper, we report on recent advances in voltage-induced switching that significantly reduce the write error rate by improving the VCMA coefficient and lowering magnetic damping of high TMR MTJs [1]. We also demonstrated VCMA-driven “static” magnetization switching by using a synthetic antiferromagnetic free layer, showing that highly reliable magnetization switching can be induced in a wide range of pulse widths [2]. This unconventional writing method is expected to be key to the development of various ultralow-power spintronic devices including VC-MRAM.

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[2] H. Nakayama *et al.*, Nat. Mater. (2026).<https://doi.org/10.1038/s41563-026-02575-w>



Shinji Yuasa

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Biography

Shinji Yuasa received a PhD in Physics from Keio University (Yokohama, Japan) in 1996. After receiving his doctorate, he served as a staff scientist at the National Institute of Advanced Industrial Science and Technology (AIST). Since 2010, he has been a Senior Principal Researcher at AIST and a Professor at Tohoku University. Since 2000, he has been studying thin film magnetism and spintronics, more specifically the tunnel magnetoresistance (TMR) effect, spin-transfer torque (STT) and other phenomena in magnetic tunnel junctions (MTJs) and their applications to various devices such as magnetic sensors and magnetoresistive random-access-memory (MRAM). His most important scientific achievements are the development of MgO-based MTJs including CoFeB/MgO/CoFeB-type MTJs and their applications to read heads of hard disk drives, STT-MRAM, and TMR magnetic sensors. For his pioneering contribution to the MgO-based MTJs, he has been awarded or co-awarded more than 20 prizes, including the Asahi Award in 2007.



3D magnetic nanostructures and effects of curvature

Dhritiman Bhattacharya^a, Colin Langton^a, Bradley J. Fugetta^a, David Raftrey^{b,c},
Claudia Fernández González^d, Subhashree Satapathy^b, Olha Bezsmertna^e, Andrea
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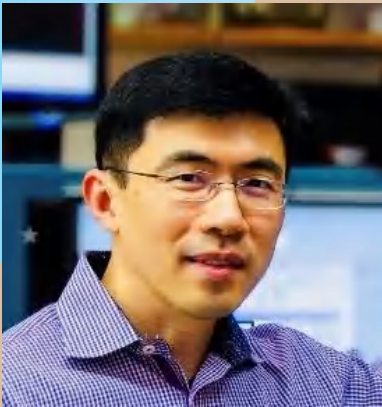
Three-dimensional (3D) nanomagnetic structures provide a fertile ground for stabilizing unconventional spin configurations. In particular, curvature can intricately modify the energy landscape and govern magnetic characteristics, including topology and chirality. Recently, we have demonstrated curvature-induced modification of magnetic configuration in a Co/Pd multilayer thin film deposited over Cu nanowires (NWs) [1]. The overall domain orientation was influenced by the underlying NW-defined curvature. Domain wall (DW) chirality was also strongly affected by curvature. In particular, Néel DWs were promoted, and the effective DMI contribution was found to be $\sim 1/3$ of the intrinsic DMI of the Co/Pd film.

In another study, we have realized a prototypical 3D topological nanostructure, magnetic Möbius bands and demonstrated that their magnetic behaviors are governed by the geometric constraints of the structure [2]. Magnetometry and First Order Reversal Curve (FORC) measurements reveal a geometry-driven rotation of the spin configurations that is opposite to the geometric chirality of the bands. Furthermore, this unique geometry also promotes the fragmentation of larger domains into complex nontrivial arrangements in regions of maximal curvature. These findings are corroborated by micromagnetic simulations, and soft X-ray magnetic imaging. The resulting spin textures can then be preferentially driven along the structure by applied magnetic fields.

Our results demonstrate the potentials of using 3D nanomagnetic systems to explore how geometry influences domain structures and spin configurations across distinct material systems. This work is supported in part by the NSF (DMR-2005108, DMR-2320636 and ECCS-2429995) and DOE BES (DE-AC02-05-CH11231, NEMM program MSMAG).

[1] Raftrey, et al, ACS Nano, **19**, 31609 (2025).

[2] Langton, et al, submitted.



Kai Liu

Georgetown University

Biography

Kai Liu is a Professor and McDevitt Chair in Physics at Georgetown University. He received his Ph.D. in Physics from Johns Hopkins University in 1998, and carried out postdoctoral research at UC San Diego. He joined the UC Davis faculty in 2001, and moved to Georgetown University in 2018. His research interest is in experimental studies of magnetism and spin transport in nanostructured materials. He was recipient of an Alfred P. Sloan Research Fellowship and a UC Davis Chancellor's Fellowship. He is also elected Fellow of the National Academy of Inventors, American Association for the Advancement of Science, Institute of Physics (UK), American Physical Society, and IEEE. He served as Chair of the International Union of Pure and Applied Physics (IUPAP) Commission on Magnetism (2021–2024), and General Chair of the 2016 MMM in New Orleans.



**Driving magnetic domain walls with microwaves:
from rectification to sustained motion**

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^b Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

Magnetic domain walls (DWs) in chiral magnetic systems are key building blocks for spintronic devices, enabling fast and energy-efficient information transport in concepts such as racetrack memories [1-3]. While DW motion driven by current pulses has been extensively studied [4-5], the effect of time-periodic (radiofrequency) currents on DW dynamics remains poorly understood. In particular, it is unclear how oscillatory driving translates into net DW motion and whether it can be harnessed for controlled transport at high frequencies.

Here we demonstrate that a radiofrequency (RF) current excitation provides a powerful and previously underexplored route to manipulate chiral Néel DWs in magnetic microwires with perpendicular magnetic anisotropy. Using time-resolved magneto-optical Kerr effect measurements in a Super-Nyquist sampling scheme, we directly visualize RF-driven DW oscillations. Using Kerr microscopy, we further show that this symmetric oscillatory motion can be converted into unidirectional displacement through rectification by applying a transverse magnetic field, resulting in self-propelled DW motion. Furthermore, we demonstrate that a short electrical current pulse can initiate a long-lived, RF-driven propagation regime, referred to as sustained motion, which persists over several microseconds.*

Finally, we establish a close connection between sustained motion and microwave-assisted switching, highlighting the broader relevance of RF-driven DW dynamics for magnetization control. These results uncover new mechanisms of DW manipulation and open pathways toward high-frequency control of magnetic textures in spintronic devices.

[1] Parkin *et al.* Science **320** (2008), 190-194.

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[3] Venkat *et al.* J. Phys. D: Appl. Phys. **57** (2023), 063001.

[4] Ryu *et al.* Nat. Nanotechnol. **8** (2013), 527-533.

[5] Yang *et al.* Nat. Nanotechnol. **10** (2015), 221-226.

* Fischer *et al.* under review (2025).



Biography

Lukas Fischer is a postdoctoral researcher at the Max Planck Institute of Microstructure Physics, specializing in spintronics and magnetization dynamics. He received his PhD from Martin Luther University Halle-Wittenberg, Germany, under the supervision of Prof. Stuart Parkin, where he investigated microwave-driven magnetic domain wall motion and magnetic switching. His current research focuses on unravelling the mechanisms of microwave-driven domain wall dynamics and their role in magnetization control.





Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Thursday, 10th September	
8:00 - 9:00	Registration
ROOM A	Session chair: Kai Liu
9:00 - 9:30	Jagoda Slawinska , University of Groningen - <i>"Spin-orbit physics in altermagnets"</i>
9:30 - 10:00	Stephan Mangin , Université de Lorraine and Institut Jean Lamour - <i>"Ultrafast All-Optical Switching in Spintronic Devices"</i>
10:00 - 10:30	Rikako Yamamoto , Max Planck Institute for Chemical Physics of Solids - <i>"Nanoscale altermagnetic spin textures with local variations in α-Fe₂O₃"</i>
10:30 - 11:00	Coffee Break
ROOM A	Session chair: Tiffany Santos
11:00 -11:45	Pedram Khalili Amiri , Northwestern University - <i>"Computing with unconventional magnetic tunnel junctions"</i> (keynote)
11:45 - 12:15	Mathias Klaui , Johannes Gutenberg University, Mainz - <i>"Giant all-orbital interactions"</i>
12:15 - 12:45	Hari Srikanth , University of South Florida - <i>"Berry Curvature effects in Heusler and High-Entropy Alloys: From the Anomalous Hall Effect to Transverse Thermopower"</i>
12:45 - 14:00	LUNCH BREAK (free time)
ROOM A	Session chair: Mathias Klaui
14:00 - 14:30	Simone Finizio - <i>"Unlocking sub-10nm resolution imaging: Soft X-ray scanning microscopy at 4th generation lightsources"</i>
14:30 - 15:00	Andrea Meo - <i>"Innovative sensors solutions based on magnetic tunnel junctions"</i>
15:15 - 19:00	Social Activites - A guided tour of Milan's Cathedral

Spin-orbit physics in altermagnets

Jagoda Sławińska^a

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Spin-orbit coupling (SOC) is responsible for many of the intriguing properties of magnetic materials, including the anomalous Hall effect, weak ferromagnetism, and current-induced spin phenomena. In altermagnets, where exchange interactions generate momentum-dependent spin splitting despite vanishing net magnetization, the interplay between exchange interactions, spin-orbit coupling, and magnetic symmetry leads to a broad range of unconventional spin-related phenomena.

In this talk, I will first discuss how magnetic symmetry determines the spin-orbit-driven properties that are observed in altermagnets, focusing on the anomalous Hall effect and weak ferromagnetism [1, 2]. I will then turn to the spin polarization of bands generated by the interplay between exchange interactions and spin-orbit coupling. While the spin splitting in altermagnets originates from exchange interactions and can remain large even in materials with moderate SOC, real materials often exhibit additional SOC-induced spin textures, such as Rashba spin-momentum locking, which may compete with and partially obscure the characteristic altermagnetic spin polarization pattern.

This naturally raises the question of the relation to persistent spin textures (PSTs), which have emerged as a promising route toward long spin lifetimes in nonmagnetic materials [3, 4]. The unidirectional spin polarization around certain regions of momentum space shares similarities with the nonrelativistic spin texture of altermagnets, raising the possibility of an interplay between the two phenomena. I will discuss this interplay in several altermagnet candidates with strong SOC, focusing on chiral transition-metal sulfides TM_3S_6 . Depending on the orientation of the Néel vector and the resulting spin texture, SOC contributions can either reinforce or compete with the altermagnetic spin polarization [5]. Finally, I will discuss the consequences for charge-to-spin conversion and spin transport, providing insight into the role of SOC in realistic altermagnetic materials.

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[2] C. Chen Ye, K. Tenzin, J. Sławińska, C. Autieri, Physical Review B **113** (2026), 014413.

[3] B. Kilic, S. Alvarruiz Campos, E. Barts, B. van Dijk, P. Barone, J. Sławińska, Nature Communications **16** (2025), 7999.

[4] E. Barts, K. Tenzin, J. Sławińska, Nature Communications **16** (2025), 4056.

[5] K. Tenzin, B. Kilic, R. M. Sattigeri, Z. He, C. Chen Ye, M. Costa, M. Buongiorno Nardelli, C. Autieri, J. Sławińska, npj Spintronics **3** (2025), 46.



Jagoda Slawinska

University of Groningen

Biography

Jagoda Slawinska is an Associate Professor at the Zernike Institute for Advanced Materials, University of Groningen. She obtained her Ph.D. in Physics from the University of Lodz (2012), followed by postdoctoral positions at ICM-CSIC (Spain), CNR-SPIN (Italy), and the University of North Texas (USA). She joined Groningen in 2020 as a Rosalind Franklin Fellow. Her research focuses on modeling and designing quantum materials for nanoelectronics and spintronics, with emphasis on ferroelectric spintronics, chiral spintronics, and two-dimensional materials. Her group develops computational tools based on density functional theory and works closely with experimentalists to predict novel effects, explain observations, and explore new device concepts. She has received several grants and distinctions, including the ERC Consolidator Grant (2024).



Ultrafast All-Optical Switching in Spintronic Devices

Stéphane Mangin

Université de Lorraine, CNRS, Institut Jean Lamour, F-54000 Nancy, France

Ultrafast optical control of magnetization offers a promising route toward spintronic devices operating on sub-picosecond timescales. In this contribution, I will discuss magnetization reversal driven by ultrashort laser pulses in magnetic thin films and heterostructures. Beyond direct light-matter interaction, femtosecond excitation can generate transient heat spikes and ultrafast spin-polarized currents, which can in turn reverse magnetization in nanoscale magnetic devices [1-3].

A particular emphasis will be placed on deterministic switching induced by a single femtosecond or picosecond laser pulse in spintronic architectures such as spin valves and magnetic tunnel junctions. We demonstrate ultrafast magnetization reversal, initiated in less than one picosecond, in a variety of ferrimagnetic and ferromagnetic spin-valve systems, including both perpendicularly magnetized [4-9] and in-plane configurations [10]. In rare-earth-free spin valves of the type [Pt/Co]/Cu/[Co/Pt], the free magnetic layer can be switched from the parallel to the antiparallel state and from the antiparallel to the parallel state, revealing the action of an intense ultrafast angular-momentum transfer mechanism [9]. Related behaviour has also been observed in magnetic tunnel junctions[11], highlighting the strong potential of combining optical excitation with spin-transport functionality.

I will also show that in exchange-biased IrMn/GdCo bilayers, a single laser pulse not only reverses the ferrimagnetic GdCo layer but also changes the sign of the exchange bias, demonstrating that the magnetic state of the antiferromagnetic IrMn layer can also be modified by ultrafast optical excitation [12]. Altogether, these results illustrate how ultrafast optics and spintronic device design can be combined to achieve efficient, deterministic, and extremely fast magnetic switching, opening new perspectives for future memory and logic technologies.

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[2] J. Gorchon et al., J. Magn. Magn. Mater. 563, 169919 (2022).
[3] P. Scheid et al., J. Magn. Magn. Mater. 560, 169596 (2022).
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[9] H. Singh et al., Phys. Rev. Lett. 136, 056701 (2026).
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[11] J. Igarashi arXiv:2510.25102 (2026)
[12] Z. Guo et al., Adv. Mater. 36, 2311643 (2024).



Stéphane Mangin
Université de Lorraine

Biography

Stéphane Mangin is a fellow of the American Physical Society, a fellow of the IEEE Magnetic Society and a fellow of the Churchill College at Cambridge University. Stephane Mangin is a Co-Founder of the French-US International Associated Laboratory on Nanoelectronics at UC San Diego. He is the scientific director of a unique tool (TUBE-Davm) : a 70-meter Tube under Ultra High Vacuum which connects 30 equipments to growth and characterise material down to the atomic scale. Stéphane holds a PhD in Physics from Université Joseph Fourier in Grenoble. He is a senior member of the Institut Universitaire de France. He is a Full Professor at Université de Lorraine where he leads the research team Spintronics and Nanomagnetism at Institut Jean Lamour.



Nanoscale imaging of altermagnetic spin textures in α -Fe₂O₃

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Simone Finizio^e, Eugen Weschke^f, Markus Weigang^f, Warley H. Campos^g,
Libor Šmejkal^g, Jan Kuneš^h, Claire Donnelly^{a,b}, and Sebastian Wintz^f

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^d Laboratory for Mesoscopic Systems, Department of Materials, ETH Zürich, 8093 Zürich, Switzerland

^e Department of Physics and Electronics, Graduate School of Engineering, Osaka Metropolitan University, 1-1 Gakuen-cho, Nakaku, Sakai, Osaka 599-8531, Japan

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Recent proposals of altermagnetism have triggered intense researches owing to its unconventional magnetic order, characterized by zero net magnetization yet exhibiting anisotropic spin splitting [1]. To date, experimental studies of altermagnetism have focused primarily on spin splitting observed by angle-resolved photoemission spectroscopy [2,3]. Although many emergent responses of altermagnets are governed not by spin splitting itself but rather by the orientation of the Néel vector $\mathbf{L}$, accessing such Néel vector-dependent phenomena, particularly at the nanoscale, remains a major experimental challenge.

In this study, we harness nanoscale X-ray magnetic spectro-microscopy to investigate the modulation of altermagnetic responses in α -Fe₂O₃ (hematite) [4]. By performing spectroscopic X-ray magnetic circular dichroism (XMCD) measurements, we observe a finite XMCD signal at room temperature and confirm its altermagnetic origin through DFT+DMFT calculations. Having established the altermagnetic origin of XMCD, we employ high-spatial resolution XMCD imaging to map its spatial distribution, revealing complex spin textures including domain walls and vortices.

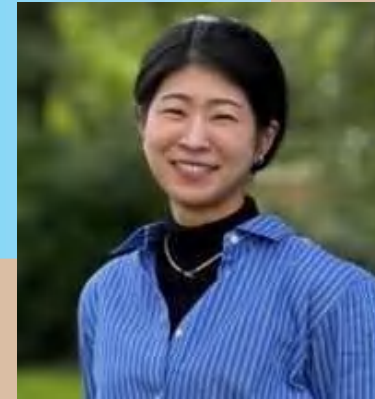
We further exploit the $\mathbf{L}$ orientation dependence of XMCD to demonstrate the switching on and off of an altermagnetic response. α -Fe₂O₃ undergoes the Morin transition T_M , in which the Néel vector reorients from an in-plane configuration that allows XMCD to an out-of-plane configuration for which XMCD is forbidden. We observe a temperature-driven global switching of the XMCD signal across this transition. Furthermore, below T_M , we identify nanoscale spin textures exhibiting locally modulated altermagnetic responses, including domain walls embedded within surrounding domains where XMCD is forbidden. These nanoscale spin textures with distinct altermagnetic responses establish a new platform for exploring and engineering altermagnet-based spintronic functionalities.

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[4] R. Yamamoto et al., arXiv:2603.09934 (2026).



Rikako Yamamoto

Max Planck Institute

Biography

Rikako Yamamoto is a postdoctoral researcher in condensed-matter physics affiliated with the Max Planck Institute for Chemical Physics of Solids in Germany and the WPI-SKCM² at Hiroshima University, Japan. She received her PhD from Hiroshima University in 2023, where she studied strongly correlated electron systems using low-temperature experimental techniques. Since 2025, she has been supported by the JSPS Overseas Research Fellowship.

Her current research focuses on magnetic imaging using synchrotron-based X-ray spectro-microscopy. She investigates altermagnetism, topological spin textures, and other emergent magnetic phenomena by visualizing magnetic order and spin configurations at the nanoscale.



Computing with unconventional magnetic tunnel junctionsPedram Khalili Amiri^{a,b}^a Dept. of Electrical and Computer Engineering, Northwestern University, Illinois, USA^b Applied Physics Program, Northwestern University, Illinois, USA

The integration of magnetic tunnel junctions (MTJs) within CMOS semiconductor manufacturing technology provides unprecedented opportunities for the development of application-specific integrated circuits (ASICs) for probabilistic (p-) computing. At the same time, the emergence of new “unconventional” types of magnetic tunnel junctions – where either the *type of magnetic order*, or the *mechanism for its electrical control* are different from today’s conventional MTJs – provides an exciting perspective for engineering such computing systems in the future.

This talk will consist of two parts: (1) We first discuss how appropriately designed voltage-controlled MTJs can serve as compact and high-throughput entropy sources for p-computing hardware [1]. We discuss device-circuit interactions and trade-offs and show experimental results from a 130-nm ASIC interfaced with voltage-controlled MTJs [2], along with projections for more advanced technology nodes. We also discuss how appropriately designed extended probabilistic variables (broadly termed probabilistic d-dimensional bits, or p-dits) can further accelerate the solution of various optimization problems, with two concrete examples being integer programming using probabilistic integer (p-int) variables [3] and frequency assignment in wireless communication networks [4]. (2) In the second part of the talk, we present the first experimental observation of the octupole-driven spin-transfer torque (OTT) effect [5], whereby all-antiferromagnetic tunnel junctions (ATJs) [5, 6] can be switched by direct tunneling current through the device in a two-terminal geometry. We discuss the physical mechanism of OTT and the potential of OTT-ATJs for p-computing applications, as well as for other applications such as spintronic memory and terahertz devices.

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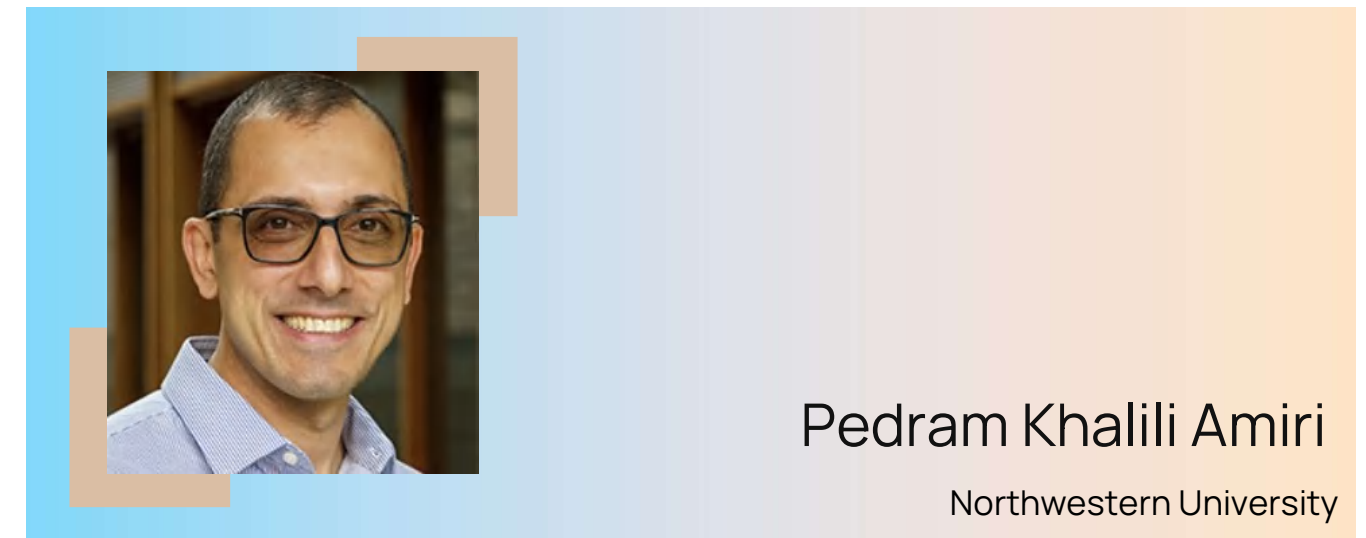
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Pedram Khalili Amiri

Northwestern University

Biography

Pedram Khalili is a Professor of Electrical and Computer Engineering at Northwestern University, where he is also Co-Director of the Applied Physics Program and Director of the Physical Electronics Research Lab. Prof. Khalili is a recipient of the IEEE Nanotechnology Technical Achievement Award, has served as a Distinguished Lecturer of the IEEE Nanotechnology Council, and has received the Northwestern University ECE Allen Taflove Best Teacher Award. He received the Ph.D. degree (cum laude) from Delft University of Technology (TU Delft) in 2008. He is an Associate Editor of Frontiers in Physics, and serves on the Editorial Advisory Board of Newton (Cell Press). He serves on the IEEE Magnetics Society Administrative Committee (AdCom), is past Chair of the Chicago Chapter of the IEEE Magnetics Society, and has served on the IEEE Task Force for Rebooting Computing (TFRC) Executive Committee. He is a Senior Member of the IEEE.



Giant all-orbital interactionsMathias Kläui^{a,b}^a Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany^b Center for Quantum Spintronics, Norwegian University of Science and Technology, 7491 Trondheim, Norway

Experimentally, orbital currents for efficient manipulation of magnetization have only recently started to be explored. In order to generate orbital currents, materials with orbital Hall effects can be used that can be light metals and thus cheap, abundant and environmentally friendly.

In our work we explore orbital torques, orbital magnetoresistance and transport effects in multilayer heterostructures and going to the 2D limit using van der Waals systems.

We start with spin orbit torques generated in TmIG/Pt/(Cu(O)x) heterostructures that are enhanced by a factor up to 16 if the CuOx is added on top of the Pt compared to the conventional TmIG/Pt stack [1]. We found that the Orbital Rashba-Edelstein Magnetoresistance can be observed in Py/Cu(O)x, which is an orbital magnetoresistance effect related to the conventional spin Hall magnetoresistance [2]. In particular, in this work, the length scale of the orbital to spin current conversion in Py could be identified as a key step to harnessing orbital currents efficiently even without a heavy metal based orbital to spin conversion layer [3,4].

For MRAM devices, we show that using orbital torques, reduced switching current densities can be realized, which is a key step to functional devices [5]. We observe that in non-local spin valve devices the transport using Ru-based OHE and iOHE is non-reciprocal [6].

To overcome the limitations by the orbital to spin conversion that are set by the weak relativistic nature of spin-orbit coupling, we use orbital magnets, such as nitrides and oxides where the magnetic moment is dominated by orbital angular momentum. For CoO, which has magnetic sub-lattice moments that are dominated by orbital angular momentum, we find a two orders of magnitude enhanced interaction between the orbital currents and the orbital moments by measuring and orbital magnetoresistance effect [7]. By varying the Cu(O)x layer and in particular by controlled oxidation, we identify the O-Cu bonds at the CoO/Cu interfaces as the origin of the strong interaction. This strong interfacial interaction for orbital magnets opens a new paradigm to exploiting orbitronic effects [under review].

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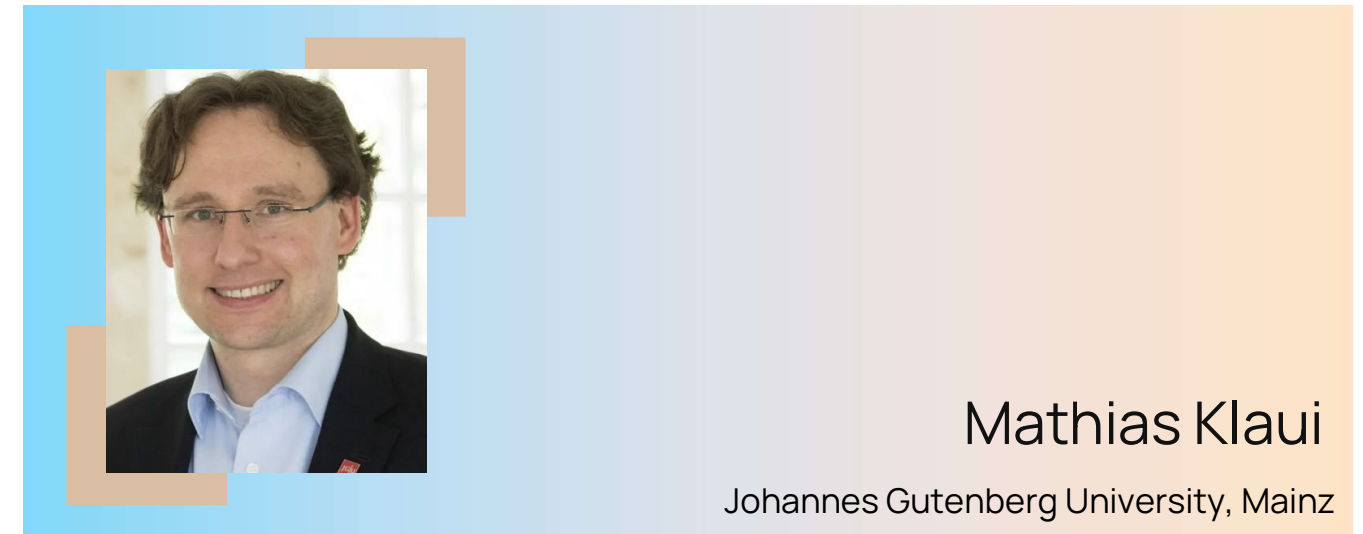
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Mathias Kläui

Johannes Gutenberg University, Mainz

Biography

Mathias Kläui is professor of physics at Johannes Gutenberg-University Mainz and adjunct professor at the Norwegian University of Science and Technology. He received his PhD at the University of Cambridge, after which he joined the IBM Research Labs in Zürich. He was a junior group leader at the University of Konstanz and then became associate professor in a joint appointment between the EPFL and the PSI in Switzerland before moving to Mainz. His research focuses on nanomagnetism and spin dynamics on the nanoscale in new materials. His research covers from blue sky fundamental science to applied projects with major industrial partners. He has published more than 400 articles and given more than 300 invited talks. He is a Fellow of the IEEE, IOP and APS and has been awarded a number of prizes and scholarships. He has been one of the 2020/2021 IEEE Magnetics Society Distinguished Lecturers and is a 2024 Clarivate Highly Cited Researcher. Contact details and more information at www.klaui-lab.de



Berry Curvature effects in Heusler and High-Entropy Alloys: From the Anomalous Hall Effect to Transverse Thermopower

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Magnetic materials with complex electronic band structures provide fertile ground for Berry-curvature-driven transport phenomena that couple charge, spin, and heat currents. Heusler compounds and emerging high-entropy magnetic alloys offer exceptional opportunities to engineer electronic topology and magnetic order through compositional design. In this talk, I will present recent results from our group on anomalous transverse transport phenomena in these tunable magnetic systems, focusing on the anomalous Hall effect (AHE), anomalous Nernst effect (ANE), and topological Hall effect (THE) [1,2]. Through systematic alloy synthesis, structural characterization, and detailed magnetotransport measurements, we investigate how chemical substitution, lattice tuning, compositional disorder, and structural phase transitions influence Berry curvature near the Fermi level and generate enhanced transverse responses. In several Heusler systems, we observe large anomalous Hall conductivities and strong thermomagnetic signals linked to spin-orbit coupling and nontrivial band topology. We also present recent results on the Heusler compound *CrRuMnGe*, where a structural transformation from the cubic to a tetragonal phase, reminiscent of a martensitic transition, is accompanied by the emergence of a topological Hall effect, highlighting the intimate interplay between structural instabilities, magnetic textures, and topological transport. Extending these studies to high-entropy alloys, we demonstrate that multi-principal-element compositions stabilize robust ferromagnetism while enabling tunable anomalous Hall and thermomagnetic coefficients. These findings establish Heusler and high-entropy magnetic alloys as versatile platforms for engineering Berry curvature and emergent topological phenomena, opening new avenues for thermomagnetic energy conversion, waste-heat harvesting, and next-generation spin-caloritronic and spintronic technologies.

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Hari Srikanth
University of South Florida

Biography

Hari Srikanth is a Distinguished University Professor at the University of South Florida. He received his Ph.D. in experimental condensed matter physics from the Indian Institute of Science, Bangalore and has been at USF since 2000 where he leads the Functional Materials Laboratory. He is also the Director of Florida Institute of Emergent Low-Dimensional Quantum Materials (FIELD-QM). Hari’s research spans a wide range of topics like quantum materials, magnetic materials and nanoscience. At USF Hari has graduated 25 PhD students and mentored over 15 postdoctoral scholars in his career. He has over 325 journal publications (with 13,400+ citations and an h-index of 66) and has given over 230 invited talks around the world. In 2019, he was an IEEE Magnetics Society Distinguished Lecturer. He is a Fellow of the American Physical Society, Fellow of the Institute of Physics and a Senior Member of IEEE. He currently serves as an Associate Editor for Physical Review B. Hari has been closely involved with the MMM and INTERMAG conferences for over 20 years serving as Publication Editor, Publication Chair and on program committees. He was the Special Events Chair for the MMM 2025 in Palm Beach, FL and also serves as a voting member on the IEEE Magnetics Society AdCom. Hari is a recipient of an Alexander von Humboldt Research Award and a Fulbright Scholar Award and holds visiting professorships at University of Duisburg Essen in Germany, IIT Bombay and Indian Institute of Science Bangalore in India.



Unlocking sub-10nm resolution imaging: Soft X-ray scanning microscopy at 4th generation lightsources

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Diffraction limited synchrotron (DLSR), or 4th generation, light sources are a novel design delivering an increase in the coherent photon flux of several orders of magnitude compared to the older 3rd generation storage ring design. These improvements are revolutionizing synchrotron-based experiments, allowing for the unlocking of routine high-resolution imaging, of fundamental importance for condensed matter physics research.

For scanning transmission X-ray microscopy (STXM), the increase in coherent photon flux will allow us to routinely perform high-resolution imaging, as it will tackle all the issues occurring for high-resolution X-ray optics. In addition, the increase in coherent photon flux, in the available computational power, and in the performances of 2D soft X-ray detectors [1] will also enable for the routine performing of high-resolution soft X-ray ptychographic imaging.

In this presentation, I will show the recent breakthroughs in high-resolution scanning X-ray microscopy enabled by DLSR sources, both regarding coherent diffractive imaging, in particular focusing on ptychography imaging, and in direct STXM imaging. For soft X-ray ptychography imaging, I will present the current commissioning status of a new dedicated soft X-ray ptychography endstation, called SOPHIE [2]. To showcase the sub-10 nm spatial resolutions routinely achievable with the technique, I will present the imaging of the magneto-electric coupling between ferroelectric domains and spin cycloid in freestanding multiferroic BiFeO₃ thin films (see Ref. [3,4] and Fig. 1a).

For STXM imaging, I will present a newly developed protocol for fast high-resolution imaging, called *supersampled microscopy* [5]. In this protocol, we change from the established approach and stop fighting the unavoidable environmental vibrations at the nanoscale: by relaxing the precision requirements of the sample positioning and sampling the position faster than the mechanical eigenfrequencies of the sample assembly, we can generate a vibration-free high-resolution image (see Ref. [5] and Fig. 1b) without the significant overheads that would otherwise be required. The unavoidable environmental vibrations are no longer an enemy but become an ally in guaranteeing a uniform sampling at the nanoscale. In addition, this method can be easily combined with time-resolved imaging.

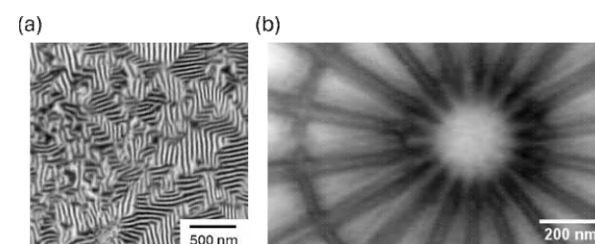
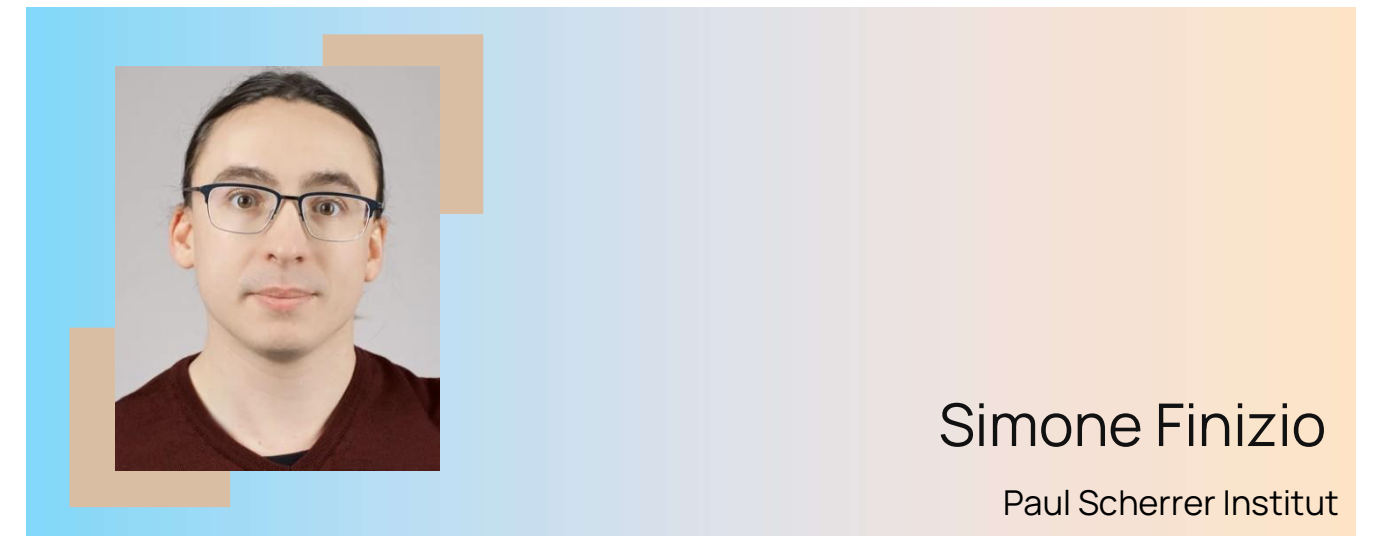


Figure 1: (a) X-ray linear dichroism ptychography image of the ferroelectric and spin cycloidal configuration of a BiFeO₃ freestanding lamella [4]. (b) Supersampled STXM image of a 10 nm Ir Siemens star [5].

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Biography

Simone Finizio studied Physics Engineering (bachelor's degree – 2006-2009), at the Politecnico di Milano (Italy), and then studied Nuclear Engineering (master's degree – 2009-2011), at the Politecnico di Milano (Italy) and finally obtained PhD in Physics (2012-2015) at the University of Mainz (Germany) in the group of Mathias Kläui. Thesis project on magneto-electric multiferroic materials, with focus on X-ray microscopy investigation using photoemission electron microscopy. He was a postdoc (2015-2019) within the MAGicSky EU Horizon 2020 project in the Microspectroscopy group of the Paul Scherrer Institut (Switzerland), focused on the investigation of the dynamics of magnetic skyrmions with time-resolved scanning transmission X-ray microscopy (STXM). He is a Beamline Scientist (2019-now, tenured since 2023) at the PolLux STXM beamline of the Swiss Light Source, Paul Scherrer Institut (Switzerland). His research focus on time-resolved X-ray microscopy of spintronic systems and high-resolution X-ray magnetic microscopy.

Innovative sensors solutions based on magnetic tunnel junctions

Andrea Meo

Politecnico di Bari, Bari, Italy

Magnetic tunnel junctions (MTJs) combine a nanoscale footprint with CMOS compatibility, low-power operation, scalability, tunability and intrinsic radiation hardness. In addition to converting a magnetic state into an electrical signal through tunnelling magnetoresistance, their dynamic response enables the spin-torque-diode effect, in which a radio-frequency excitation is rectified into a dc voltage. This invited contribution presents modelling-led MTJ sensor concepts for inertial and thermal sensing.

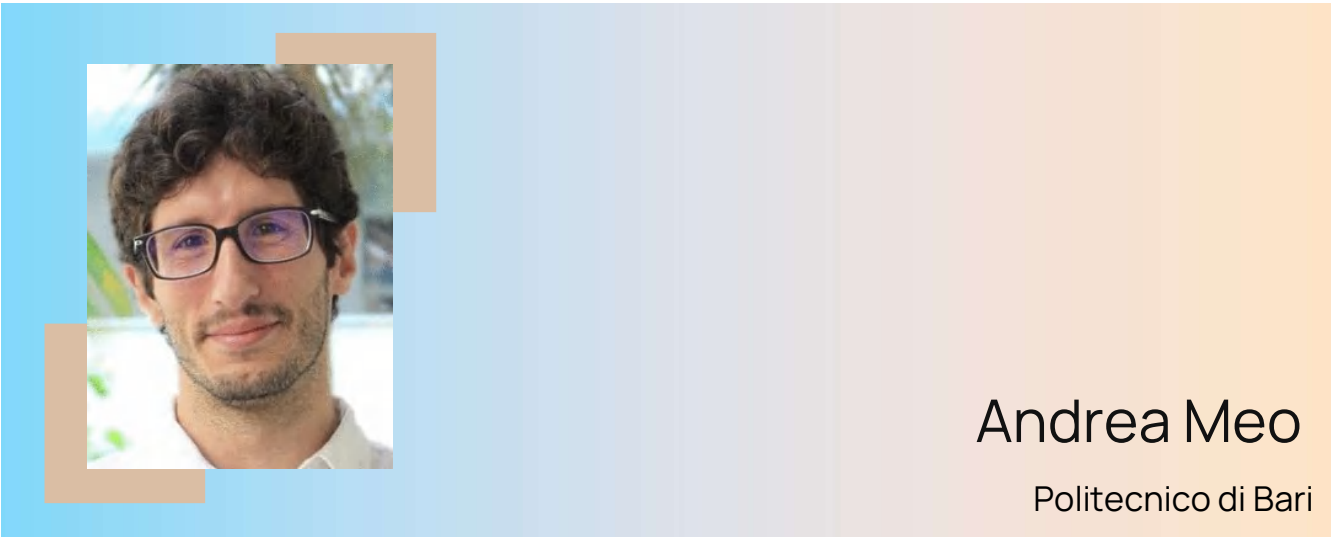
For inertial sensing, magneto-mechanical coupling is used to integrate MTJs operating as spin-torque diodes with mechanically compliant structures. In the proposed accelerometer, an external acceleration displaces the substrate and changes the stray-field coupling between MTJs, thereby modulating the rectified voltage [1,2]. The same principle is extended to a gyroscope: a driven oscillation under rotation produces a Coriolis displacement in the orthogonal sense direction, and the resulting voltage variation provides a direct measure of angular velocity. These architectures retain mature microelectromechanical technology while augmenting or replacing capacitive readout with a fast magnetic response, offering routes towards compact, low-power and radiation-hard devices.

For nanoscale thermal sensing, we consider an MTJ whose free layer hosts a magnetic skyrmion. The amplitude and frequency of the skyrmion resonance vary with temperature, while the spin-torque-diode response provides a direct electrical output. Analytical calculations and micromagnetic simulations predict an approximately linear variation of both the maximum rectified voltage and the resonance frequency over a broad temperature range. These two observables enable redundant readout and improve measurement reliability[3].

Together, these concepts show how it is possible to exploit MTJS to develop integrated sensor platforms spanning acceleration, angular velocity and temperature. They provide a promising basis for next-generation sensing in miniaturized, harsh-environment and nanoelectronic applications.

Acknowledgements This work was partially supported by the project PRIN_20225YF2S4 – Magneto-Mechanical Accelerometers, Gyroscopes and Computing based on nanoscale magnetic tunnel junctions (MMAGYC), and by the Contract n. 2025-40-I.0 (SPINAM) funded by the Italian Space Agency within the call “Studi di concetti innovativi di sistemi spaziali”.

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Andrea Meo

Politecnico di Bari

Biography

Dr Andrea Meo is an Assistant Professor in the Department of Electrical and Information Engineering at the Politecnico di Bari, in Bari, Italy. Andrea began his career with the PhD at the University of York in the group led by Prof. Roy Chantrell and Prof. Richard Evans, where he characterized magnetic tunnel junctions for memory applications at the atomistic level. He then moved to Mahasarakham, Thailand, in the group led by Prof. Phanwadee Chureemart and Jessada Chureemart to work on the development of Heat Assisted Magnetic Recording technology in collaboration with Seagate Technology. Andrea moved, after a brief parenthesis in York, to the Politecnico di Bari, Italy, where he joined the Petaspin research group led by Prof. Mario Carpentieri and Prof. Giovanni Finocchio. His work focuses mainly on the study of magnetism and spintronics from fundamentals, such as the characterization of antiferromagnets, to applications, including memories, sensors and hardware-based security primitives.





Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Friday, 11th September		
8:00 - 9:00	Registration	
	ROOM A	ROOM B
	Session chair: Andrea Meo	Session chair: Simone Finizio
9:15 - 9:30	Dmitry Berkov - "Single-stage direct Langevin dynamics simulations of transitions over arbitrarily high energy barriers: optimal solution of the Kramers problem"	Alessandro Cataldo - "Exploring the full magneto-ionic oxidation spectrum in Pt/CoFeB/HfO2"
9:30 - 9:45	Elia Strambini - " Unveiling Helical Magnetism in Al/NiBr2 thin films via the Supercurrent Diode EffectX "	Gaspere Varvaro - "Rolled spin valves with perpendicular magnetic anisotropy"
9.45 - 10:00	Rüdiger Klingeler - "Uniaxial strain effects on the skyrmion lattice phases and phase diagrams in centrosymmetric Gd2PdSi3 and GdRu2Si2"	Emma Van Meirvenne - "Strain transfer mechanisms and voltage generation in scaled composite magnetoelectric devices"
10:00 -10:15	Nikhil Vijayan - "All-electrical detection of individual skyrmion motion in ferromagnetic multilayers via the anomalous Hall effect"	Piotr Mazalski - "The magnetic and electric properties of interlayer coupled cobalt layers induced by Ir/Pt spacer"
10:15 - 10:30	Maddalena Fiorentino - "Compositional optimization of CoTbGd ferrimagnetic films for skyrmion stabilization"	Alexander Chizhik - "Nanoscale coating induced control of magnetic states in amorphous magnetic microwires"
10:30 - 11:00	Coffee Break	
ROOM A	Session chair: Stephan Mangin	
11:00 -11:30	Can Avci , Institut de Ciència de Materials de Barcelona - "Rare-Earth Iron Garnets as a Platform for Emerging Spintronic Functionalities"	
11:30 - 12:00	Giovanni Finocchio , University of Messina - "New directions in probabilistic computing with extended probabilistic variables"	
12:00 - 12:30	Daoqian Zhu , Beihang University, China - "Spin-torque manipulation of antiferromagnets in magnetic tunnel junctions"	
12:30 - 13:00	Award and Closing	

Rare-earth iron garnets as a platform for emerging spintronic functionalities

Can Onur Avci

Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Carrer dels Til·lers s/n,
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Spintronics has matured into a vibrant, interdisciplinary field at the intersection of condensed matter physics, materials science, and nanotechnology. Advances in our understanding of spin transport and magnetic interactions, combined with the discovery of novel materials and experimental techniques, have driven remarkable progress. Central to spintronics research is the ability to control and detect magnetization using electrical currents, enabling efficient, nonvolatile memory, logic, and signal transmission devices. Such technologies promise not only to enhance existing CMOS architectures but also to facilitate beyond-CMOS concepts that may lead to transformative shifts in microelectronics [1]. While conventional spintronic devices primarily rely on metallic and semiconducting materials, magnetic insulators, particularly rare-earth iron garnets (REIGs), have recently emerged as promising alternatives due to their unique and highly tunable properties and efficient manipulation of their magnetization [2,3,4].

In this talk, I will discuss how rare-earth iron garnets can serve as a versatile platform for engineering emergent spintronic functionalities through both bulk and interfacial design. First, I will show how Al substitution enables systematic tuning of the magnetic properties of perpendicular-anisotropy REIG films, providing continuous control over saturation magnetization, magnetic anisotropy, and compensation temperature [5]. This compositional engineering further gives rise to an intrinsic giant exchange bias effect with both deterministic and stochastic characteristics [5], as well as unconventional magnetotransport phenomena originating from Zeeman-exchange frustration in systems with spatially inhomogeneous compensation [6]. In the second part, I will demonstrate how interfaces between REIGs and metallic ferromagnets provide an additional avenue for creating novel magnetic states and functionalities. Direct exchange coupling to a perpendicular REIG can cant an otherwise in-plane magnetized Co layer out of the film plane, enabling enhanced magnetoresistive readout of the insulating magnetization [7]. Furthermore, the interfacial coupling acquires a chiral character through strong interlayer Dzyaloshinskii-Moriya interaction, opening an alternative route for current-driven magnetization control mediated by Joule-heating-induced modification of the exchange interaction [8]. These examples illustrate how the rich interplay between ferrimagnetic order, magnetic compensation, and interfacial exchange interactions in REIG-based heterostructures can be harnessed to realize new spintronic functionalities.

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Biography

Dr. Can Onur Avci is a Group Leader at the Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Spain, where he leads research on spintronics, magnetism, and magnetic materials. His work focuses on spin-orbit phenomena, electrical control of magnetization, magnetic insulators, and energy-efficient spintronic devices. Prior to joining ICMAB, he held research positions at ETH Zürich and the Massachusetts Institute of Technology. He has authored more than 55 peer-reviewed publications, holds a U.S. patent, and has delivered over 50 invited talks. He is the recipient of the IUPAP Early Career Scientist Prize in Magnetism and an ETH Medal for his doctoral thesis, and currently leads the ERC Starting Grant project MAGNEPIC, which explores magnetic insulators as a platform for next-generation spintronic concepts.



New directions in probabilistic computing with extended probabilistic variables

Giovanni Finocchio

University of Messina, Messina, Italy

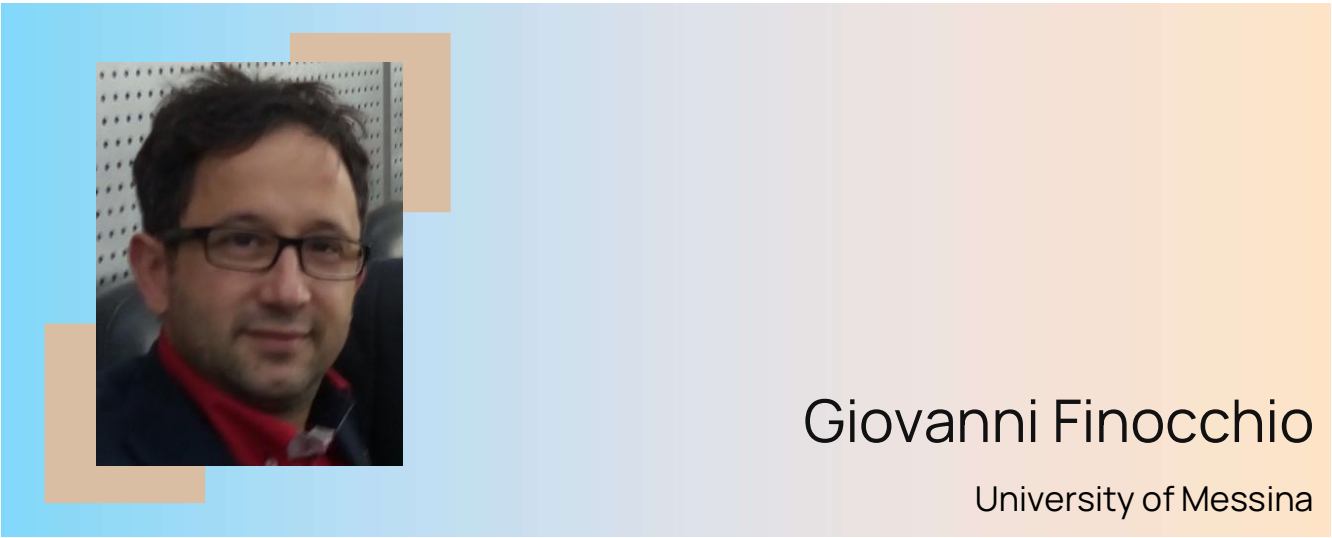
In this talk, I will focus on probabilistic computing which is one direction to implement Ising Machines. Probabilistic computing is a computational paradigm using probabilistic bits (p-bits), unit in the middle between standard bit and q-bits. As a first point, I will show how to solve hard combinatorial optimization problems (Max-Sat, Max-Cut, etc) with Ising machine and how to implement those in spintronic technology. I will present new direction in this field considering the concept of extended probabilistic variable such as p-dit and p-int with a particular focus on future 6G wireless networks where it is expected to rely on extremely large-scale multiple-input multiple-output (XL-MIMO) architectures to achieve unprecedented spectral efficiency and spatial multiplexing. However, signal detection in XL-MIMO systems constitutes a high-dimensional optimization problem whose computational complexity rapidly increases with the number of antennas and modulation order. In the last part of this talk I will investigate physics-inspired probabilistic computing as an unconventional hardware-aware approach to near-optimal MIMO detection[1]. Specifically, we map the detection problem onto Ising-like optimization frameworks and employ probabilistic Ising machines (PIMs) and oscillator-based Ising machines to perform maximum-likelihood inference for binary modulation schemes. The proposed approach achieves optimal detection performance for systems containing up to 2048×2048 antennas using only 100 update iterations, matching sphere-decoder accuracy in tractable regimes while significantly outperforming the conventional minimum mean-square error (MMSE) detector.

To address higher-order modulation formats, we introduce a generalized probabilistic-computing framework based on multi-state stochastic variables, or *p-dits*, [2] that directly encode M-QAM symbols without requiring binary decomposition. This formulation enables efficient detection for modulation orders up to 256-QAM and antenna arrays as large as 256×256 while maintaining low bit-error rates and reduced algorithmic complexity. Our results demonstrate that probabilistic computing provides a powerful and scalable paradigm for solving large-scale communication inference problems. Beyond establishing a direct connection between spin-based optimization dynamics and wireless signal processing, this work highlights the potential of Ising-inspired hardware accelerators and probabilistic devices as energy-efficient computing engines for next-generation 6G communication systems.

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This work was supported under the project number 101070287 — SWAN-on-chip — HORIZON-CL4-2021-DIGITAL-EMERGING-01 and by the PETASPIN association (www.petaspin.com).



Biography

Giovanni Finocchio received the Ph.D. degree in advanced technologies in optoelectronic, photonic and electromagnetic modeling from the University of Messina, Italy, in 2005. He is full professor at the Department of Mathematical and Computer Sciences, Physical Sciences and Earth Sciences of the University of Messina and director of the PETASPIN laboratory (Petascale computing and Spintronics). His research interests include spintronics, skyrmions, and unconventional computing (<https://scholar.google.co.uk/citations?user=eKDbn-oAAAAJ&hl=en>). In the last 10 years, he was involved with leading role in more than 10 research projects, served on many technical program committees of international conferences and organized more than 10 international conferences and workshops as Chair, Program Committee Member, or in other positions including program chair of the IEEE NANO 2024 and program co-chair of the 2025 joint Intermag-MMM conference. He is regularly invited at well-established conferences in Magnetism and Spintronics and he was the organizer of the first international conference on Ising Machines. He is also past AdCOM member of the IEEE Magnetics Society (2019-2024), chair of the TC-16 on Quantum, neuromorphic and unconventional computing of the IEEE Nanotechnology Council (NTC), past-chair of the IEEE Magnetics Italy Chapter (2019-2022) and Distinguish Lecturer of the NTC for 2026 and 2027. Since 2022, he is also associate editor of Physical Review Applied (APS).



Spin-torque manipulation of antiferromagnets in magnetic tunnel junctions

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Antiferromagnets (AFMs) offer compelling advantages for next-generation magnetic random-access memory (MRAM), including negligible stray fields and ultrafast spin dynamics in the terahertz regime [1,2]. However, their vanishingly small net magnetic moments pose substantial challenges for the electrical manipulation and readout of the antiferromagnetic order. To address this issue, we employ a hybrid AFM/FM free-layer structure, where the AFM state is imprinted onto the ferromagnetic (FM) layer via the exchange bias (EB) effect. This imprinting enables electrical detection of the AFM state using CoFeB/MgO-based magnetic tunnel junctions (MTJs). Furthermore, we show that the hybrid AFM/FM state can be electrically manipulated through spin torques, thereby achieving data writing functionality. Building on these principles, we have developed a new type of magnetic memory, which is termed as EB-MRAM [3-5].

In this talk, we will discuss the performance and future prospects of the EB-MRAM scheme. Over the past five years, we have successfully demonstrated all-electric, sub-nanosecond switching of EB-MRAM devices via spin-orbit torque (SOT) and spin-transfer torque. Benefiting from the incorporation of antiferromagnetic materials, these devices exhibit a field immunity exceeding 2 T [3-5]. Notably, recent demonstrations include a 128-kb EB-MRAM array [6] and multi-level data storage in nanoscale devices [7], underscoring the viability of this scheme. Nevertheless, the critical switching current density, which currently reaches around 300 MA·cm⁻², remains a substantial challenge relative to conventional SOT-MRAM schemes. To address this issue, we have recently developed orbital-torque MRAM [8], which achieves a five- to eight-fold reduction in switching voltage compared with β -W-based SOT-MRAM. Finally, we will discuss ongoing efforts and further optimization strategies for this emerging technology.

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Daoqian Zhu
Beihang University

Biography

Daoqian Zhu received his Ph.D. in Microelectronics from Beihang University in 2022. He joined Beihang as a postdoctoral researcher in 2022 and is currently an Associate Professor at the School of Integrated Circuit Science and Engineering, Beihang University. His research interests include spinorbit torque, antiferromagnetic materials and magnetic memory.



Single-stage direct Langevin dynamics simulations of transitions over arbitrarily high energy barriers: optimal solution of the Kramers problem

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The evaluation of thermally activated escape rates over high energy barriers – the celebrated Kramers problem [1] – is a cornerstone task in magnetism, chemistry, biology and information storage. The classical analytical treatments by Brown, Klik–Günther and Mel’nikov–Meshkov [2] are restricted to systems with very few degrees of freedom, and no closed-form solution is available for strongly interacting many-particle systems or spatially inhomogeneous micromagnetic configurations. Hence general numerical methods are indispensable. Direct Langevin dynamics (LD) – the most rigorous of these – becomes impracticable already for moderate barriers ($\Delta E/k_B T \geq 10$), since switching times grow exponentially with ΔE .

All state-of-the-art alternatives – forward flux sampling (FFS), string method, metadynamics and the “energy bounce” algorithm – circumvent this obstacle through a multi-stage “climbing” procedure across a sequence of interfaces. Two intrinsic drawbacks follow: (i) their computational cost grows at least linearly with the barrier height, because finer interface spacing is required for larger ΔE ; (ii) the final escape rate is the product of many conditional transition probabilities, so that even minute statistical or systematic errors accumulate catastrophically – a 2% bias on each of 50 interfaces already inflates the final result by nearly 300%.

In this work [3] we present a unique algorithm which delivers, to the best of our knowledge, the optimal numerical solution of the Kramers problem: the first genuine *single-stage* direct LD scheme capable of treating arbitrarily high barriers. The key idea is a novel concept of an energy-dependent temperature $T(E)$ entering the stochastic equation of motion: the effective temperature is chosen high in the vicinity of the energy minima and smoothly decreases to the physical room temperature at the saddle point. This prescription removes the exponential trapping near the minima without distorting the dynamics where it matters most – in the neighborhood of the barrier top. A rigorous Markov-chain formalism then allows to recover the true constant-temperature switching time τ_{sw} from the drastically accelerated EDT trajectory.

The algorithm has been benchmarked on the biaxial magnetic macrospin – the archetypal two-well system. EDT-LD switching times agree with the established FFS results within statistical error across more than 20 orders of magnitude, in the full tested range $10 \leq \Delta E/k_B T \leq 60$. Decisively, and in sharp contrast to every multi-stage method, the EDT simulation time does *not* grow with ΔE ; for $\Delta E = 60 k_B T$ we obtain a speedup of more than 40× over our already highly optimized FFS version with energy-equispaced interfaces, while being entirely immune to the error-propagation problem inherent to climbing methods. Since the method requires only the height of the energy barrier (obtainable e.g. by NEB) and standard LD, it generalizes without modification to strongly interacting many-particle systems and full-scale micromagnetics, thereby constituting the most optimal single-stage numerical solution of the Kramers problem available to date.

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Exploring the full magneto-ionic oxidation spectrum in Pt/CoFeB/HfO₂

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Voltage-controlled magnetic anisotropy via ion migration (i.e. magneto-ionics) has become a compelling strategy for non-volatile and energy-efficient control of magnetic properties [1-2]. While most studies have focused on tuning a limited portion of the oxidation landscape, the ability to exploit the entire oxidation spectrum remains underexplored. This work addresses this challenge by investigating a Pt/Co₆₀Fe₂₀B₂₀/HfO₂ heterostructure gated by ionic liquid [3]. Using voltage driven oxygen ion migration, we access and control three distinct magnetic states: under-oxidized IPA, PMA, and over-oxidized IPA.

Magnetic characterization via anomalous Hall effect reveals that a gate voltage of -2.3 V applied for 300 s drives the system from IPA to PMA state. A subsequent voltage of -2.4 V for 360 s results in an over-oxidized IPA state. X-ray photoelectron spectroscopy complemented by synchrotron-based X-ray absorption spectroscopy at the Co and Fe edges shows a reduction in the metallic Co and Fe components by ~ 30% and ~ 50%, respectively, confirming voltage-driven oxidation (Fig. 1).

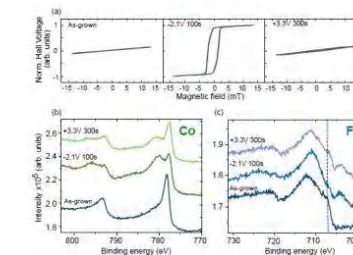


Figure 1: Hysteresis loops (panel a) for the as-grown and voltage application. XPS spectra of Co (panel b) and Fe (panel c) for samples as-grown and after gating.

The full IPA → PMA → IPA cycle is repeatable over at least 10 voltage cycles, proving a robust reversibility. Such results show accessible intermediate oxidative states between IPA and PMA transitions and push the capabilities of magneto-ionic devices for multi-state memories.

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Unveiling Helical Magnetism in Al/NiBr₂ thin films via the Supercurrent Diode Effect

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The interplay between non-collinear magnetic textures and superconducting order parameters provides a fertile ground for exploring exotic transport phenomena and advancing superconducting spintronics¹. While uniform ferromagnetic insulators, such as EuS, in proximity with conventional superconductors (e.g., Al) have been widely investigated for quasiparticle spin-filtering and thermoelectric applications²⁻⁵, Van der Waals antiferromagnets exhibiting complex non-collinear spin textures, such as NiBr₂, offer new routes for engineering functional magnetic interfaces.

In this work, we demonstrate that the non-collinear helical magnetic order of NiBr₂ thin films directly manifests through an asymmetric transport of Cooper pairs known as the supercurrent diode effect (SDE) when coupled to a thin aluminum layer. By utilizing the helical superconducting condensate as a sensitive phase-probe, we resolve the underlying vectorial symmetry of the interfacial magnetic order as a function of an in-plane magnetic field. At high magnetic fields, where the magnetic structure is forced into a quasi-canted state, the SDE obeys conventional magnetochiral symmetries, exhibiting maximum rectification for magnetic fields orthogonal to the current direction. Crucially, at low fields, the symmetry relations become richer, directly revealing the signature of the non-trivial non-collinear helical and conical spin configurations at the NiBr₂ surface⁶.

Micromagnetic and theoretical simulations of the NiBr₂ spin texture under applied magnetic fields corroborate our transport measurements, confirming that the directional asymmetry of the supercurrent directly tracks the evolution of the helical magnetic phase. Our findings highlight Van der Waals non-collinear magnets as a versatile platform for probing complex magnetic textures via quantum transport, laying the groundwork for unusual helical superconductivity and next-generation spintronic interfaces based on low-dimensional magnetic materials.

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⁵ C.I.L. de Araujo, et al, Nat Commun **15**(1), 4823 (2024).

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Rolled spin valves with perpendicular magnetic anisotropy

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Spin valves (SVs) with perpendicular magnetic anisotropy (PMA) are key components of spintronic devices. While planar systems have been extensively investigated, translating them into 3D architectures remains largely unexplored and offers new opportunities for both fundamental studies and advanced device concepts [1].

Here we report the first observation of magnetoresistance in rolled spin-valves microtubes with perpendicular anisotropy (PMA). Co/Ni-based synthetic antiferromagnetic spin-valves [2] are fabricated from a thin-film deposited on a sacrificial PMMA resist. Ultrasonic agitation during resist dissolution fragments the film into flakes that subsequently self-roll into microtubes (80- 100 μm long, 10 μm in diameter). Individual rolls are electrically contacted via Ti/Au edge pads for magnetoresistive (MR) measurements, while VSM and micromagnetic simulations probe how the rolled geometry affects the local magnetization and the resulting MR vs field. Planar reference films display the characteristic out of plane three-step switching behaviour, together with a step-like MR increase associated with the reversal of the free layer. Powder of rolled microtubes exhibits the same switching in all directions, meaning PMA-SV properties are now isotropically distributed. The MR is preserved in individual rolled structures, showing angular dependence on the orientation of the applied magnetic field. Sharp transitions in the MR are present when the field is applied radially to the tube (consistently with a locally preserved PMA), while with longitudinal fields (parallel to the roll axis), the MR is consistent with a hard-axis response. One-dimensional micromagnetic calculations with graded-radius profiles reproduce the key experimental trends such as the hysteresis and the MR loop shapes. The result highlights the dominant role of the Zeeman interaction: although the applied field is constant in the laboratory frame, the curvature of the roll causes the angle between the field and the local PMA axis to vary continuously along the structure. Simulations with external field applied in-plane, out-of-plane and with 45° tilting angle have been performed to assess the effect of possible asymmetries due to the rolled geometry. The validated model provides a powerful tool for designing rolled spintronic devices for applications in multidirectional sensing and novel architectures.

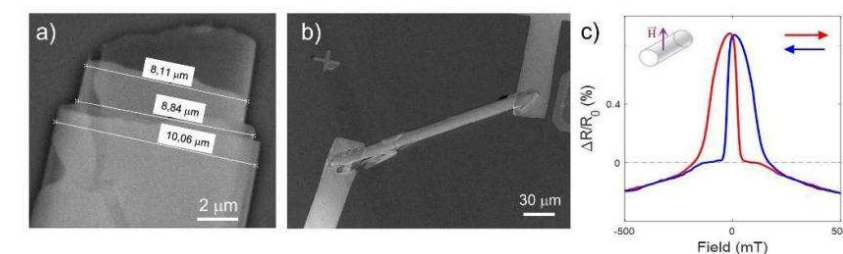


Figure: (a) SEM image of a rolled spin-valve termination, showing the multiple folding. (b) roll endowed with electrical contacts. (c) MR curve versus radial magnetic field

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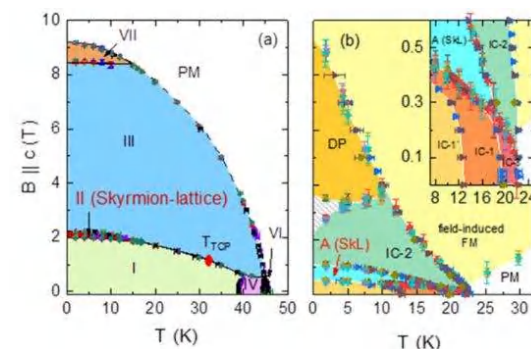
Uniaxial strain effects on the skyrmion lattice phases and phase diagrams in centrosymmetric Gd₂PdSi₃ and GdRu₂Si₂

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High-resolution capacitance dilatometry studies are a versatile tool to study the phase diagrams and to elucidate uniaxial pressure effects in complex magnetic systems. We have investigated high-quality single crystals of centrosymmetric magnetic skyrmion-hosting GdRu₂Si₂ and Gd₂PdSi₃. We establish the magnetic phase diagrams and find unreported magnetic phases, investigate magneto-elastic coupling and quantify the uniaxial pressure effects on the phase boundaries, with a particular focus on the skyrmion-lattices phases.

In Gd₂PdSi₃, pronounced anomalies associated with antiferromagnetic order imply significant magnetelastic coupling. Grüneisen analysis shows the onset of magnetic contributions around 60 K, i.e., well above T_N . Uniaxial pressure dependencies of the various phase boundaries are extracted. In particular we show that the skyrmion lattice phase is strongly enhanced by uniaxial pressure as it widens at a rate of $d(\Delta T)/dp_c \sim 6$ K/GPa. Widening of a skyrmion phase under uniaxial pressure is also observed in GdRu₂Si₂ where it increases with 0.07 T/GPa for $p \parallel c$ axis. Further findings are the observation of a third antiferromagnetic phase in zero magnetic field and additional unreported phases in the magnetic phase diagram. The relevance of fluctuations is highlighted by the presence of a tricritical point at the phase boundary separating two double-Q magnetic configurations between which the skyrmion pocket phase evolves upon further cooling.



Magnetic phase diagram for GdRu₂Si₂ (left) and Gd₂PdSi₃ (right) of for $B \parallel c$ (for $B \perp c$ and description of the phases see the references). SkL are the skyrmion-lattice phases, T_{TCP} a tricritical point [1,2].

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Strain transfer mechanisms and voltage generation in scaled composite magnetoelectric devices

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Composite magnetoelectric devices have attracted considerable interest due to their ability to exhibit strong magnetoelectric coupling at room temperature. In the direct magnetoelectric effect, an applied magnetic field induces an electric polarization in the piezoelectric layer. For microelectronic applications, sufficiently large magnetoelectric coupling is required to generate usable open-circuit voltages. Because the coupling is strain-mediated, efficient strain transfer from the magnetostrictive to the piezoelectric layer is critical. In rigidly supported devices, however, substrate clamping can significantly suppress in-plane strain transmission. Device miniaturization has been proposed as a potential strategy to mitigate this surface clamping effect, yet its impact remains insufficiently explored.

In this work, we systematically investigate the strain transfer mechanisms and differential voltage generation in magnetoelectric composite devices. Using calibrated finite-element models in COMSOL Multiphysics® [1,2], we explore how device geometry and material

selection govern strain-mediated coupling at reduced dimensions. Our results demonstrate that downscaling the pillar diameter significantly enhances strain transfer and enables large differential voltages, as surface-clamping effects are progressively mitigated (see Fig.1). By analyzing devices with different geometries and magnetostrictive materials, we identify two distinct strain-transfer mechanisms whose relative contributions are determined by the device aspect ratio and magnetic state. At the nanoscale, these mechanisms may either reinforce or counteract each other, highlighting the importance of careful structural design to suppress bending and maximize effective strain transfer. In addition to geometrical optimization, material selection is critical, as magnetostrictive materials with strong magnetoelastic coupling and favourable elastic properties, such as a high Poisson ratio, significantly enhance voltage generation upon scaling

Overall, this study establishes clear design guidelines for scaled magnetoelectric devices and

demonstrates that differential voltages exceeding 200 mV can be achieved at sub-100-nm dimensions. These results highlight the strong potential of nanoscale magnetoelectric composites for integration into future microelectronic and low-power functional devices.

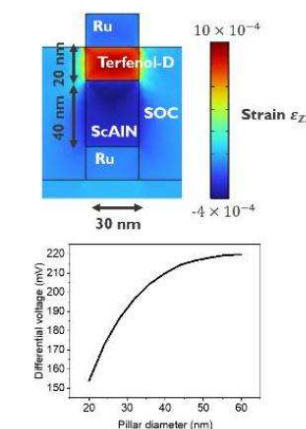


Figure 1: Top: The distribution of the normal strain component ϵ_{zz} of the ME-induced strain in a clamped scaled device. Bottom: Corresponding output differential voltage in ME devices based on Terfenol-D/ScAlN for different pillar diameters.

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All-electrical detection of individual skyrmion motion in ferromagnetic multilayers via the anomalous Hall effect

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While optical characterization of magnetic skyrmions is well-established¹, an all-electrical approach for nucleating and detecting skyrmions is highly desirable for practical applications and on-chip integration. Electrical detection via the anomalous Hall effect (AHE) is sensitive to the integrated local magnetization, making it applicable across a wide range of skyrmion sizes.

Here, we demonstrate fully electrical nucleation and detection of individual skyrmions in a Ta/CoFeB/MgO ferromagnetic multilayer using a microfabricated Hall bar (Fig. 1(a)). We perform a comprehensive analysis with a simplified readout system, systematically mapping the operating regime as a function of out-of-plane DC and AC magnetic fields (B_Z^{DC} , B_Z^{AC}), and temperature.

Within the stability window, skyrmion size and velocity are extracted as a function of these parameters, showing good agreement with theoretical expectations^{2,3}. The smallest stable skyrmions, with a diameter of approximately 500 nm, are resolved with SNR ~ 70 .

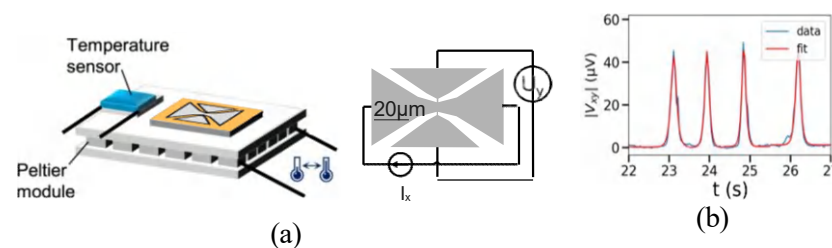


Figure 1: (a) Schematic of the Peltier module and temperature sensor used to maintain a stable temperature, and the Hall cross used for electrical measurements. (b) Skyrmion peaks and model fit² gives $R = 992 \pm 32$ nm, and $v = 53.68 \pm 7.53$ $\mu m/s$.

Our results demonstrate that AHE-based electrical detection is a simple yet quantitative tool for characterizing individual skyrmion stability and dynamics without any optical infrastructure, with potential applications in skyrmion-based rotation sensors⁴.

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The magnetic and electric properties of interlayer coupled cobalt layers induced by Ir/Pt spacer

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The ultrathin ferromagnetic films sandwiching between asymmetric heavy metal layers (like W, Pt, Ir, etc.) are interesting to study due to strong spin-orbit coupling and large interfacial Dzyaloshinskii-Moriya interaction (DMI) [1, 2]. Changing magnetic and/or heavy metal layer thicknesses allow to manipulate the magnetic and electric properties together with magnetic domain structure including possibility to create bubble/skyrmions structures [1, 3]. Current induced magnetization switching via spin-orbit torque provides an energy-efficient and fast method for magnetization control in the ferromagnetic layers required for potential applications in the spintronic devices like random access memories, high-frequency nano-oscillators, or bioinspired neuromorphic computations [4]. In the case of antiferromagnetically coupled layers the skyrmions propagate with high speed and negligible spin Hall angle [5].

In this work, we have investigated the magnetic and electrical properties of single Pt/Co(d_{Co} wedge)/Ir and double Pt/Co(d_{Co} wedge)/Ir(d_{Ir})/Pt(d_{Pt})/Co(d_{Co} wedge)/Ir multilayer structures varying the d_{Co} , d_{Pt} , d_{Ir} thicknesses. All layers were deposited by magnetron DC sputtering on Si substrates [6]; for electrical measurements part of the samples were lithographically patterned into micrometer-sized Hall-bar devices. Polar magneto-optical Kerr effect based magnetometry allow us to study the magnetic and magneto-optical properties of the samples. For all the samples one can distinguish two critical thicknesses corresponding to: superparamagnetic/ferromagnetic transition and out-of-plane/in-plane spin reorientation. The thickness of Ir/Pt spacer between two cobalt layers influences on the value of magneto-optical response and changes their magnetic properties (coercivity, magnetic anisotropy). Interestingly, even for the highest used spacer thickness ($d_{Ir} = d_{Pt} = 3$ nm) the Co layers remain ferromagnetically coupled. The nonreciprocity in spin-wave dispersion using Brillouin light scattering allow to show the increase of H_{DMI} field in Co bilayer with thinner spacers. The switching of magnetic domain structure was occurred simultaneously in both bilayers sample.

To study electrical properties and characterize the spin-orbit torque (SOT) and spin Hall angle we performed the harmonic Hall measurements [7]. As a result, SOT effective fields of damping-like (H_{DL}) and field-like (H_{FL}) components were obtained – the differences between effective fields for double Pt/Co/Ir layers and single Pt/Co/Ir were observed. H_{FL} is several times smaller than H_{DL} for almost all d_{Co} range. For the highest spacer thickness H_{DL} and H_{FL} decrease with increasing d_{Co} . Furthermore, using Hall based technique proposed by Zhou [8] we evaluate DMI field dependences for cobalt with perpendicular magnetic anisotropy – the maximal estimated value was hundreds of Oe.

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Compositional optimization of CoTbGd ferrimagnetic films for skyrmion stabilization

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Alloys of transition metals (TM), such as Co, and rare-earth (RE) elements, such as Tb and Gd, have attracted significant interest in spintronics and magnetism due to their ferrimagnetic properties [1]. Ferrimagnetic materials are promising hosts for skyrmion-based devices as they exhibit faster current-driven motion and strongly suppressed skyrmion Hall effect compared to ferromagnets [2]. Unlike antiferromagnet materials, ferrimagnets remain responsive to external magnetic fields. When Tb is alloyed with Co, it induces strong perpendicular magnetic anisotropy (PMA). Incorporating Gd in the alloy, it introduces a new degree of freedom for tuning both the anisotropy and the saturation magnetization, enabling precise engineering of the film properties required to host topological spin textures. Here, we investigate amorphous $\text{Co}(\text{Tb}_x\text{Gd}_{1-x})_{1-y}$ films by systematically varying the total RE concentration and the Tb-Gd ratio to tune the magnetic anisotropy and Dzialoshinskii-Moriya interaction (DMI). Additionally, we investigate the interfacial effects from different seed/capping layers and annealing effects. Vibration Sample Magnetometry (VSM) and Magnetic Force Microscopy (MFM) are used to provide a comprehensive understanding of the material platform.

The alloys were grown on AlZr seed layer with a 1 nm Ta dusting layer and a Ta capping layer, as shown in Figure 1a, which minimized intermixing and interfacial effects. The magnetic compensation point of the CoTb alloy was identified at a Tb concentration of 21% and for all composition, VSM and MFM measurements revealed large magnetic domains, including bubble domains (>100 nm), consistent with strong PMA and a relatively weak DMI.

To reduce the PMA, Gd was systematically introduced into the system, substituting Tb while maintaining the overall TM:RE ratio. As shown in Figure 1b, films with a higher Co concentration (87%) maintain strong PMA, despite the high ratio of Gd to Tb, still yielding large domain structures that prevent the stabilization of skyrmions under an applied magnetic field. In contrast, reducing the Co concentration to 66%, with a lower Gd ratio, significantly decreases the characteristic domain size to ~20 nm, enabling magnetic skyrmions to stabilize under an applied magnetic field (Figure 1c). This transition highlights a crucial reduction in PMA, allowing the DMI to play a more dominant role in stabilizing skyrmions, demonstrating the effectiveness of Gd substitution in tailoring spin configurations. These results demonstrate that fine-tuning the Tb/Gd ratio and total rare-earth concentration provides precise control over the balance between PMA and DMI. This compositional engineering strategy establishes Co-Tb-Gd ferrimagnetic alloys as highly versatile platform for stabilizing and manipulating nanoscale magnetic skyrmions in next-generation spintronic devices.

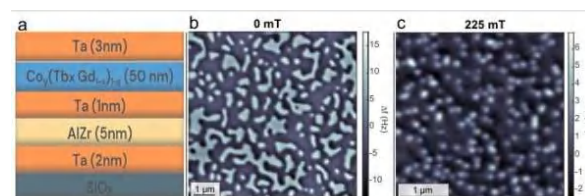


Figure 1: (a) Schematic of the deposited sample stack. (b) MFM data of $\text{Co}_{87}(\text{Tb}_{35}\text{Gd}_{45})_{13}$ at 0 mT showing domains. (c) MFM data of $\text{Co}_{66}(\text{Tb}_{55}\text{Gd}_{45})_{34}$ at 225 mT showing skyrmions.

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Nanoscale coating induced control of magnetic states in amorphous magnetic microwires

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The influence of both magnetic and non-magnetic coatings on the magnetic behavior of glass-coated amorphous microwires is investigated (Fig. 1). Non-magnetic tungsten layers with thicknesses between 300 and 1000 nm were deposited onto glass-coated Co-rich microwires, and their effect on magnetization reversal, magnetic bistability, and domain wall formation was analyzed [1]. Hysteresis measurements reveal a clear distinction between

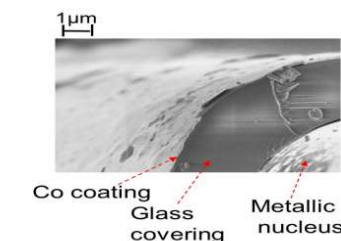


Figure 1: SEM image of Co-coated sample.

coated and uncoated regions: uncoated segments exhibit smooth, non-bistable magnetization reversal, whereas tungsten-coated regions demonstrate pronounced magnetic bistability induced by stress-mediated magnetoelastic anisotropy. In parallel, magnetic cobalt coatings deposited on glass-coated Fe-rich microwires were studied to evaluate their influence on domain wall mobility and magnetization dynamics using fluxmetric and Sixtus-Tonks measurements. Magnetic Co coatings directly modify domain wall propagation through magnetostatic interaction, where stray fields generated by the coating superimpose with the external magnetic field and produce a smooth, field-dependent acceleration of domain wall motion. The observed effects strongly depend on coating thickness and geometry, demonstrating that both magnetic and non-magnetic coatings provide effective routes for controlling magnetization reversal and domain wall dynamics in microwire-based magnetic devices.

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Zhukova, J. M. Blanco, A. Zhukov, Sens. Actuators A Phys. 397 (2026), 117259.



Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Monday, 7th September - POSTER SESSION A	
ROOM C	Session chair
14:00 - 16:00	Opening
Poster Code	Presenting Author - Poster Title
M01	Antonio Angotti - Politecnico di Milano, Italy - <i>"MEMS-magnonic devices for reconfigurable spin-wave interference and inverse design"</i>
M02	Mohamed Belmeguenai - LSPM, Université Sorbonne Paris Nord, France - <i>"Temperature and buffer layer dependences of magnetic properties of Fe/MgO-based systems"</i>
M03	Dmitry Berkov - General Numerics Research Lab e.V., Germany - <i>"Local energy minima and density of energy barriers in dense clusters of magnetic nanoparticles"</i>
M04	Dmitry Berkov - General Numerics Research Lab e.V., Germany - <i>"Single-stage direct Langevin dynamics simulations of transitions over arbitrarily high energy barriers: optimal solution of the Kramers problem"</i>
M05	Anna Giordano - University of Messina, Italy - <i>"A GPU-accelerated solver for polarization dynamics in ferroelectrics materials"</i>
M06	Pietro Milanese - Politecnico di Milan, Italy - <i>"Ultrathin CoO films and their interfaces for spintronics and molecular spintronics applications"</i>
M07	Hassan Chamati - Bulgarian Academy of Sciences, Bulgaria - <i>"Phase Constraints of electron orbitals in molecular magnets"</i>
M08	Dominik Czernia - Jagiellonian University, Poland - <i>"Magnetic cooling in a frustrated triangular-lattice Co(II) coordination compound"</i>
M09	Mathew Davies - Loughborough University, United Kingdom - <i>"Microscopic magnetic modelling of manganese-based olivines Mn2AX4"</i>
M10	Giulio Maria Fumagalli - Politecnico di Milano, Italy - <i>"Tunable directional coupling in vertically stacked magnonic waveguides"</i>
M11	Rafikul Hussain - University of Zagreb, Croatia - <i>"Crystal structure and magnetic properties of (R-DAP)₂[CuCl₆], (S-DAP)₂[CuCl₆], and (rac-DAP)₄[CuCl₆]"</i>
M12	Yurii Ivonyak - IHPP Polish Academy of Sciences, Poland - <i>"Terahertz optical anisotropy of the altermagnet α-MnTe"</i>
M13	Ewa Jedryka - Polish Academy of Sciences, Poland - <i>"Field-induced spin reorientation in magnetic topological insulator MnBi₂Te₄ - ⁵⁵Mn and ²⁰⁹Bi NMR study"</i>
M14	Ikuzo Kanazawa - Tokyo Gakugei University, Japan - <i>"Chiral-like spin glasses, short-range spin-fluctuation, and the Cooper pairing mediated by Higgs-like bosons in high-T_c cuprates"</i>
M15	Vladimir Kostishin - National University of Science and Technology «MISIS»,Russia - <i>"BaFe₁₂O₁₉ thick magnetic films for microwave electronics, magnonics and terahertz spectroscopy"</i>
M16	Renata Lei - Max Planck Institute of Microstructure Physics, Germany - <i>"Direct integration of Mott neurons and spintronic memory for event-driven spiking neural networks"</i>
M17	Arianna Paris - Politecnico di Milano, Italy - <i>"Magnetic nanopatterning of reprogrammable energy landscapes and moiré spin-texture lattices via direct laser writing"</i>
M18	Nikola Miše - Faculty of Science, Zagreb, Croatia - <i>"Left, right, racemic: chiral organic cations between magnetic tetrachlorocuprate(II) layers"</i>
M19	Constantinos Nicolaides - University of Cyprus, Cyprus - <i>"Low dimensional spin correlations in Blatter radical single crystals"</i>
M20	Sebastian Serra - Politecnico di Milano, Italy - <i>"From Growth to Band Structure Under UHV: An Integrated MBE-ARPES Platform for Quantum Materials"</i>
M21	Efe Ersoy - University of Basel / PSI, Switzerland - <i>"Spin wave imaging and control at the nanoscale"</i>
M22	Rajesh Kumar - University of Iceland, Iceland - <i>"Double Waveguide Magnonic Resonator with Single Mode and Field Free"</i>

MEMS-magnonic devices for reconfigurable spin-wave interference and inverse design

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The wave-like nature of spin waves (SWs) enables information encoding and offers promising perspectives for magnon-based computing. To fully exploit this potential, precise spatial control of the spin-wave amplitude is required. This can be achieved by locally tailoring the magnetic field landscape; similarly to optics, diffraction effects arise depending on the ratio between the SW wavelength and the spatial extent of the field perturbation [1,2]. In this work, we present an integrated and reconfigurable approach to locally tune the effective magnetic field experienced by spin waves, enabling controlled diffraction. A controllable magnetic scatterer is realized by vertically displacing a micro-magnet integrated on a micro-electro-mechanical system (MEMS), coupled to a YIG-based magnonic chip via flip-chip bonding. Thanks to piezoelectric MEMS technology, the device operates with very low power consumption (nW range). The magnetic scatterer is then used as the basic element of a matrix architecture for inverse design computing, enabling more complex functionalities and paving the way for ultra-low-power spin-wave computing.

The tunable response of the MEMS-magnonic device, which is shown in Fig. 1a, has been probed by all-electrical spin waves spectroscopy. Fig. 1b shows a frequency scan of the absolute value of the transmission scattering parameter S_{12} as a function of the applied voltage to the MEMS, that displaces the actuator in the out-of-plane direction, as shown in the inset of Fig. 1b. The amplitude modulation of the transmitted RF can be explained in terms of controllable diffraction of spin waves with wavelength comparable to the micromagnet lateral size (100 μm). This interpretation is confirmed by micro-BLS experiments, showing a large influence of the micromagnet on the spin wave propagation.

The magnetic scatterer can be exploited as the building block for the spin wave inverse design architecture shown in Fig. 1c. Exploiting the concept above explained, we can redirect spin wave power towards one of the desired output antennas at a target frequency, implementing simple filtering functionalities.

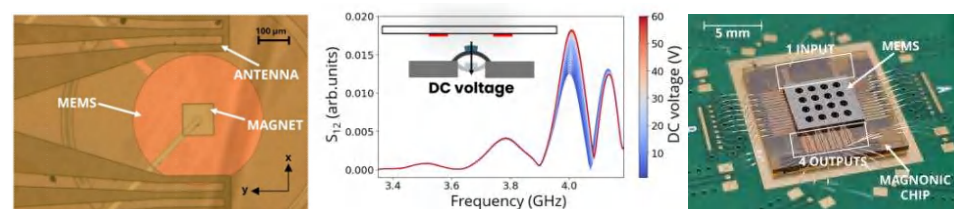


Figure 1: a) Optical picture of the single element MEMS-magnonic device. b) Absolute value of S_{12} for the single scatterer, as a function of the applied voltage to the MEMS. c) Overview of the spin wave processor in flip-chip configuration used for magnonic inverse design architecture.

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Temperature and buffer layer dependences of magnetic properties of Fe/MgO-based systems

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Achieving faster, denser, and more energy-efficient spintronic devices requires a precise control and optimization of the magnetic material parameters relevant to their operation [1]. Magnetic damping, interfacial Dzyaloshinskii–Moriya interaction (DMI) and perpendicular magnetic anisotropy (PMA) are among the critical key magnetic parameters that should be tuned for spintronic device functionalities. Furthermore, understanding the temperature dependence of PMA, damping, is therefore essential, as spintronic devices must operate reliably within specific temperature ranges. Beyond their functional relevance, such investigations also provide insight into degradation mechanisms such as interdiffusion and interfacial oxidation, which may significantly alter magnetic properties under thermal stress. In this work, we systematically investigate the temperature dependence of PMA, two magnon-scattering contribution to magnetic damping in FM/MgO-based systems. Special attention is given to the effect of the temperature of measurement as well as the buffer layer. The objective is to employ various materials and different combinations to discern the distinct contributions to PMA, DMI, and damping. The choice of different underlayers was motivated by their distinct crystal structures, which may promote different Fe growth modes and therefore modify the strength of two-magnon scattering (TMS). To achieve this, ferromagnetic resonance and Brillouin light scattering, where homemade heating system was integrated, coupled with vibrating sample magnetometry techniques were used. The temperature was varied from room temperature up to 250 °C while spectra were recorded under an in-plane applied magnetic field.

The investigated samples have the structure Si/SiO₂/NM/Fe(t_{Fe})/MgO(1)/Ta(2.5), where NM= SiO₂, Ru(3), Pt(3), Ta(2.5)/Cu(3), Ta(2.5) and Ti(3). The numbers in parentheses denote the layer thicknesses in nanometers. To investigate interfacial magnetic properties, in particular the interface-induced perpendicular magnetic anisotropy (PMA), the Fe thickness was varied in the range 1.4 nm ≤ t_{Fe} ≤ 10 nm. By varying both the underlayer material and the ferromagnetic layer thickness, we identify the individual contributions of each interface to the overall PMA and we show that TMS at the FM/oxide interface is significantly weaker than at the FM/metal interface. Indeed, the analysis of the experimental data reveals a significant contribution of two-magnon scattering (TMS) to the thickness dependence of the damping for in-plane magnetized films within the nanometer thickness and GHz frequency ranges relevant for spintronic applications. It also revealed that Ru/Fe, SiO₂/Fe, and Fe/MgO interfaces induce relatively weak Dzyaloshinskii–Moriya interaction. Furthermore, the temperature dependence of both the interface PMA and the TMS strength is found to be strongly buffer-layer dependent.

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Local energy minima and density of energy barriers in dense clusters of magnetic nanoparticles

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Multicore aggregates of magnetic nanoparticles (clusters) containing tens to hundreds of single-domain particles in a common polymer shell – are of central importance for biomedical applications such as magnetic hyperthermia, targeted drug delivery, magnetic particle imaging etc. [1]. Predicting the ac-susceptibility and the magnetization relaxation after a field change requires knowledge of local energy minima and of the energy barriers between them, since both processes proceed via thermally activated jumps with $\tau_{sw} \propto \exp(\Delta E/kT)$. Due to this exponential dependence direct Langevin dynamics is not feasible for such clusters. A reliable mapping of the energy landscape of strongly magnetodipolarly coupled aggregates is therefore an open problem, which we address in this work [2].

Methods. We have developed efficient numerical techniques for (i) the identification of local energy minima and (ii) the reliable evaluation of the ‘true’ energy barriers between them. A central ingredient is a rigorous distinction between ‘true’ and ‘false’ optimal transitions found by NEB-type searches. The problem is illustrated by the simplest non-trivial case of two non-interacting bistable particles (Fig. 1): direct saddle-point search returns the ‘false’ transition (1)→(3) with barrier $2\Delta E_{lp}$, whereas the physical path proceeds through intermediate states (2) or (4) and has the barrier ΔE_{lp} . In many-particle systems this feature becomes the main problem. We identify ‘true’ paths via introduction of small perturbations in the initial NEB-trajectory and relaxing to energy minima from these perturbed states.

Results. With this method we have computed the distribution of overlaps between local minima $P(q)$ and the density of ‘true’ energy barriers as a function of the reduced single-particle anisotropy $\beta = 2K/M_s^2$ for clusters with up to $N = 2000$ particles. $P(q)$ is Gaussian with a width unambiguously tending to zero in the macroscopic limit $N \rightarrow \infty$, ruling out a spin-glass ground state in dipolarly coupled clusters for all studied anisotropies. The barrier distribution itself is qualitatively different for various anisotropies, evolving from a sharp peak around the single-particle value $\Delta E/KV \approx 1$ for high anisotropy ($\beta = 50$) to the distribution diverging at $\Delta E \rightarrow 0$ for low anisotropy ($\beta = 0.5$), where transitions over barriers involve many particles (Fig. 2).

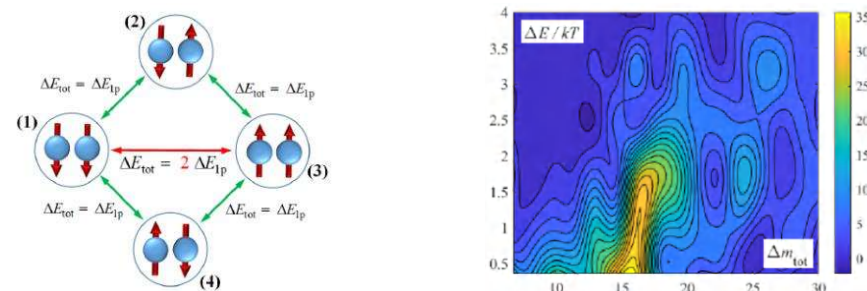


Figure 1: Difference between ‘true’ (green) and ‘false’ (red) transitions in a two-particle system.

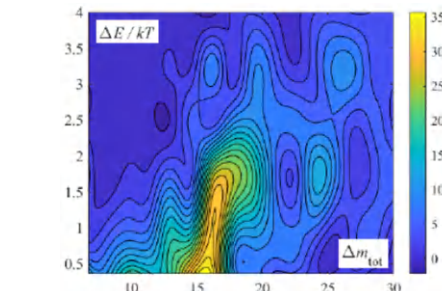


Figure 2: Density of energy barriers in $(\Delta m_{tot}, \Delta E/kT)$ coordinates for a low-anisotropy cluster ($\beta = 0.5$);

These findings have direct implications for the dynamic response of aggregated ferrofluids: in low-anisotropy clusters the pronounced density of near-zero barriers associated with cooperative multi-particle flips is expected to dominate the low-frequency ac-susceptibility and the long-time magnetic relaxation, an effect which is particularly relevant for magnetite-based biomedical applications.

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Single-stage direct Langevin dynamics simulations of transitions over arbitrarily high energy barriers: optimal solution of the Kramers problem

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The evaluation of thermally activated escape rates over high energy barriers – the celebrated Kramers problem [1] – is a cornerstone task in magnetism, chemistry, biology and information storage. The classical analytical treatments by Brown, Klik–Günther and Mel’nikov–Meshkov [2] are restricted to systems with very few degrees of freedom, and no closed-form solution is available for strongly interacting many-particle systems or spatially inhomogeneous micromagnetic configurations. Hence general numerical methods are indispensable. Direct Langevin dynamics (LD) – the most rigorous of these – becomes impracticable already for moderate barriers ($\Delta E/k_B T \geq 10$), since switching times grow exponentially with ΔE .

All state-of-the-art alternatives – forward flux sampling (FFS), string method, metadynamics and the “energy bounce” algorithm – circumvent this obstacle through a multi-stage “climbing” procedure across a sequence of interfaces. Two intrinsic drawbacks follow: (i) their computational cost grows at least linearly with the barrier height, because finer interface spacing is required for larger ΔE ; (ii) the final escape rate is the product of many conditional transition probabilities, so that even minute statistical or systematic errors accumulate catastrophically – a 2% bias on each of 50 interfaces already inflates the final result by nearly 300%.

In this work [3] we present a unique algorithm which delivers, to the best of our knowledge, the optimal numerical solution of the Kramers problem: the first genuine *single-stage* direct LD scheme capable of treating arbitrarily high barriers. The key idea is a novel concept of an energy-dependent temperature $T(E)$ entering the stochastic equation of motion: the effective temperature is chosen high in the vicinity of the energy minima and smoothly decreases to the physical room temperature at the saddle point. This prescription removes the exponential trapping near the minima without distorting the dynamics where it matters most – in the neighborhood of the barrier top. A rigorous Markov-chain formalism then allows to recover the true constant-temperature switching time τ_{sw} from the drastically accelerated EDT trajectory.

The algorithm has been benchmarked on the biaxial magnetic macrospin – the archetypal two-well system. EDT-LD switching times agree with the established FFS results within statistical error across more than 20 orders of magnitude, in the full tested range $10 \leq \Delta E/k_B T \leq 60$. Decisively, and in sharp contrast to every multi-stage method, the EDT simulation time does *not* grow with ΔE ; for $\Delta E = 60$ k_BT we obtain a speedup of more than 40× over our already highly optimized FFS version with energy-equispaced interfaces, while being entirely immune to the error-propagation problem inherent to climbing methods. Since the method requires only the height of the energy barrier (obtainable e.g. by NEB) and standard LD, it generalizes without modification to strongly interacting many-particle systems and full-scale micromagnetics, thereby constituting the most optimal single-stage numerical solution of the Kramers problem available to date.

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A GPU-accelerated solver for polarization dynamics in ferroelectrics materials

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Ferroelectric materials have attracted significant interest in both theoretical and experimental research due to their non-volatility, switchable spontaneous polarization, small dimensions, low-power actuation, and electrical tunability. Their wide range of applications, including memory devices, logic gates, and capacitors, demands high-performance and physically accurate three-dimensional simulation tools. To address this need, we present a fully GPU (Graphics Processing Unit) accelerated and scalable numerical solver, PETASPIN microelectrics. The solver computes the full polarization vector field of ferroelectric systems using the Ginzburg-Landau formalism [1] and the Landau-Khalatnikov-Tani equation [2], incorporating an optimized and validated calculation of the self-consistent electrostatic field.

The solver is implemented using CUDA and the Thrust library [3], efficiently leveraging GPU hardware to simulate realistic and engineered heterostructures. The framework supports non-uniform material properties across the device, enabling accurate modeling of complex multi-material systems and allowing parallel execution of multiple simulations on a single GPU. For time integration, we provide three methods: Heun's method, the Runge-Kutta 4(5) scheme with fixed or adaptive step sizes, and the Adams-Bashforth-Moulton (AB3M2) method. This flexibility enables a balance between computational speed and accuracy, depending on the complexity and timescales of the physical problem.

We systematically validate the solver using several benchmark problems, including temperature-dependent phase transitions in BaTiO₃ and ferroelectric domain wall profiles. Our simulations reproduce temperature-driven hysteretic phase transitions in BaTiO₃, as well as the corresponding characteristic hysteresis loops. Additionally, we demonstrate the stabilization of a three-dimensional polar skyrmion in a PbTiO₃/SrTiO₃ bilayer system. Our results show quantitative agreement with analytical theory and prior experimental studies. Furthermore, the implementation of the Landau-Khalatnikov-Tani equation which incorporates polarization inertia beyond the standard overdamped Landau-Khalatnikov formulation enables the simulation of ferron propagation, which can facilitate domain wall motion and potentially reveal novel polarization switching phenomena inaccessible to static or overdamped solvers. Overall, the proposed solver provides an efficient and accurate platform for large-scale simulations of ferroelectric materials, including the stabilization of topological textures such as domain walls, bubbles, vortices, and skyrmions, thereby supporting predictive modeling for next-generation ferroelectric device design.

Acknowledgements: This research is part of the TOPOCOM project, which is funded by the European Union's Horizon Europe Programme Horizon.1.2 under the Marie Skłodowska-Curie Actions (MSCA), Grant Agreement No. 101119608. This work was supported under the project number 101070287 — SWAN-on-chip — HORIZON-CL4-2021-DIGITAL-EMERGING-01 and by the PETASPIN association (www.petaspin.com).

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Ultrathin CoO films and their interfaces for spintronics and molecular spintronics applications

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Layered magnetic structures including ultrathin antiferromagnetic (AF) materials have been widely investigated in the last decades, revealing extremely interesting magnetic phenomena such as exchange bias and interlayer exchange coupling [1]. The interest around AF materials have been further strengthened more recently, on account of the rapid progresses in *AF Spintronics* and *AF Magnonics* [2]. Among AF materials, transition metal oxides are highly significant in spintronics, both for their use as passive elements in exchange-biased memory devices and for their emerging potential as media for non-dissipative magnonic solutions at THz frequencies [3]. In our recent work, we have been considering the role that ultrathin AF oxides can play to possibly realize *molecular antiferromagnetic spintronic* systems, extending the knowledge brought forward with several studies on molecular systems coupled to FM materials (spinterfaces) [4]. In this context, we have been investigating different AF spinterfaces, based on Cr₂O₃, NiO, and CoO, interfaced with several different organic molecules, including compounds, such as Metal-Tetra Phenyl Porphyrins (MTPP; e.g., CoTPP) and Metal Phthalocyanines (MPc; e.g., FePc) [5,6].

In this presentation, we focus on the last results we obtained regarding the growth and characterization of FePc on CoO, including the crystalline, morphologic, and electronic properties of the spinterface. Fig. 1 reports a scanning tunneling microscopy (STM) image of a self-assembled FePc layer onto CoO(001), as an example. Furthermore, the effects of molecular adsorption on the magnetic properties of the CoO surface have been studied by x-ray magnetic dichroism methods, while we employed magneto-optics to gain a further insight into CoO-based AF spinterfaces, by further analyzing the hardening effects on an AF/FM interface [7]. The ongoing research and the potential applications will be discussed.

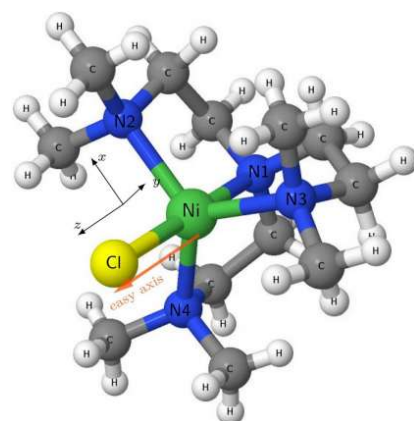


Figure 1: STM image (75 x 75 nm²) of a FePc self-assembled layer on CoO/Ag(001).

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Phase Constraints of electron orbitals in molecular magnetsH. Chamati^{a,b}, M. Georgiev^c^a Institute of Solid State Physics, Bulgarian Academy of Sciences, Sofia, Bulgaria^b Centre of Excellence Mechatronics and Clean Technologies, Sofia, Bulgaria^c Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Molecular magnets with large magnetic anisotropy and high blocking temperature attracts considerable interest due to their potential applications in spintronics. Their magnetic behaviour is tightly related to the nature of the zero-field splitting related to the crystal field and the nature of the metal ion's open subshell. Thus, unravelling the underlying electrons' configurations is crucial to their design [1]. These molecules may exhibit a multitude of microscopic magnetic states that are inaccessible via familiar parametrization schemes regarding the electrons' orbital dynamics as unconstrained. Thus, to properly describe all probable microscopic magnetic states and uniquely distinguish the one fundamental to the compound's magnetic properties, the use of a more powerful theoretical approach is necessary. To this end, we integrate a semi-classical multi-electron Hamiltonian formalism and the exact diagonalization method to formulate a general theoretical framework based on the post Hartree-Fock method that tackles constrained electron's orbital dynamics and its effects on the occurrence of zero-field splitting. This method was successfully used to explore the unusual magnetic properties of two Nickel based single-ion magnets [2,3] and display its potential for investigating arbitrary mononuclear nanomagnets [4]. It turns out that constraining the phases of the electrons' orbital dynamics is an essential tool for studying the magnetic properties of molecule magnets containing metals ions with a highly filled valence subshell.

Ball and stick representation of the complex $[\text{Ni}(\text{Me}_6\text{tren})\text{Cl}](\text{ClO}_4)$

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Magnetic cooling in a frustrated triangular-lattice Co(II) coordination compoundDominik Czernia^a, Gaja Wota^a^a Jagiellonian University, Faculty of Chemistry, Kraków, Poland

Magnetically frustrated materials have been widely explored as promising systems for improving magnetocaloric efficiency, especially at low temperatures. Significant isothermal entropy changes have been observed across various geometrically frustrated architectures, such as triangular, kagome, and pyrochlore networks. This enhancement is linked to the existence of highly degenerate ground states in zero magnetic field, which contrasts with the typically non-degenerate ground state found in conventional magnetic refrigerants.

In this study, we examine the magnetocaloric behavior of the triangular-lattice cobalt compound $\text{K}_2\text{Co}(\text{HPO}_4)(\text{C}_2\text{O}_4)(\text{H}_2\text{O})\cdot\text{H}_2\text{O}$, focusing on how magnetic frustration and effective spin reduction influence the entropy change. Due to pronounced spin-orbit coupling and crystal-field interactions, the Co(II) ions can be effectively described by a total angular momentum $J_{\text{eff}} = 1/2$ at low temperatures. This emergent spin-1/2 nature, combined with geometric frustration, inhibits long-range magnetic ordering and promotes a high density of low-energy spin configurations, which is advantageous for magnetocaloric applications.

The magnetic entropy variation was determined from isothermal magnetization data using the Maxwell relation. Under an applied field of 4 T, the peak entropy change reaches about $14 \text{ J kg}^{-1} \text{ K}^{-1}$ at 2.5 K. To better assess the practical cooling potential of this material, additional performance indicators such as relative cooling power (RCP) and temperature-averaged entropy change (TEC) are considered, offering a more application-oriented evaluation across a finite temperature interval.

A comparison with other cobalt-based magnetocaloric systems, including both non-frustrated and weakly frustrated compounds, is also presented to clarify the impact of frustration on the magnitude and temperature range of the effect. The findings reinforce the idea that geometrically frustrated magnets with effective low-spin ground states represent a promising route toward efficient magnetic refrigerants, particularly for low-temperature operation.

Microscopic magnetic modelling of manganese-based olivines Mn₂AX₄

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Manganese-based olivine compounds with the stoichiometry Mn₂AX₄ (A=Si, Ge; X=S, Se) have attracted significant interest due their intriguing magnetic properties, in particular, the sequence of reorientation transitions, the presence of multicritical points, and the sharp peak of the magnetization in the vicinity of the Néel temperature [1-3]. This study [4] aims to explore the interplay of geometrical frustration and magnetic anisotropy in these compounds, as well as their corresponding H-T magnetic phase diagrams, using microscopic insights from *ab initio* Density Functional Theory calculations and various numerical and analytical semi-classical approaches. By analysing several key magnetic parameters (including the Néel and Curie-Weiss temperatures, the saturation and spin-flop re-orientation transition fields) and comparing with reported experimental data, we arrive at a minimal microscopic model, common for all Mn-based olivines, that sheds light into the impact of the sawtooth-like chain structure of Mn ions in the crystallographic a-b plane, the non-trivial inter-plane exchange pathways, as well as the crucial role of magnetic anisotropy. We also aim to make predictions for the spin-wave excitation spectrum, thus setting the stage for further experimental and theoretical exploration of the transition-metal olivine compounds.

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Tunable directional coupling in vertically stacked magnonic waveguides

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Magnonics has emerged as a promising platform to overcome the intrinsic limitations of conventional electronics. However, most existing magnonic devices are planar, which fundamentally constrains integration density. Here, we introduce a vertically coupled waveguide system enabling three-dimensional architectures and paving the way toward magnon-based directional couplers.

The dynamic dipolar interaction between two ferromagnetic layers leads to a splitting of the spin-wave dispersion relation into two branches [1,2], as shown in fig. 1.a. These modes can be distinguished by the phase relation between the magnetization precession in the two layers: in the symmetric mode (S) the oscillations are in phase, whereas in the antisymmetric mode (AS) they occur in phase opposition. When both modes are excited at a fixed frequency, their interference results in a periodic transfer of energy between the two waveguides. The corresponding coupling length is given by $L = \pi / |k_s - k_{as}|$, where k_i denotes the wavevector of the *i*-th mode. Since the dispersion relations depend on the applied bias field, the coupling length can be tuned, enabling magnetic-field-controlled directional coupling.

Following structural optimization performed using the Ubermag Python interface to OOMMF, the system, constituted by two 80-nm-thick CoFeB layers separated by a 10-nm-thick MgO spacer, was fabricated and experimentally characterized via VNA measurements and BLS spectroscopy. The presence of both modes is confirmed by two distinct dips in the S_{22} parameter of the VNA response. Moreover, good agreement between simulations and experiments is observed for both the dependence on waveguide width (fig. 1.c) and the applied magnetic field (fig. 1.b).

These results demonstrate the feasibility of vertically coupled magnonic waveguides and establish a platform for tunable magnonic directional couplers.

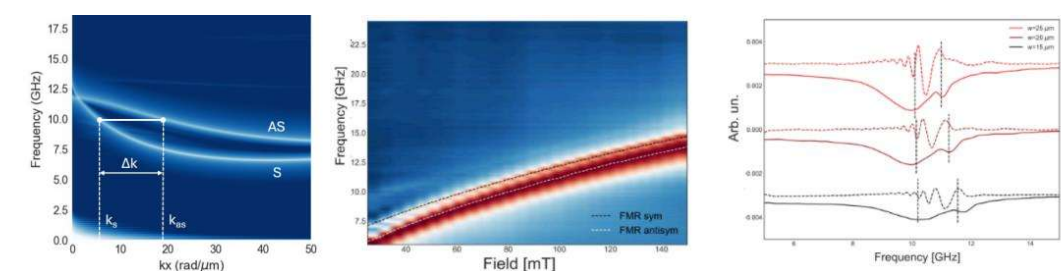


Figure 1. a) Dispersion relation for two vertically coupled magnonic waveguides. b) FMR dependence on the applied bias field for the symmetric and the antisymmetric modes extracted from S_{22} analysis. c) Absolute values of S_{22} (continuous lines) and imaginary part (dashed lines) of S_{12} for different waveguides width. Vertical dashed lines are in correspondence with the simulated FMR values of the system.

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Crystal structure and magnetic properties of (R-DAP)₂[CuCl₆], (S-DAP)₂[CuCl₆], and (rac-DAP)₄[CuCl₆]

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Hybrid organic-inorganic halometallates (HOIHs) have been the focal point of recent studies in optoelectronics as well as spintronic nanodevices [1]. Magnetic molecular materials with a chiral organic cations are attractive candidates for sensing, information storage and spintronics [2]. Compounds of (RNH₃)₂CuX₄, where R is an organic molecule and X is Cl or Br are series of hybrid inorganic organic perovskite material. Magnetic interactions in these compounds are very weak and usually antiferromagnetic.

In this work, (R-1,2-DAP)₂[CuCl₆], (S-1,2-DAP)₂[CuCl₆], and (rac-1,2-DAP)₄[CuCl₆] were synthesized by mechanochemical syntheses. The resulting materials were subsequently recrystallized to obtain single crystals suitable for analysis. Racemic compound crystallize in centrosymmetric space group *P*-1 with *a* = 7.45588(10) Å, *b* = 9.78012(13) Å, *c* = 11.4646(2) Å, β = 100.2400(13)°, and other two compounds crystallize in non-centrosymmetric chiral space groups with *a* = 6.65890(10) Å, *b* = 6.65890(10) Å, *c* = 40.5950(6) Å. In racemic compound, one of the anions present is octahedrally shaped [CuCl₆]⁴⁻. Namely, Cu-Cl distance is significantly larger than the remaining two Cu-Cl distances. The magnetic properties of all three compounds were studied in the 1.8 K to 300 K temperature range and in fields up to 7 T using SQUID magnetometer. The magnetic interactions for R and S chiral structures are paramagnetic. Moreover, the magnetic ordering for racemic structure arises below ~12K. The Curie-Weiss fit on the reciprocal susceptibility at high temperatures for racemic, R and S chiral structure gives the Weiss parameter (θ) of 14.10K, 0.52K and 0.31K respectively. Further research is needed to understand other symmetry breaking events caused by complex interactions.

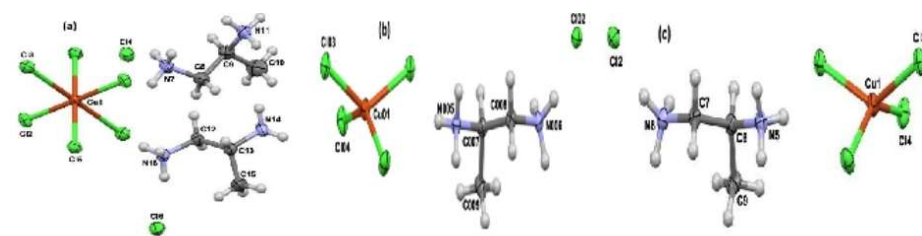


Figure 1: Molecular structures of (a) (rac-DAP)₄[CuCl₆], (b) (S-DAP)₂[CuCl₆] and (c) (rac-DAP)₄[CuCl₆]

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Terahertz optical anisotropy of the altermagnet α-MnTe

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We present a terahertz (THz) polarization-resolved spectroscopic study of the optical properties of the altermagnetic compound α-MnTe. In the THz frequency range, α-MnTe exhibits pronounced optical anisotropy, including both birefringence and strong dichroism, reflected in the anisotropy of the real and imaginary parts of the refractive index. To our knowledge, neither the THz dielectric properties nor the THz optical anisotropy of α-MnTe have been reported previously. The birefringence rises with temperature until the Néel temperature of approximately 310 K. In addition, the dichroic response displays a nonmonotonic temperature dependence at low temperatures, with a pronounced feature around 50 K. This behavior correlates with the temperature dependence of the dc transport properties, where a maximum in electrical conductivity is observed as a result of increasing carrier concentration and decreasing mobility. In the THz transmission spectra, this transport anomaly manifests itself as a plasma-edge-like feature. The coexistence of temperature-dependent birefringence, strong dichroism, and a THz plasma response highlights the rich low-energy electrodynamics of α-MnTe and calls for further theoretical and experimental studies to fully clarify the microscopic origins of these effects.

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This work was also partially supported by the Sonata Bis-13 2023/50/E/ST3/00584 grant of the National Science Centre of Poland

Field-induced spin reorientation in magnetic topological insulator MnBi_2Te_4 - ^{55}Mn and ^{209}Bi NMR study

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MnBi_2Te_4 (MBT) is the first intrinsic magnetic topological insulator, combining a topologically protected surface metallic state and an intrinsic magnetic order. Structural compatibility with the nonmagnetic parent compound Bi_2Te_3 (BT) gives a possibility to create MBT/BT heterostructures and manipulate their magnetic state in view of optimizing the Quantum Anomalous Hall Effect (QAHE) [1]. In this work an extensive NMR study, supported by bulk magnetization measurements was performed at 4.2 K on a self-organized single crystal $\text{MnBi}_2\text{Te}_4/(\text{Bi}_2\text{Te}_3)_n$ heterostructure. ^{55}Mn NMR spectra (Fig. 1) were recorded in the out-of-plane magnetic field up to 6 T, covering a spin-flop transition in MBT from an antiferromagnetic (AFM) to a canted antiferromagnetic (CAFM) configuration, thus extending the up-to-date ^{55}Mn NMR data on this system [2]. Moreover, ^{209}Bi NMR signals were observed for the first time in the MBT/BT heterostructures.

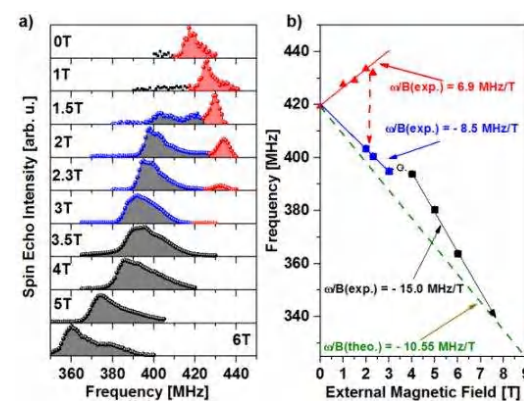


Fig. 1 (a) ^{55}Mn NMR spectra recorded at 4.2 K from $\text{MnBi}_2\text{Te}_4/(\text{Bi}_2\text{Te}_3)_n$ heterostructure, (b) spectrum gravity center vs. external field

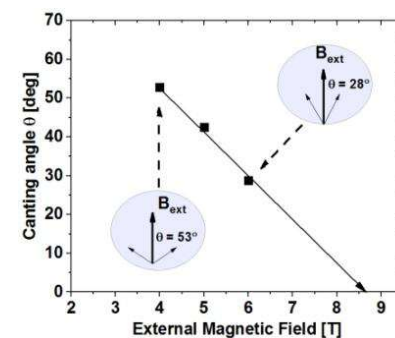


Fig. 2 Canting angle θ in a CAFM state of MnBi_2Te_4 versus the out-of-plane external magnetic field

The experiments demonstrate that the investigated heterostructure contains a significant amount of pure MBT environments. A spin-flop transition from an A-type AFM configuration to a CAFM state takes place over an extended field range 3- 3.5 T. The canting angle θ was estimated at 53° at 4 T and 28° at 6 T (Fig.2). Presence of the AFM-coupled Mn antisites was evidenced and shown to induce an antiparallel magnetic moment on Bi atoms within the host Bi layer. Detection of the induced magnetic moment on bismuth, contributing a new ferromagnetic component, is of utmost importance for understanding the magnetic interactions within the MBT/BT system. These findings have potentially important implications for engineering the QAHE devices.

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Chiral-like spin glasses, short-range spin-fluctuations, and the Cooper pairing mediated by Higgs-like bosons in high-Tc cuprates

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The relation among the short-range spin-fluctuation, chiral-like spin glasses, and the pseudogap provide a clue to clarifying anomalous properties in high-Tc cuprates. Also, it is of significance to discuss the spin-glass mechanism and short-range spin-fluctuation in lightly doped high-Tc cuprates. Inelastic X-ray scattering experiments have shown that damped magnetic excitations are present inside the electron-hole spin-flip continuation (up to ~ 300 meV) in doped high-Tc cuprates [1]. The frequency-dependent dissipation of the optical conductivity has been interpreted as the coupling of holes to bosonic excitations of high energies (~ 300 meV) [2]. Kanazawa and coworkers [3-5] have introduced quantized massive collective-gauge fields with massive Higgs-like bosons around the doped holes as collective modes, which contain effects of Jahn-Teller fluctuation and charge-fluctuation. In this study, taking account of the interaction between the hole and massive Higgs-like bosons, we suggest that massive Higgs-like boson fields might be mediating Cooper pairing in high-Tc cuprates.

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BaFe₁₂O₁₉ thick magnetic films for microwave electronics, magnonics and terahertz spectroscopy

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BaFe₁₂O₁₉ (BaM) thick magnetic films are promising materials for microwave electronics, magnonics, and terahertz spectroscopy. In this work, thick magnetic bams with a thickness of several tens of microns to 800 microns were obtained and studied by the method of slip casting. The starting material is ferritized barium hexaferrite powder synthesized using standard ceramic technology. Polyvinyl butyral was used as a film-forming agent, ethyl alcohol, butyl acetate and dibutyl phthalate were used as a solvent. The ratio of BaFe₁₂O₁₉ powder to solvent film-forming agent was 70/30. Al₂O₃ plates with a thickness of 350 microns were used as substrates.

The crystal structure of the obtained films was studied using an Empyrean X-ray diffractometer (PANalytical company) in Co-radiation: $\lambda_{a1} = 1.789190 \text{ \AA}$; $\lambda_{a2} = 1.793210 \text{ \AA}$. Diffraction peaks from the BaFe₁₂O₁₉ film and the Al₂O₃ substrate were observed on the X-ray images according to ICDD cards (98-015-7056) and (98-007-3725), respectively. No extraneous phases were detected in the films. Magnetic hysteresis loops of the study objects were recorded at room temperature using an M-155 vibration magnetometer (Princeton Applied Research).

Figure 1 shows the magnetic hysteresis loops of some of the films obtained.

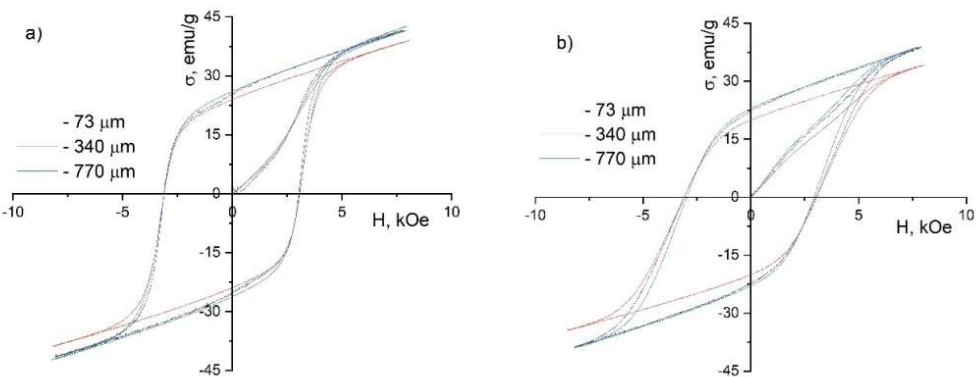


Figure 1: Magnetic hysteresis loops of some samples of the obtained thick films
a) magnetic field of the film plane; b) magnetic field $\perp$ of the film plane

The obtained results are analyzed. The possibilities of practical application of thick BaM films in the production of microstrip devices of microwave electronics, magnonics devices and terahertz spectroscopy are discussed.

Direct integration of Mott neurons and spintronic memory for event-driven spiking neural networks

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Neuromorphic architectures based on spiking neural networks (SNNs) enable power-efficient, event-driven computation [1]. However, much of their inherent advantage is compromised by the energy-intensive shuttling of data between processing neurons and external memory. This inefficiency arises because current memristor-based SNNs lack integrated, non-volatile memory for recording asynchronous spike histories [2].

In this work, we developed a hybrid compute-and-store (CAS) core that directly interfaces a spiking neuron with a spintronic memory element. To realize a spiking neuron exhibiting leaky integrate-and-fire (LIF) dynamics, we utilized two thermally coupled vanadium dioxide (VO₂) devices. In this configuration, the temporal correlation and amplitude of incoming events in the first VO₂ element can trigger the second thermally linked VO₂ device to generate an outgoing spike train. These signals are forwarded directly to spintronic storage elements: either domain-wall racetracks or spin-orbit torque magnetic tunnel junctions (SOT-MTJs). Using microscopic racetrack memory fabricated adjacent to the VO₂ units on a single Al₂O₃ substrate, we visualized that VO₂-generated spikes drive domain wall motion, effectively converting temporal events into spatial information. Furthermore, to address scalability, we demonstrated spike-induced writing in nanoscopic SOT-MTJs. In both cases, the encoding of neuronal output spikes into non-volatile memory is achieved without power-hungry signal conditioning circuits, such as amplifiers or analog-to-digital converters. The system's functionality was validated through an image classification task, showing a significant reduction in energy consumption per spike-to-memory event. Overall, this work establishes a versatile all-in-memory architecture for efficient spike-based processing, storage, and retrieval in neuromorphic computing.

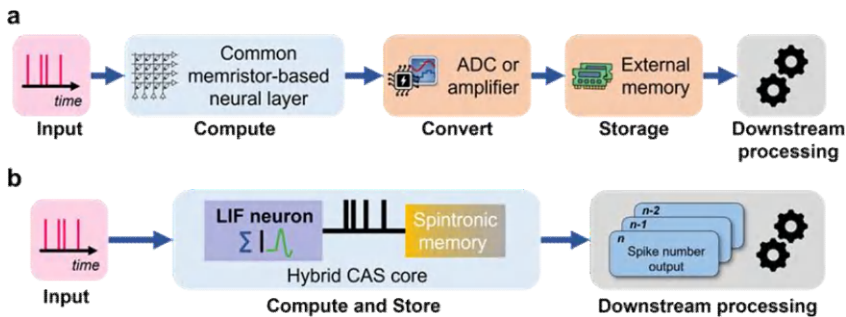


Figure 1: (a) Common memristor-based neural networks with separate compute units and memories that save the neuron outputs for downstream processing. (b) Spike-based computing architecture with a hybrid Mott-spintronic compute-and-store (CAS) unit. The CAS unit will compute, then directly store output spikes within the spintronic memories. The spike history of the firing neuron can be acquired after each process cycle n .

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Magnetic nanopatterning of reprogrammable energy landscapes and moiré spin-texture lattices via direct laser writing

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Magnetic textures offer promising opportunities for next-generation data storage and processing devices due to their nanoscale dimensions, stability, and tunability [1,2]. A key challenge is achieving deterministic control and reconfiguration of the magnetic energy landscape that governs the nucleation and stability of these textures, while preserving the structural integrity of the underlying heterostructure. Here, we introduce a focused, laser-assisted local field-cooling strategy that enables fully reversible, quantitative, and grayscale tuning of the exchange-bias anisotropy in perpendicular magnetic thin-film heterostructures, without altering structural properties [3]. Spatial modulation of the laser power generates smooth, spatially resolved energy landscapes that precisely define local switching thresholds, domain-nucleation, and the stability of chiral spin configurations. This scalable approach enables programmable magnetic patterning with tunable hysteresis, field-dependent readability, and reconfigurable switching behavior. We demonstrate the deterministic writing, erasure, and rewriting of magnetic lattices with arbitrary symmetry, including square, hexagonal, and Kagome arrangements. By superimposing designed landscapes, we additionally create Moiré spin-texture superlattices arising from controlled lattice twisting. Fig 1a illustrates this approach schematically while Fig 1b shows an MFM image of a Moiré spin-texture lattice produced by a 5.5° rotational misalignment between two initial lattices with the same periodicity. These results position laser-programmed exchange-bias engineering as a versatile and reconfigurable platform for the deterministic formation of complex magnetic phases, artificial superlattices, and dynamically programmable spin-texture architectures for advanced spintronic and magnonic technologies.

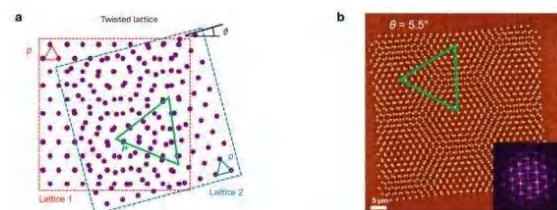


Fig 1. Generation of Moiré magnetic lattices via geometric superposition. (a) Overlap of two identical magnetic lattices with periodicity p and a relative rotation angle θ . (b) MFM image of Moiré magnetic lattice induced by a 5.5° rotational misalignment between the two lattices.

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Left, right, racemic: chiral organic cations between magnetic tetrachlorocuprate(II) layers

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Quasi-two-dimensional hybrid organic-inorganic perovskites offer a versatile platform for tuning spin-related properties through chemical composition, via halide and organic cation substitution. [1, 2] Introducing chiral organic cations could further tune material properties and enable chirality-dependent effects. Magnetic interactions are dominant within layers of corner-sharing $[\text{CuCl}_4]^{2-}$ octahedra separated by 1,2-diaminopropane (hereafter 1,2-DAP). Magnetization measurements of powder and single crystal samples were using SQUID magnetometer as a function of temperature, field and orientation.

As enantiomers, the R- and S-1,2-DAP- CuCl_4 compounds share identical superexchange pathways and, consequently, identical magnetic properties. Interestingly, the racemic compound exhibits magnetic behaviour that departs from enantiopure materials, not merely in magnitude but in character, too. Across all three compounds, the antiferromagnetic cusp in the temperature dependence persists even under high applied fields, indicating robust antiferromagnetic interactions, even within the plane, which is extremely rare behaviour for this class of materials. [3] Closer inspection reveals a far richer picture: linear field dependence along each crystallographic axis coexisting with ferromagnetic interactions, ZFC/FC splitting, magnetic axis reorientation, and weak ferromagnetism. This combination of magnetic phenomena and competing interactions is itself uncommon, made all the more remarkable by the fact that most materials in this class display in-plane ferromagnetism. [4]

Studying these systems could reveal the mechanisms of magnetic frustration and competing anisotropic interactions in quasi-2D materials, with implications for designing layered magnets with tunable spin textures. [5]

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Low dimensional spin correlations in Blatter radical single crystals

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Materials exhibiting low dimensional spin properties have recently attracted significant attention due to their potential applications in emerging technologies such as quantum computing and spintronics [1]. However, low dimensional magnetism in metal-free organic materials is rarely reported, mainly due to weak exchange interactions and small magnetic anisotropy [2]. Nevertheless, understanding spin dimensionality in such systems is a key step toward identifying organic materials capable of replacing inorganic ferromagnets as metal-free spin sources. Here, we present an experimental investigation of the spin dimensionality and spin correlations in single crystals of a Blatter radical derivative (BRD) at room temperature. Electron spin resonance (ESR) measurements were performed at X-band frequency (9.4GHz), with angular dependent spectra recorded in three mutually perpendicular planes aligned with the crystallographic axes, as determined by single crystal X-ray diffraction. The analysis of both the ESR resonance field and the peak to peak linewidth reveals characteristic anisotropies associated with low dimensional magnetic behavior. These results demonstrate that BRD single crystals constitute a promising metal-free organic platform with well defined low dimensional spin properties, highlighting their potential use as spin sources for organic spintronic devices and spin current generation schemes.

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From Growth to Band Structure Under UHV: An Integrated MBE–ARPES Platform for Quantum Materials

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The development of quantum and spintronic materials increasingly relies on predictive band-structure calculations and demanding experimental platforms capable of validating electronic properties under controlled conditions. However, exposure to ambient atmosphere often alters surface and electronic states, limiting the reliability of *ex-situ* characterization.

Here we present a fully integrated UHV cluster tool combining MBE and angle-resolved photoemission spectroscopy (ARPES), enabling *in-situ* growth and direct access to the electronic band structure without breaking vacuum. The system, developed within the Nanoscience Foundries and Fine Analysis – Digital Infrastructure (NFFA-DI) PoliFab Node, is optimized for chalcogenide-based materials and related compounds.

The MBE chamber (CreaTec GmbH) is equipped with up to eight sources (Ge, Te, Sb, etc.) and allows the growth of high-quality thin films with thickness uniformity within $\pm 2\%$ on both 2-inch wafers and small samples. Growth dynamics and surface ordering and reconstruction are monitored in real time via reflection high-energy electron diffraction (RHEED).

The MBE system is UHV-connected to a Proven X system by SPECS. A preparation chamber enables deposition of metals (Fe, Co, Al, etc.), surface preparation via Ar-ion sputter-etching and annealing up to 1200 °C, verification via low-energy electron diffraction (LEED), and Auger electron spectroscopy (AES) on small samples. The analysis chamber manipulator operates from room temperature down to 6 K and can apply a bias to the sample. ARPES measurements using He I/II radiation (21.2/40.8 eV) provide direct access to band dispersion, while X-ray photoelectron spectroscopy (XPS) with two photon energies (Al-K α and Mg-K α) enables quantitative chemical and thickness analysis.

Representative applications include *in-situ* studies of band structure evolution even *in-operando* (voltage bias), compositional analysis of alloys, growth of complex heterostructures, and optimized surface preparation protocols for high-resolution ARPES measurements (Fig. 1).

The facility is open to external users through the NFFA-DI access program [1], offering transnational access. Users are warmly invited to participate in the periodic calls after discussing the feasibility of the proposed experiments with the staff.

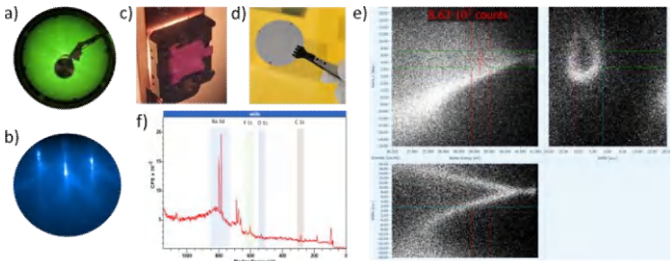


Figure 1 : a) Si(111) 7x7 reconstruction LEED pattern. b) Si(111) RHEED pattern. c) Annealing with e-beam heater. d) GeTe thin film on 2" Si wafer. e) XPS spectrum of BaF₂. f) ARPES of graphene Dirac cones.

[1] <https://nffa-di.it/>

Spin wave imaging and control at the nanoscale

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Magnonic devices, which use spin waves as information carriers, offer a promising route toward low dissipation information processing [1], particularly when integrated with nanoscale magnetic textures that can act as tunable magnon sources, scatterers, or waveguides [2]. However, finding a material platform combining stable and controllable textures with long-range spin wave propagation has been challenging. An alternative approach is interfacing yttrium iron garnet (YIG), a magnetic insulator with exceptionally low damping, with texture-hosting materials. Past works have already demonstrated the steering and scattering of magnons in decorated YIG samples [3]. Building on this, we aim to integrate YIG with interfacial coupled spin textures to modify and control magnon transport.

Our experimental platform employs scanning nitrogen-vacancy (NV) magnetometry for imaging such YIG heterostructures. This technique provides nanoscale, quantitative magnetic imaging ability under ambient conditions and allows us to visualize both static textures and propagating spin waves [4, 5]. As initial steps, we have imaged spin waves in YIG, and skyrmion bubble lattices in a texture-hosting material, namely NdMn₂Ge₂. In addition, we demonstrate local manipulation of the lattice with laser pulses, highlighting the potential for on-chip texture engineering.

By integrating YIG with such tunable textures, we aim at studying their channeling and scattering behavior, as well as the possibility of magnon emission from dynamic spin textures. The combination of NV magnetometry with such systems will provide a powerful experimental platform for systematic studies of magnon-texture interactions at the nanoscale. This approach can pave the way toward programmable, texture-based magnonic devices.

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Double Waveguide Magnonic Resonator with Single Mode and Field Free

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In data processing systems, efficient transfer of energy (and information) is desirable, and reduction of energy consumption and Joule loss. Magnonic ring resonators with double waveguides have been explored with multimode coupling and external field dependence [1][2]. These multimode coupling and external field-dependent devices have less efficient energy transfer and require an external field, which makes the device less compatible with computing and processing systems. Here, we introduce the double waveguide magnonic ring-resonator (DWMR) with single-mode coupling and external-field-free operation for efficient data transfer. We have demonstrated the design and operation of the DWMR using micromagnetic simulations, analyzing its transmission spectra and spin-wave profile in the gigahertz regime. We have designed a DWMR with two waveguides and a ring, where the mean radius of the ring is R , and the width of the ring and waveguides is the same, $w=100\text{nm}$. The lengths of the two waveguides are also the same, $L=2400\text{nm}$, and the heights of both the waveguides and the ring are identical, with a value of $h=50\text{nm}$ (Fig. 1a). Yttrium iron garnet (YIG) is used for both the waveguides and the ring, with magnetization parameters taken from experimental data. To generate the spin wave, an oscillating field ($h_{rf} = h_0 \sin(2\pi f t)$), where h_0 is the amplitude of h_{rf} and f is the frequency of the radio-frequency current, is applied. The transmission spectra for the through and drop ports of the DWMR show a single-mode resonance dip and peak in the frequency range from 2.58 GHz to 2.68 GHz (Fig. 1d). In Figures 1b and 1c, the spin-wave profiles (out-of-plane component of the spin-wave amplitude, m_z) are shown for the resonance frequency (2.634 GHz) and off-resonance frequency (2.680 GHz), respectively. Furthermore, the proposed structure has been studied for spiking neuron behavior, in which a sudden change in transmission is observed by increasing h_0 (Fig. 1e). Our proposed study and structure may help in developing unconventional magnonic integrated circuits for data processing systems and computing.

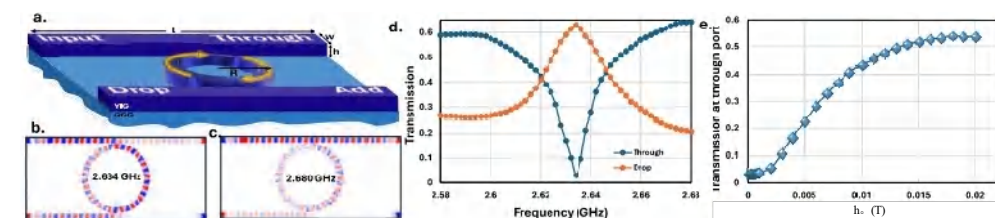


Figure 1: a) 3D model of DWMR. Spin wave profile of DWMR at: b) at resonance frequency and c) at off-resonance frequency. d) Transmission spectra of DWMR for through and drop port. e) Plot of Transmission at through port vs h_0 .

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Trends in MAGnetism 2026

7th-11th September 2026, Milano, Italy

Tuesday, 8th September - POSTER SESSION B	
ROOM C	Session chair
14:00 - 16:00	Opening
Poster Code	Presenting Author - Poster Title
T01	Riza Erdem - Akdeniz University, Türkiye - <i>"Irreversible thermodynamics of a spin-1 quantum Ising system: Relaxation dynamics based on Onsager theory"</i>
T02	Daniil Pashnev - Polish Academy of Sciences, Poland - <i>"Strong magnon-photon coupling in layered antiferromagnet NiPS3"</i>
T03	Muhammad Rehan - Politecnico di Milano, Italy - <i>"High-frequency characterization of AMR sensor dies with integrated excitation coil"</i>
T04	Izuru Shigeta - Kagoshima University, Japan - <i>"Superconducting properties of superconductor NbN/Heusler alloy Co2FeSi epitaxial films in high magnetic fields"</i>
T05	Andrei Shumilin - ICMol, Universidad de Valencia, Spain - <i>"Intrinsic (non)-Gilbert damping in magnetic insulators calculated from a minimal model and ab initio spin Hamiltonians"</i>
T06	Bhuvan Sosale Vasudeva - Lappeenranta-Lahti University of Technology, Finland- <i>"Controlling spin-wave packets via pulse-shape engineering"</i>
T07	Mislav Trbušić - University of Maribor, Slovenia - <i>"Thermal stabilization of the RF pickup coils in the system for characterization of paramagnetic materials"</i>
T08	Huiwen Wang - Beihang University, China - <i>"Effect of Ion Irradiation on Magnetic properties of Pt/Co/X Thin Films"</i>
T09	John Wilkinson - ISIS Neutron and Muon Source, STFC, UK - <i>"Entangled muons as a probe of ultrafast paramagnetic dynamics"</i>
T10	Marek Wójcik - Polish Academy of Sciences, Poland - <i>"Helical magnetic structure in Mn2GaC MAX phase films"</i>
T11	František Máca - Institute of Physics CAS, Czech Republic- <i>"Stability and magnetic ordering near the antiphase boundary in Ni2MnGa"</i>
T12	Jakub Zazvorka - Charles University, Czech Republic- <i>"Control of compensation and anisotropy in Co/Tb multilayers using a buffer layer"</i>
T13	Koplak Oksana - Università degli Studi di Milano-Bicocca, Italy - <i>"Chitosan-coated iron-based nanoparticles for magnetic hyperthermia application"</i>
T14	Benjamin Mimica Figari - Politecnico di Bari, Italy - <i>"Dynamic Characterization of Nanowire Arrays with Interlayer Exchange Coupling"</i>
T15	Filippo Lorenzoni - Università delle Marche, Italy- <i>"Ultra-Compact Magnetoelectric Antenna for RF Energy Harvesting"</i>
T16	Sreya Pal - Politecnico di Milano, Italy - <i>"Wafer-scale deposition of SmCo films by remote plasma sputtering: A route to high-performance permanent micromagnets"</i>
T17	Valentyn Volobuiev - Polish Academy of Sciences, Poland - <i>"Epitaxial growth and characterization of NiAs-type altermagnetic MnTe thin films on (111) substrates"</i>
T18	Abhishek Erram - Indian Institute of Technology Bombay, India - <i>"Reciprocity in Charge-Orbital-Spin interconversion"</i>
T19	KV Shilna - Indian Institute of Technology Bombay, India - <i>"Observation of Ferromagnetism in Sputtered Co-doped HfO2 Thin Films"</i>
T20	Ildus Sharafullin - Ufa University of Science and Technology , Russia - <i>"Surface properties and spin waves of ferroelectric/ferromagnetic superlattices"</i>
T21	Marica Licciardi - Politecnico di Milano, Italy - <i>"Non-Reciprocal Band Effect in Magnetic Materials: from Symmetry Constraints to First-Principles Validation"</i>

**Irreversible thermodynamics of a spin-1 quantum Ising system:
Relaxation dynamics based on Onsager theory**

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Time-dependent properties of a spin-1 quantum Ising system with three-spin interactions on a two-dimensional triangular lattice [1] are studied using Onsager's theory of irreversible thermodynamics [2]. To analyze these properties, it is assumed that the time derivative of dipolar and quadrupolar moment order parameters is treated as thermodynamic fluxes and corresponding generalized forces are found from the mean-field free energy production. From the relations between fluxes and forces, the kinetic equations are derived and characterized by the slow and fast relaxation times describing the irreversible process in the system. It is found that the slow relaxation time (τ_s) diverges to infinity near the critical and tricritical points, whereas the fast relaxation time (τ_F) exhibits a cusp singularity at these points. On the other hand, τ_s and τ_F display sharply-cusped and jump-discontinuity behaviours, respectively, at the first-order phase temperatures. The obtained results are compared with the recent kinetic theory calculations carried out for similar model systems [3, 4], yielding a very good overall agreement.

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Strong magnon–photon coupling in layered antiferromagnet

NiPS₃

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Strong coupling between electromagnetic cavity modes and collective spin excitations is a key ingredient in hybrid quantum systems and spin-cavitronics [1]. Antiferromagnets offer a particularly appealing platform in this context, owing to their intrinsically high-frequency spin dynamics and the absence of a need for external magnetic fields [2]. Strong magnon-photon coupling was reported in the case of classical three-dimensional antiferromagnets [3]. However, placing layered antiferromagnets in the regime of strong light–matter coupling at terahertz (THz) frequencies remains an outstanding challenge.

Here, we report the observation of strong magnon–photon coupling in the layered antiferromagnet NiPS₃ in the THz frequency range. Using THz time-domain spectroscopy in a reflection geometry, we detect the formation of magnon–polaritons near 1.2 THz, persisting up to temperatures of approximately 80 K. The sample itself forms a Fabry–Perot cavity due to its finite thickness of about 190 μm. As a function of crystal temperature, the magnon frequency softens and, upon approaching resonance with the sixth cavity mode, an anticrossing is observed. The resulting vacuum Rabi splitting reaches approximately 9 GHz, enabling a precise determination of the magnon oscillator strength. We further characterize the terahertz dielectric response of NiPS₃, as well as the temperature and magnetic-field dependence of the magnon modes in external magnetic fields up to 9 T. The experimental results are in good agreement with electrodynamic modelling based on the transfer-matrix method. Notably, the coupling emerges naturally from the electrodynamic boundary conditions without the need to introduce explicit interaction terms, highlighting the intrinsic nature of magnon–cavity coupling in finite-thickness magnetic crystals.

Our results demonstrate NiPS₃ as a viable platform for terahertz spin-cavitronics and extend the range of materials exhibiting strong light–matter coupling to layered antiferromagnets.

This work was partially supported by the Sonata Bis-13 2023/50/E/ST3/00584 grant of the National Science Centre of Poland

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High-frequency characterization of AMR sensor dies with integrated excitation coil

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The demand for rapid transient detection of electric currents in power electronics applications has pushed the bandwidth requirements for magnetic sensors into the Megahertz regime [1]. Most of current sensing relies on integrated current detection, which suffer from limited accuracy and lack of galvanic isolation. For this reason, the use of magnetic field sensor offers a valid solution to remotely sense electric currents while providing galvanic isolation and potentially higher accuracy. While Hall sensors have demonstrated bandwidth up to the MHz regime [2], Anisotropic Magnetoresistance (AMR) sensor have seen few demonstrations of high-frequency signal detection.

In this work, conducted in collaboration with STMicroelectronics, we present a high-bandwidth magnetic field sensing platform based on an industry-grade AMR sensor. We utilized an integrated micro-coil embedded directly within the sample architecture (Figure 1a). This coil is designed to generate a localized magnetic field which can be sensed by AMR sensor.

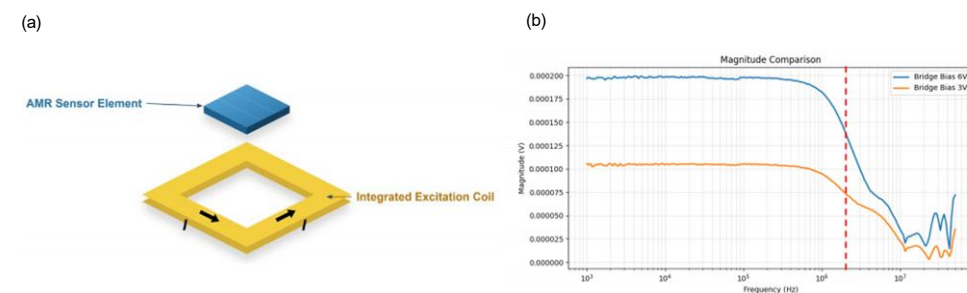


Figure 1: (a) Working principle of the device. (b) Frequency sweep analysis at different bridge bias voltages.

We measured the output of the AMR Wheatstone bridge as a function of the frequency and the bias of the bridge (Figure 1b). Experimental characterization shows a robust and linear frequency response, with a bandwidth reaching approximately 4 MHz. We believe that this cut-off is currently limited by parasitic capacitance in the electronics and the sensor itself and could be further improved. Nevertheless, this is among the highest reported experimental measurements of an AMR response.

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Superconducting properties of superconductor NbN/Heusler alloy Co₂FeSi epitaxial films in high magnetic fields

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The superconductor/ferromagnet multilayers and junctions have been widely studied to explore the interplay between superconductivity and ferromagnetism. Although coexistence can occur in special cases, producing effects such as the π state in superconductor/ferromagnet/superconductor junctions, the superconducting order parameter is generally suppressed in the superconducting layer and extends into the ferromagnetic layer. Many studies have focused on systems in which the ferromagnetic component is composed of 3d transition metals such as Fe, Co, and Ni. In contrast, only a limited number of reports are available on epitaxial superconductor NbN/Heusler alloy heterostructures and related devices. Therefore, we focus on the superconducting properties of epitaxial NbN films interfaced with highly spin-polarized Heusler alloy Co₂FeSi, where superconductivity penetrates into the ferromagnetic layer.

NbN/Co₂FeSi epitaxial films were fabricated on MgO substrates using an ultrahigh-vacuum (UHV)-compatible magnetron sputtering system. Superconducting properties of the epitaxial films were evaluated from four-terminal resistivity measurements in magnetic fields up to 17 T applied parallel and perpendicular to the film surface. Resistivity $\rho(T)$ was measured as a function of temperature for various magnetic fields applied parallel and perpendicular to the NbN/Co₂FeSi surface. The superconducting transition temperature T_c of the NbN/Co₂FeSi films was determined to be 16.1 K in zero magnetic field. The temperature dependence of the upper critical field $\mu_0 H_{c2}(T)$ was obtained from measurements of the resistivity $\rho(T)$. Figure 1(a) shows the upper critical fields $\mu_0 H_{c2}^{\parallel}(T)$ and $\mu_0 H_{c2}^{\perp}(T)$ of the NbN/Co₂FeSi film for magnetic fields applied parallel and perpendicular to the NbN/Co₂FeSi surface. Figure 1(b) shows the field dependence of the pinning potential $U(H)$ for both applied magnetic field directions deduced from the Arrhenius plots for the $\rho(T)$ curves in various magnetic fields. As illustrated in Fig. 1(b), $U(H)$ for fields above 5 T is well described by $H(1 - H/H^*)$ based on a model analogous to that for the field dependence of the pinning force density, where H^* denotes the irreversibility field at 0 K. The experimental results in high magnetic fields reveal that the superconductivity of the NbN layer is influenced by its interplay with the highly spin-polarized Co₂FeSi layer.

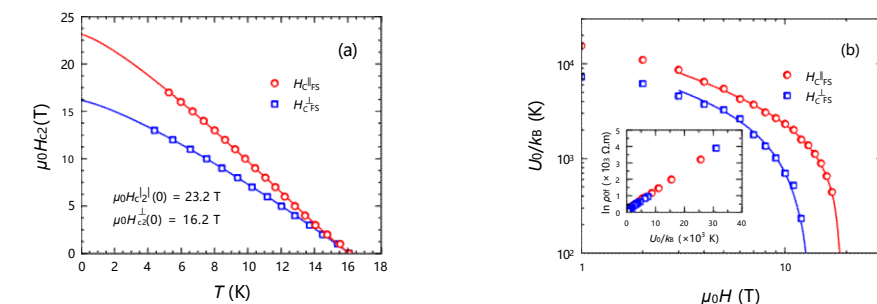


Figure 1: (a) Upper critical field $H_{c2}(T)$ as a function of temperature for high magnetic fields applied parallel and perpendicular to the NbN/Co₂FeSi surface. (b) Pinning potential $U_0(H)$ as a function of magnetic field H . Inset: Relationship between $\ln \rho_0 f$ and U_0 for both applied magnetic fields.

Intrinsic (non)-Gilbert damping in magnetic insulators calculated from a minimal model and *ab initio* spin Hamiltonians

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Magnon damping remains a key bottleneck for magnonic technologies. It is expected to be minimal in magnetic insulators, where scattering from itinerant electrons is absent. In these systems, two intrinsic mechanisms dominate the damping in pristine materials: magnon-phonon and magnon-magnon scattering. We propose a minimal model [1] that

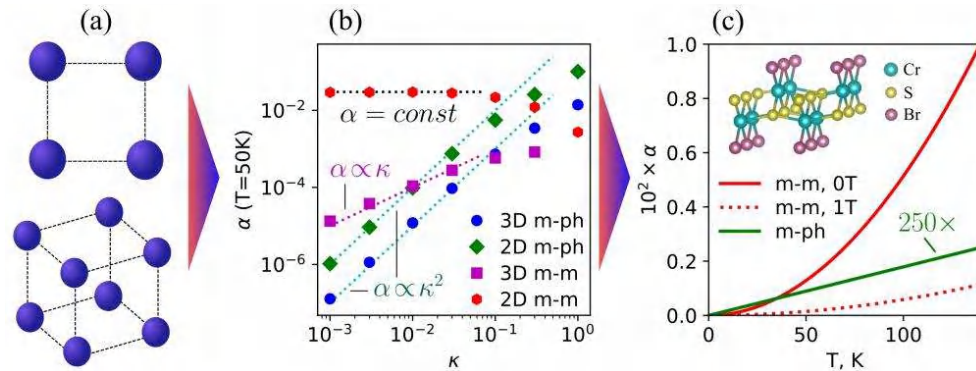


Figure 1 : (a) structure of the analytically solved toy model; (b) the dependence of damping α on the SOC parameter κ for both magnon-phonon and magnon-magnon scattering in 2D and 3D calculated from the toy model; (c) The magnon-phonon and magnon-magnon contributions (at the magnetic field of 0T and 1T) to the damping in a monolayer of CrSBr.

yields analytical expressions for both mechanisms and enables their comparison as a function of spin-orbit coupling (SOC), introduced via a single parameter κ . Magnon-phonon damping is strongly suppressed at low SOC, scaling as $\alpha \propto \kappa^2$. In contrast, magnon-magnon damping scales as $\alpha \propto \kappa$ in 3D and remains finite in the 2D limit. This results in pronounced non-Gilbert behavior, with the effective damping parameter decreasing under an external magnetic field. To assess the relevance of these results to real materials, we developed the *MagnoFallas* code [2], which computes damping from *ab initio* inputs, including magnon-magnon and magnon-phonon scattering, as well as SOC and dipole-dipole interactions. In several cases, the *ab initio* results are well captured by the analytical model, including magnetic-field and temperature dependences of magnon decay. In particular, a CrSBr monolayer exhibits strong magnon-magnon damping with high field sensitivity. In bulk yttrium iron garnet (YIG), magnon-magnon scattering is significantly weaker, comparable to that measured in high-quality samples, though still non-Gilbert.

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Coherent control of spin-wave packets via pulse-shape engineering in dual-antenna systems

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Spin-wave-based computing is a promising paradigm for beyond-CMOS information processing [1]. A key challenge is the precise local control of propagating spin-wave packets in magnetic media, which is essential for functional magnonic devices.

Using micromagnetic simulations [2], we demonstrate coherent control of spin-wave packets in a dual-antenna configuration, identifying pulse-shape engineering as a key control parameter. By modulating the envelope of a carrier-frequency excitation at the control antenna, we analyze the resulting spatiotemporal evolution of the magnetization. We examine the interaction of a propagating spin-wave packet with a spatially separated control antenna after a defined delay, using representative control signals (Fig. 1). The control antenna induces phase- and amplitude-dependent interference, enabling deterministic reshaping of the spin-wave packet and pulse-shape-dependent control of transmission and reflection at the control antenna.

The control antenna acts as a tunable local scattering center, enabling controlled redistribution of spin-wave energy. We further explore different antenna geometries and excitation profiles, demonstrating the versatility of dual-antenna architectures for programmable magnonic signal processing, including interference-based logic and parametric amplification schemes [3,4].

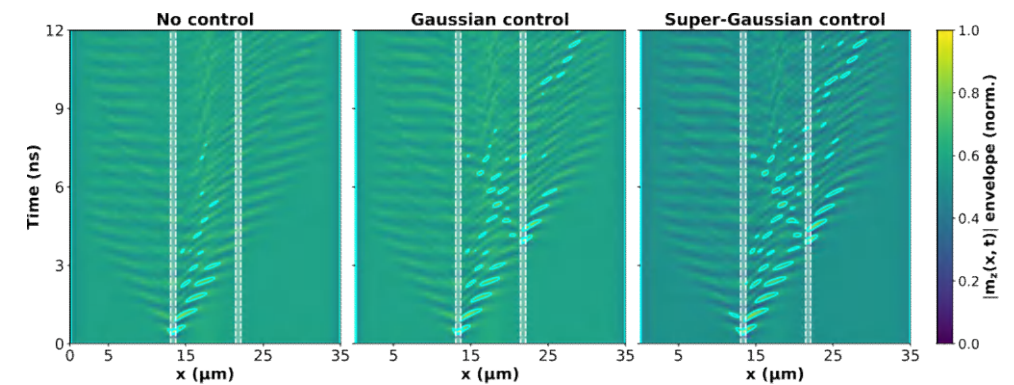


Figure 1: Spatiotemporal maps of the normalized spin-wave envelope from $m_z(x,t)$: (left) no control, (middle) Gaussian control at the second antenna, and (right) super-Gaussian control at the second antenna. All excitations at $f_c = 3.75$ GHz in a bias field $\mu_0 H_{\text{bias}} = 50$ mT. Cyan contours show iso-amplitude levels (varying between panels). White lines mark antenna positions; damping suppresses reflections.

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Thermal stabilization of the RF pickup coils in the system for characterization of paramagnetic materials

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The magnetic characterization of paramagnetic materials, such as magnetic powders, paramagnetic gels, and magnetic liquids, is usually conducted at high-frequency (RF) excitation magnetic fields. This process involves using a measuring or pickup coil tightly wound around the sample space. Coil exposure to the high-frequency excitation field induces eddy currents in the coil's wire, which generate heat and can cause an undesired rise in the sample's temperature. Furthermore, the dynamic temperature profile recorded within the sample can be significantly influenced by this heating effect, particularly when measuring weakly paramagnetic materials. To mitigate this issue, it is essential to stabilize the pickup coil temperature to match the sample's initial temperature. In this way, the observed temperature rise pertains to the measured object and is solely due to the interaction between the excitation magnetic field and the sample. This work presents a proposed method for effectively stabilizing the pickup coil's temperature. Additionally, the impact of temperature stabilization on the dynamics of the temperature curve is analyzed in both scenarios, with and without stabilization.

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Effect of Ion Irradiation on Magnetic properties of Pt/Co/X Thin Films

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Magnetic damping, interfacial Dzyaloshinskii–Moriya interaction (DMI), and perpendicular magnetic anisotropy (PMA) are key parameters that control the creation and motion of skyrmions [1]. Minimizing skyrmion size and achieving faster domain wall velocity are important for spintronic devices. Ion irradiation, as a low-temperature, localized, and patternable post-processing technique, enables precise control of interfacial atomic mixing and defect distribution at smaller scales, and has therefore attracted widespread attention in recent years [2,3].

To investigate the effect of He⁺ ion irradiation on the magnetic properties of Pt/Co/X (where X = MgO, Au, Cu), we deposited Ta(5 nm)/Pt(4 nm)/Co(t_{Co})/MgO(1 nm)/Ta(3 nm) thin films by magnetron sputtering, with the Co layer thickness (t_{Co}) varied from 1.4 nm to 100 nm. These films were irradiated with different doses up to 1.87×10¹⁵ ions/cm². Brillouin light scattering and ferromagnetic resonance combined to vibrating sample magnetometry have been used to investigate the interfacial magnetic properties of above-mentioned systems. Based on a comprehensive thickness-dependent analysis, we observed an increase in intrinsic damping and two-magnon scattering, as well as tunable DMI. We also developed a method to separate the contributions from the top Co/MgO interface and the bottom Pt/Co interface. These insights into the underlying physics demonstrate the utility of ion irradiation for magnetic thin films, which paves the way for future spintronic applications.

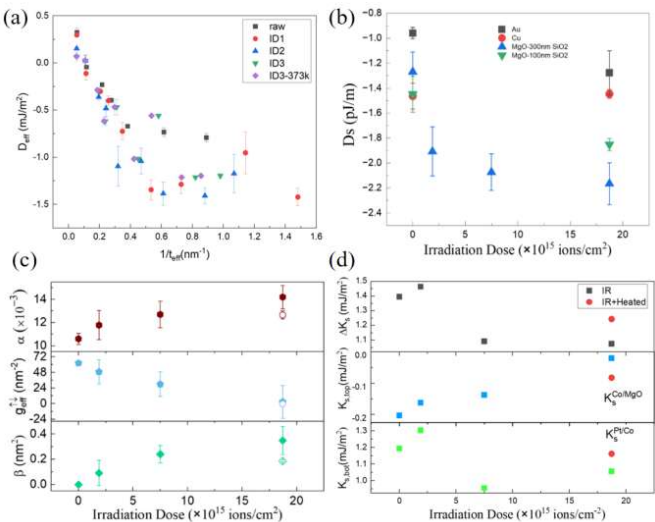


Figure 1: (a) D_{eff}, (b) D_s, (c) damping contribution, and (d) surface anisotropy variations with increasing He⁺ ion irradiation dose.

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Entangled muons as a probe of ultrafast paramagnetic dynamics

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Muon spin relaxation, one of the most sensitive techniques for probing magnetism, has been used very successfully to observe spin dynamics in a wide range of materials. Electronic dynamics typically manifest through a muon spin relaxation function that decays exponentially with time, with the decay rate related to the local field-field autocorrelation function. This relationship can then be used to extract the dynamical parameters of the system [1]. However, there are many systems in which the μ SR spectrum decays in a manner that deviates from a simple exponential model, and the experimenter often has to resort to a phenomenological stretched exponential function to describe the muon relaxation.

In recent years, there has been a strong drive within the muon community to move beyond phenomenological methods of data analysis and towards simulation-based approaches for understanding muon data. Such approaches have been successfully used to interpret experiments in terms of muon entanglement [2], quantum decoherence [3], and charge environments [4], allowing for significantly greater insight into the experimental data. Nevertheless, many of these successes rely on the assumption that the muon's Hamiltonian is time-independent, which is not valid when dynamics occur on the muon timescale. In this presentation, I will show that a muon entangled with its nearest-neighbour nuclei can act as a probe of ultrafast paramagnetic dynamics, removing the need for phenomenological descriptions of the muon's relaxation and allows one to determine the width of the field distribution and the correlation times of the magnetic moments. This has important implications for measuring dynamics with μ SR in systems where the nuclei have non-negligible magnetic moments.

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Helical magnetic structure in Mn₂GaC MAX phase films

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Structural and magnetic properties of self-organized, atomically layered Mn₂GaC MAX-phase thin films epitaxially grown on MgO (111) and Si (100) were investigated by means of ⁵⁵Mn NMR spectroscopy, X-ray diffraction and STEM-HAADF imaging. Mn₂GaC films crystallize in a hexagonal structure and are formed by repetitive stacking of Mn-C-Mn blocks interleaved with Ga layers along the c-axis. According to the room temperature structural data all Mn atoms occupy structurally equivalent positions.

Zero-field ⁵⁵Mn NMR measurements at 4.2 K reveal a critical thickness of ~100 nm for Mn₂GaC/MgO films, marking a significant transition in magnetic behavior. Below this threshold, films display epitaxial stacking with low grain roughness and indicate presence of magnetically nonequivalent Mn sites, revealed by the four well-resolved ⁵⁵Mn NMR lines. Above 100 nm the X-ray data show that a structural registry is maintained but STEM-HAADF images reveal that the films develop irregular grain structure, leading to a strong modification of NMR spectra (Fig. 1). The films grown on Si substrates consistently exhibit structural and magnetic (NMR) characteristics similar to thicker MgO-based films.

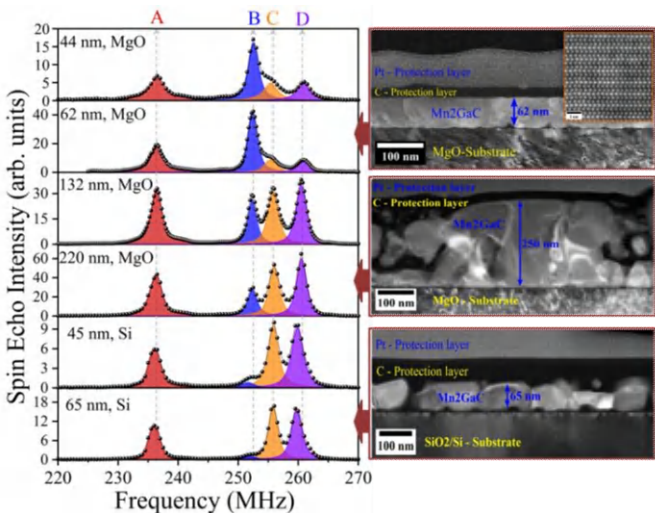


Figure 1 Left: ⁵⁵Mn NMR spectra at 4.2 K from Mn₂GaC(0001)/MgO(111) and Mn₂GaC/SiO₂/Si(001) films. Right: The respective STEM-HAADF images of selected Mn₂GaC(0001)/MgO(111) films along [100] axis and 65 nm film of Mn₂GaC/Si. (the inset in case of a 62 nm MgO-based film is a highly magnified image confirming epitaxial stacking)

The magnetic ground state is highly sensitive to these structural changes. NMR experiments in an external magnetic field demonstrate that epitaxial Mn₂GaC/MgO films (<100 nm) display a helical spin arrangement stabilized by competing ferromagnetic and antiferromagnetic exchange interactions between nearest and next-nearest Mn-C-Mn blocks [1]. On the other hand, thicker MgO films and all Si-based films exhibit ferrimagnetic (in-plane) ordering. These results indicate that the choice of a substrate and the growth mode are the primary mechanisms for controlling exchange coupling and the resulting low temperature magnetic structure in the Mn₂GaC MAX phase compound.

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Stability and magnetic ordering near the antiphase boundary in Ni₂MnGa

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Ni-Mn-Ga alloy is the most promising candidate as material for magnetic shape memory applications. In addition to austenite, it is also found in variety of martensite phases. Antiphase boundaries (APBs) are planar defects that play a critical role in strengthening Ni-based alloys, and their sensitivity to alloy composition offers a flexible tuning parameter for alloy design. In Heusler alloys it can be formed thermally upon the ordering transition or by mechanical deformation.

We combine experimental and theoretical (ab initio) methods to analyse the stability and magnetic ordering near the antiphase boundary (APB) in Ni₂MnGa with L21 ordering. Ab initio electronic structure calculations based on density functional theory (DFT) are used to investigate the magnetic ordering in a structure simulating APB's in cubic austenite. Modelling of APBs in Ni-Mn-Ga on atomic scale and micro-scale was carried out to interpret magnetic contrast measured by magnetic force microscopy based on fundamental electronic interactions. DFT calculations of supercells accommodating one or two APBs in cubic austenite Ni₂MnGa were performed. Our total energy analysis reveals that the lowest-energy APB configuration is formed by two parallel boundaries with a thin magnetic region between them with magnetization opposite to the rest of the supercell. The thickness of this region is only three Mn-Ga atomic layers. Despite being nanoscale, this region generates magnetic contrast with positive and negative peak in the perpendicular-to-surface magnetic induction, B_z, extending 100 nm around the pair of APBs.

Our DFT results are in line with the experimental evidence that APBs affect the coercivity via domain wall pinning. The underlying mechanism is the strong antiferromagnetic exchange interaction between Mn atoms on opposite sides of an APB, while the exchange interactions between neighbouring Mn atoms in bulk martensite are ferromagnetic. However, due to much smaller thickness of the APB region compared to a Bloch domain wall, the pinning is not very effective. We show that the magnetic moments of Mn atoms in ferromagnetic austenite are oriented perpendicular to the APB planes. The total energy calculations indicate that at the antiphase boundary the ferromagnetic ordering changes its orientation in the opposite direction. This sudden change in magnetization highlights the APB's, which are then readily visible by magnetic force microscopy. We find that single APB's, when close together, tend to attract each other and form thicker antiphase boundary complexes. Images are shown and discussed.

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Control of compensation and anisotropy in Co/Tb multilayers using a buffer layer

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Ferrimagnetic materials with antiferromagnetic exchange combine key advantages of ferromagnets and compensated antiferromagnets. They can be driven and read out efficiently, yet they can approach a near-zero net moment with reduced stray fields. Rare-earth/transition-metal ferrimagnets in thin-film form are particularly relevant for spintronic devices, magnetic recording, and emerging computing concepts. All-optical switching has been demonstrated in representative systems such as GdFeCo and CoTb [1]. A practical motivation is that antiferromagnetically coupled systems exhibit higher characteristic resonance frequencies than ferromagnets, supporting faster magnetic response in devices [2].

Some ferrimagnets exhibit a magnetization compensation temperature, T_{MC}, at which the opposing sublattice magnetizations cancel due to different temperature dependences. Close to T_{MC}, several phenomena of interest for applications have been reported, thus making controlled access to T_{MC} technologically valuable [3]. In compound ferrimagnets, T_{MC} is typically tuned by composition and intermixing [4]. Multilayers offer an additional degree of freedom: interface engineering. Introducing a buffer can systematically adjust interfacial structure, roughness, and effective coupling without changing the nominal layer thicknesses.

We present a systematic study of Co/Tb multilayers, focusing on the impact of an Au buffer layer on magnetic anisotropy and compensation temperature. We investigate the model stack Au(y)/Pt(5nm)/[Co(0.7nm)/Tb(x)]_{×6}/Au(5nm). Using magnetometry and magneto-optical spectroscopy, we extract T_{MC} as a function of the buffer layer parameters. Increasing the Au buffer thickness shifts T_{MC} to higher temperatures, enabling a large tuning range (approximately 90–395 K) even for nominally identical Co/Tb layer thicknesses. The trend correlates with buffer-induced changes in interface morphology [5], indicating that T_{MC} can be engineered via interfacial effects rather than solely through compositional changes.

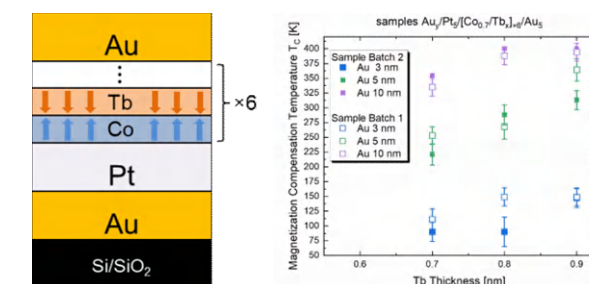


Figure 1. Left: Schematic of the investigated multilayer system. Right: Magnetization compensation temperature T_{MC} in dependence on Tb layer thickness and the thickness of the Au buffer layer.

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Chitosan-coated iron-based nanoparticles for magnetic hyperthermia application

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Magnetic hyperthermia is a promising minimally invasive approach for cancer therapy based on the remote heating induced by magnetic nanoparticles under an alternating magnetic field. Iron-based nanoparticles, including iron oxides (i.e., γ -Fe₂O₃, Fe₃O₄), and ferrites (e.g., CoFe₂O₄), are widely investigated systems for biomedical applications [1-4]. However, their clinical translation is limited by many factors, such as colloidal instability, protein corona formation, aggregation, uncontrolled biodistribution, and complex interactions with the biological environment, etc. Maintaining strong magnetic response at low doses remains crucial, as low particle size increases surface effects, but conversely can decrease the magnetic moment. A possible technological solution is to deposit an organic coating (e.g., chitosan), which can improve the colloidal stability and biocompatibility, enabling functionalization, and providing partial biodegradability, while forming a stable interface between the magnetic core and the biological medium.

In this study, we investigate chitosan-coated iron-based nanoparticles for magnetic hyperthermia applications. The structural and morphological properties (size, distribution, crystallinity, and shape) were systematically characterized and correlated with their magnetic behavior (Figure 1). Magnetic hyperthermia efficiency was evaluated before and after coating chitosan.

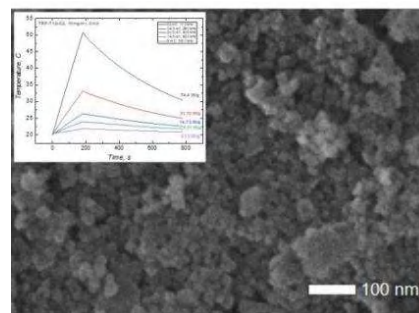


Figure 1. SEM image of CoFe₂O₄ nanoparticles and their magnetic hyperthermia response under an alternating magnetic field.

Results, although preliminary, demonstrate that by appropriately engineering iron-based nanoparticles can provide efficient and controllable heat generation under clinically relevant alternating magnetic fields, making these systems promising candidates for safe and tunable magnetic hyperthermia therapy.

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Dynamic Characterization of Nanowire Arrays with Interlayer Exchange Coupling

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The tunability of synthetic antiferromagnets and magnetic multilayers in general allows for optimization of properties that are relevant for applications including magnetic memories, sensors, refrigeration, energy storage, and neuromorphic computing schemes [1]. In metallic multilayers, interlayer coupling is commonly mediated by the Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction, which allows both the magnitude and sign of the coupling to be tuned through the thickness of a non-magnetic spacer layer [2]. While this interaction in thin films is well known, three-dimensional (3D) magnetic nanostructures with more complex geometries offer opportunities for further study [3]. Novel phenomena arising from complex geometries and competing inter-layer interactions may lead to new opportunities for advanced spintronic and magnonic functionalities.

This work explores the interplay between interlayer magnetic interaction and geometrical effects on the dynamical response of periodic arrays of magnetic nanowires. This is achieved by a systematic study of Py/Ru/Py samples with controlled geometrical parameters like magnetic and non-magnetic layer thicknesses, and nanowire separation. Quasi-static hysteresis loops of the samples are obtained by performing Magneto-Optic Kerr Effect (MOKE) magnetometry and Vibrating Sample Magnetometry (VSM) measurements to fit the quadratic (J₁) and biquadratic (J₂) interlayer-exchange coupling constants. Brillouin light scattering (BLS) measurements explore the spin-wave dispersion and its dependence on the applied magnetic field. These results can be accurately described by first-order excitations of the Landau-Lifshitz (LL) equation, which, using the Plane-Wave Method (PWM) [4], allows the exploration of the dependence of mode frequencies and their spatial profiles on the magnetic and geometrical parameters. The results reveal thickness-dependent modifications of the coupling field and dynamical mode behavior, highlighting the interplay between spacer-mediated exchange and intrinsic layer properties. Also, the exploration of propagating and laterally confined modes and their spatial profiles gives further insight into the magnetic coupling between neighboring nanowires. This establishes a robust reference framework for extending RKKY-coupled multilayer concepts to different 3D magnetic nanostructures and novel magnonic architectures.

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Ultra-Compact Magnetoelectric Antenna for RF Energy

Harvesting

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The miniaturization of GHz-range antennas is fundamentally constrained by electromagnetic scaling limits [1], driving the emergence of magnetoelectric (ME) antennas that leverage strain-mediated coupling to achieve deep subwavelength operation [2].

This work investigates the near-field coupling between magnetic, electric, and mechanical domains, along with the far-field radiation characteristics for one of the smallest ME structures designed to date. The proposed device is composed of a $100 \times 28 \mu\text{m}^2$ Mo/AlN/FeGaB multilayer stack, where strain-mediated coupling between piezomagnetic and piezoelectric layers enables efficient electromagnetic radiation at deeply subwavelength dimensions.

A systematic analysis of the FeGaB magnetic layer thickness reveals a clear shift in the resonant frequency as seen in Fig. 1(a), highlighting the key role of the piezomagnetic layer in tuning the device response.

Despite its reduced size, the device achieves far-field amplitudes of the order of $4.73 \mu\text{V/m}$, at resonant frequency $f_r = 2.1 \text{ GHz}$ (Fig. 1(b)), exceeding previously reported microscale ME antennas.

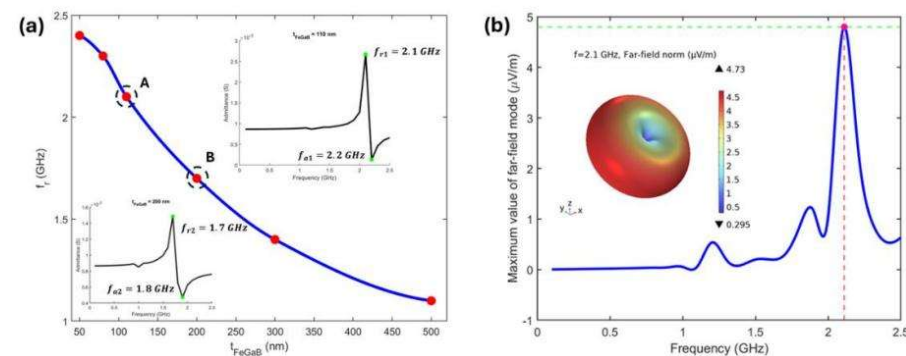


Figure 1 (a) Variation of resonance frequency versus thickness of FeGaB layer. Two admittance characteristic curves are shown for (A) $t_{\text{FeGaB}} = 110 \text{ nm}$ and (B) $t_{\text{FeGaB}} = 200 \text{ nm}$. (b) Maximum far-field mode ($\mu\text{V/m}$) as a function of frequency, highlighting the resonant response and corresponding 3D radiation pattern.

Furthermore, polarization analysis indicates that the radiated electric field is predominantly oriented in the Y-Z plane, corresponding to a tilted dipole-like radiation mechanism. These results demonstrate that efficient radiation can be achieved at the nanoscale through balanced coupling between electric and magnetic dipoles. Thus highlighting the potential of ME antennas for highly integrated energy harvesting systems.

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Wafer-scale deposition of SmCo films by remote plasma sputtering:
A route to high-performance permanent micromagnetsSreya Pal^a, Marco Asa^a, Federico Maspero^a, Riccardo Bertacco^a^aDipartimento di Fisica, PoliFAB, Politecnico di Milano, Via Giuseppe Colombo 81, Milano 20133, Italy

Rare-earth-transition-metal (RE-TM) alloys are central to magnetic materials research owing to their large magnetocrystalline anisotropy, high Curie temperature, and excellent thermal stability [1]. Among them, samarium-cobalt (Sm-Co) alloys are particularly attractive for integrated permanent micromagnets due to their high coercivity and thermal robustness. However, conventional SmCo thin-film deposition typically requires high-temperature post-deposition annealing and exhibits limited scalability to large-area wafers, restricting wafer-level integration [2]. This limitation is especially critical for emerging spintronic and magnonic platforms, where SmCo micro- and nanomagnets are being explored as integrated bias-field sources to replace bulky external electromagnets. Their practical implementation in MEMS-compatible magnonic device architectures therefore remains constrained by the lack of CMOS-compatible deposition processes [3].

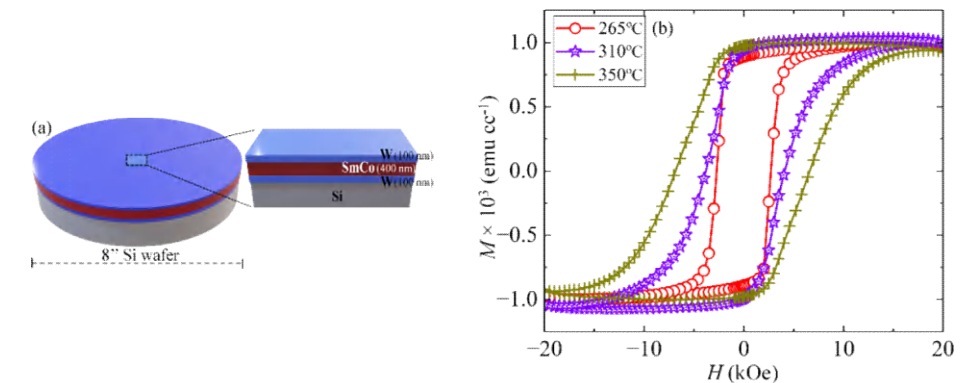


Figure 1: (a) Schematic illustration of the W/SmCo/W thin-film stack deposited on an 8'' wafer. (b) In-plane M-H hysteresis loops of the W/SmCo/W films,

Here, we demonstrate the systematic optimization of a process for deposition of SmCo film with tungsten as buffer layer as well as capping layer on large-scale 8'' Si wafers using remote plasma sputtering based on high target utilisation sputtering (RPS-HiTUS®) technology [4], in which plasma generation is spatially decoupled from the sputtering target, enabling independent control of plasma density and ion energy at the substrate. The influence of target bias, process pressure, and substrate temperature on structural evolution, and magnetic performance is comprehensively investigated and optimized with good wafer-scale uniformity. Importantly, by employing in-situ substrate heating up to 350°C, robust magnetic hardness of SmCo is achieved without post-deposition annealing, resulting in coercivity values up to 0.67 T together with good wafer-scale uniformity, thereby significantly reducing the thermal budget and enhancing compatibility with silicon-based electronics.

These results demonstrate that RPS-HiTUS® provides a CMOS-compatible and manufacturable pathway for integrating high-coercivity permanent magnets into MEMS, spintronic, and magnonic device architectures, thereby enabling power-hungry electromagnet free magnetic functionalities in next-generation on-chip systems.

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Epitaxial growth and characterization of NiAs-type altermagnetic MnTe thin films on (111) substrates

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Manganese telluride (MnTe) has recently attracted significant attention as a promising altermagnetic material, exhibiting strong momentum-dependent spin splitting in its electronic band structure while maintaining nearly zero net magnetization [1]. These properties make MnTe particularly attractive for next-generation spintronic applications, especially in thin-film form compatible with conventional semiconductor platforms.

In this work, we report the epitaxial growth of high-quality MnTe thin films in the hexagonal NiAs phase on (111)-oriented InP, SrF₂, BaF₂, and Si substrates using molecular beam epitaxy. In situ reflection high-energy electron diffraction confirms a two-dimensional growth mode, evidenced by well-defined streaky patterns, while atomic force microscopy reveals atomically smooth surfaces. Epitaxial growth on Si (111) is achieved for film thicknesses down to 20 nm, highlighting the feasibility of integrating MnTe with silicon-based technologies.

Structural characterization by X-ray diffraction and high-resolution transmission electron microscopy (HRTEM) demonstrates highly oriented (0001) epitaxial films with a hexagonal NiAs-type structure across all substrates. Substrate-dependent strain, arising from lattice and thermal expansion mismatches is observed. For MnTe films grown on SrF₂(111) and BaF₂(111), which exhibit minimal thermal mismatch, the lattice parameters ($a = 0.4146$ nm, $c = 0.6716$ nm) are close to bulk values [2, 5]. The observed c/a ratio ranges between 1.60 to 1.62 for all substrates we used. Elemental analysis using SEM-EDX indicates a slightly Mn-rich composition ($\sim 53 \pm 2$ at.%), consistent with previously reported values for MnTe thin films [3]. Magnetotransport measurements reveal weak ferromagnetism attributed to the Dzyaloshinskii–Moriya interaction [4,5], as evidenced by hysteresis in magnetoresistance curves.

Overall, these results establish a reliable route for the growth of high-quality epitaxial NiAs-type MnTe thin films on technologically relevant substrates, advancing their potential for integration into spintronic devices.

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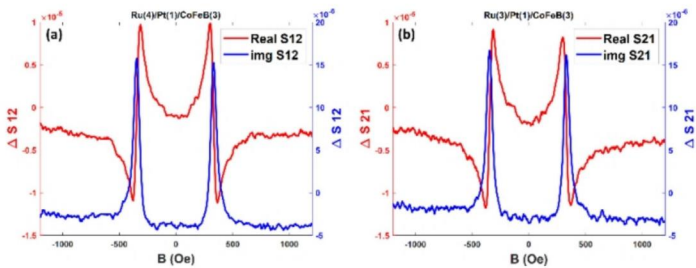
Reciprocity in Charge–Orbital-Spin interconversion

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Orbital current transport (J_o) has emerged as a promising alternative to conventional spin transport, offering larger signal magnitudes since it is not intrinsically limited by relativistic effects. Through spin–orbit coupling (SOC), orbital currents can be converted into spin currents, making them attractive for low-power spintronic applications. Recent work in orbitronics has focused on generating orbital currents via the orbital Hall effect (OHE) and orbital Rashba–Edelstein effect (OREE), as well as orbital pumping, where ferromagnetic precession emits a pure orbital current without charge flow. This latter mechanism avoids conductivity-mismatch issues and enables efficient generation in simple bilayer structures. These developments motivate studies of both direct (OHE, OREE) and reciprocal (iOHE, iOREE) orbital transport effects. However, charge-to-orbital and orbital-to-charge conversion have not yet been examined within a single device platform, leaving open whether they satisfy Onsager reciprocity.

In orbital Hall heterostructures such as Ru/Pt/CoFeB, S-parameter measurements were performed using a coplanar waveguide (CPW) electrically insulated from the device. The ferromagnetic strip was connected to Port 2, and the CPW to Port 1. Devices were fabricated via standard optical lithography, sputtering, and lift-off, and prior ST-FMR measurements confirmed current-induced excitation of the ferromagnet. Exciting Port 2 generates spin currents in Pt via the Orbital/Spin Hall effects, which drive CoFeB magnetization through Spin Orbit torque. The resulting dynamics induce a voltage in the CPW via inductive coupling, detected as S_{12} . Conversely, excitation at Port 1 drives magnetization precession, which pumps angular momentum into Pt and is converted into a charge signal via inverse Spin/Orbital Hall effects, contributing to S_{21} . We found, $S_{12}(B) = S_{21}(-B)$, demonstrating reciprocity [1] between direct and inverse processes.



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Observation of Ferromagnetism in Sputtered Co-doped HfO₂ Thin Films

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Magnetic semiconductors are promising candidates for multifunctional spintronic device applications [1]. The magnetic properties of undoped and Co-doped HfO₂ thin films sputtered on a Si substrate were studied. The room-temperature ferromagnetism has been observed in Co-doped HfO₂. XRD studies confirm that the undoped and Co-doped HfO₂ thin films exhibit a monoclinic structure, and upon doping, an improvement in crystallinity is observed. Moreover, no secondary impurity phases are observed in the Co-doped HfO₂ films. SEM and AFM images confirm that both undoped and Co-doped films show uniform and homogeneous surfaces. Upon doping, the film crystallinity enhances and leads to the formation of smoother and more uniform grain boundaries, thereby reducing the surface roughness, which is obtained from AFM roughness. EDX and XPS analysis confirm the presence of Hf and O in the undoped samples and Hf, Co, and O in the doped samples. Magnetic characterization reveals the diamagnetic nature of HfO₂. On the other hand, the doped samples show M-H hysteresis loops at various temperatures (300, 50, 10, 2 K), suggesting ferromagnetic ordering. It may be due to dopant-induced magnetic exchange interactions, bound magnetic polaron formation, and defect-induced magnetism [2][3]. Additionally, the observed ferromagnetism may be attributed to carrier-mediated exchange interactions, such as RKKY interaction, particularly observed in dilute magnetic semiconducting films. The enhanced crystallinity and dopant-driven magnetic interactions may play a significant role in the observed ferromagnetic nature in the Co-doped HfO₂ thin films.

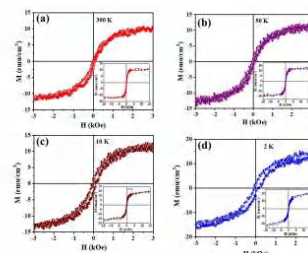


Figure 1: M-H hysteresis loop of Co-doped HfO₂ films at temperatures of (a) 300, (b) 50, (c) 10, and (d) 2 K, after subtracting the diamagnetic contribution. The inset presents the full range loop from -15 to 15 kOe.

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Surface properties and spin waves of ferroelectric/ferromagnetic superlattices

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Currently, the excitation and propagation of spin waves in chiral magnetic structures with nontrivial topology is widely considered a promising medium for spintronic devices [1], as well as perspective materials science platform for magnonic THz spintronics, and non-volatile data storage [2]. Using temperature Green's functions, we study spin wave dynamics and thermodynamic properties of ferroelectric/ferromagnetic superlattices. The magnetic subsystem is described by the Heisenberg model with competing ferromagnetic and antiferromagnetic exchange interactions [3]. The magnetoelectric interaction is taken into account at the ferroelectric/ferromagnet interface. Analytical expressions have been obtained for the spin wave spectra, and for the temperature dependences of the energy and magnetization of individual layers. It is shown that the magnetoelectric interaction increases the deviation angle of the spiral structure from the equilibrium configuration in the near-surface regions, shifts the surface modes in the dispersion law to the high-frequency range, and suppresses the effect of magnetization crossover between layers with increasing temperature (see a.b. fig. 1).

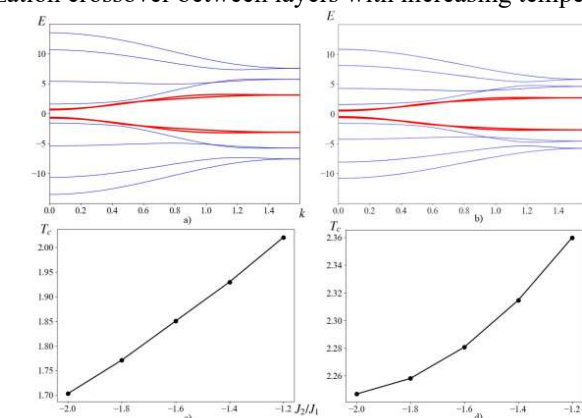


Figure 1. Dispersion curves of the film at $J_2/J_1 = -1.4$: (a) $J_{mf} = -0.1$, (b) $J_{mf} = -1.0$. The surface branches of the spectrum, localized at the interfaces with ferroelectrics, are highlighted in red. Dependence of the transition temperature T_c on J_2/J_1 at (c) $J_{mf} = -0.1$, (d) $J_{mf} = -1.0$.

We have discovered that the critical temperature of the phase transition monotonically decreases with increasing frustration parameter of exchange interactions J_2/J_1 , but increases with increasing magnetoelectric coupling parameter and anisotropy (see c.d. fig. 1). Furthermore, we revealed that quantum fluctuations at $T = 0$ reduce the effective spin wave length, with this reduction being more pronounced in the inner layers.

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Non-Reciprocal Band Effect in Magnetic Materials: from Symmetry Constraints to First-Principles Validation

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The non-reciprocal band effect (NRBE), characterized by the relation $\varepsilon(\mathbf{k}) \neq \varepsilon(-\mathbf{k})$, emerges from the simultaneous breaking of time-reversal (Θ) and inversion (φ) symmetries. By inducing unequal group velocities for opposite crystal momenta, NRBE directly affects nonlinear transport and optical responses, representing a promising mechanism for directional functionalities and bulk photovoltaic applications [1]. Despite recent predictions in specific compounds such as EuO [2], a general symmetry-based framework for identifying and understanding NRBE is still lacking.

We provide a complete symmetry classification of NRBE across all 122 Magnetic Point Groups (MPGs). Using the method of invariants, we demonstrate that 31 MPGs allow a linear contribution in $\mathbf{k}$, 27 support cubic terms, 4 exhibit fifth-order terms, and 7 permit only higher-order odd contributions. The remaining groups either preserve time-reversal symmetry (grey groups) or inversion symmetry, thereby forbidding NRBE. This classification establishes a direct correspondence between magnetic symmetry and the lowest-order non-reciprocal contribution allowed in the electronic dispersion, providing a predictive framework independent of the specific material realization.

Crucially, the $\mathbf{k} \cdot \mathbf{p}$ perturbative analysis reveals that, whenever allowed by symmetry, the NRBE emerges in all electronic bands, independently of their irreducible representation. The $\mathbf{k} \cdot \mathbf{p}$ approach further clarifies the NRBE microscopic origin: the linear term arises from intra-manifold interactions and scales directly with the spin-orbit coupling strength, whereas higher-order terms originate from the coupling between different manifolds, thus scaling also inversely with the energy separation between the involved manifolds. Consequently, the linear NRBE represents the dominant contribution in most materials. Importantly, symmetry not only determines whether NRBE is allowed, but also uniquely identifies the momentum directions along which the band asymmetry manifests. Based on these directional constraints, together with the presence (or absence) of macroscopic magnetization and polarization, the 69 MPGs.

Density Functional Theory (DFT) calculations on different materials from each symmetry class – EuO (m'm2') [2], PbNiO₃ (3m.1), SrMnO₃ (2'2'2), and Mn₂Au (m'mm) [3] – confirm these predictions and show that the effect is present across the entire electronic band structure, independently of the band irreducible representation. Figure 1 illustrates the case of PbNiO₃ as a representative example.

These results establish a general and comprehensive symmetry-based framework for identifying the NRBE, enabling the prediction of both its existence and momentum-space direction, and facilitating the discovery of non-reciprocal electronic, optical, and transport phenomena. More broadly, our work reframes NRBE from a material-specific phenomenon to a symmetry-governed property, thereby enabling the systematic search for non-reciprocal functionalities across non-centrosymmetric magnets.

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