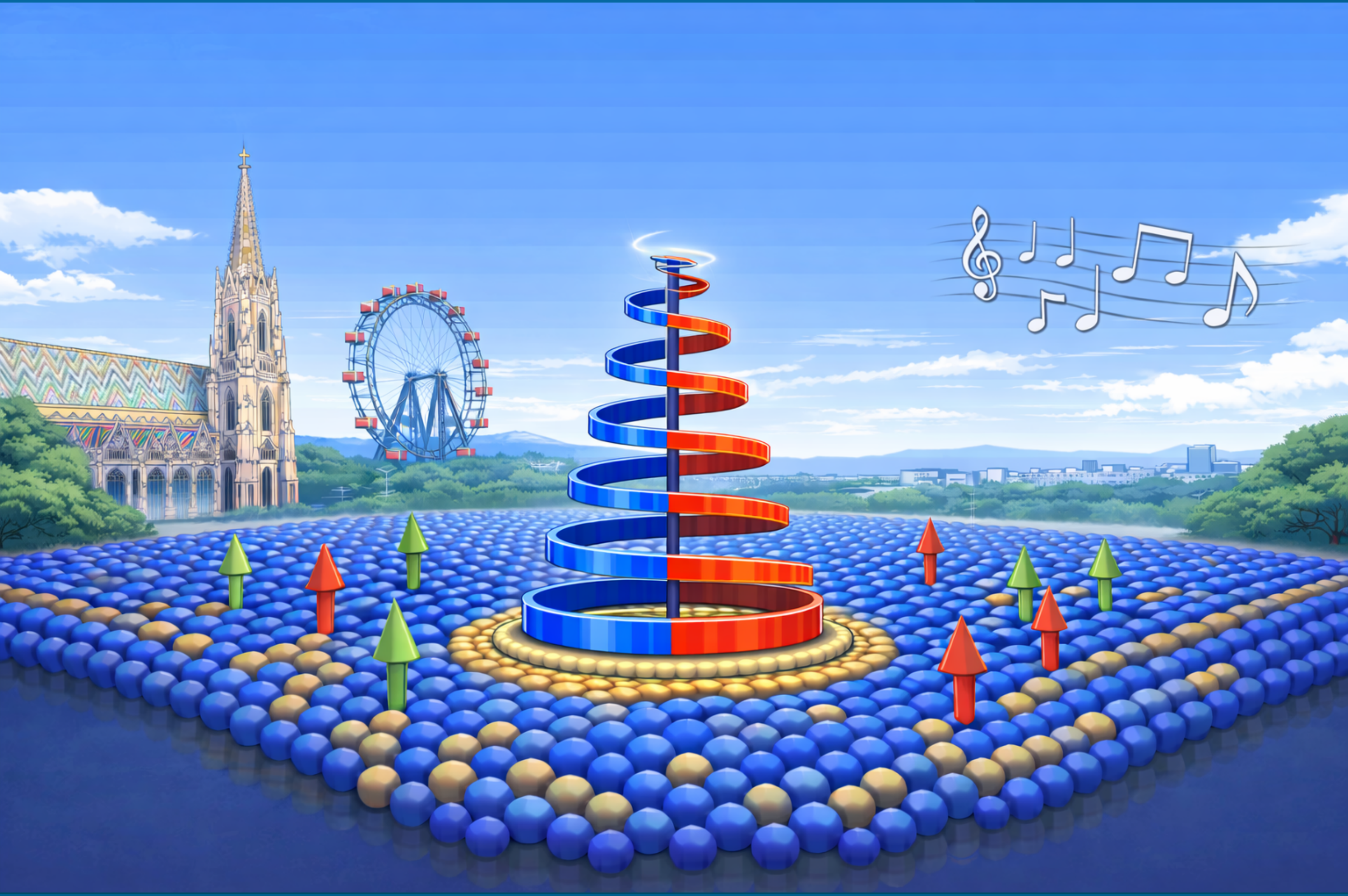
1st International Symposium on Three-Dimensional Nanomagnetism

3DMAG 2026 | 13-17 July 2026 | Vienna, Austria



Book of Abstracts

TU Wien, Freihaus Building

Vienna, Austria

2026 July 13–17

tuwien.at/en/phy/iap/conferences/3dmag-2026

Conference website

ConfTool

Hosted by 3DNANO, Institute of Applied Physics, TU Wien

CONTENTS

WELCOME

Welcome to 3DMAG 2026, the 1st International Symposium on Three-Dimensional Nanomagnetism, held in Vienna from 13 to 17 July 2026. The meeting brings together the international 3D nanomagnetism community to discuss challenges, opportunities, and future directions in nanoscale magnetic materials and phenomena in three dimensions.

3DMAG 2026 focuses on magnetic materials and phenomena at the nanoscale where geometry, topology, curvature, surfaces, and volume all become active design parameters.

USEFUL ONLINE RESOURCES

Resource	Use	QR / link
Conference website	Latest general information, programme, social events, travel and sponsor information.	
ConfTool 3DMAG	Registration account, registration and payment details, attendance certificate and payment confirmation download.	
Programme page	Latest programme PDF, speaker timings and poster format.	Programme page

Certificates and payment documents. This abstract book is intended as the stable conference reference. The conference website and ConfTool remain the live sources for updates, registration records, certificates, and payment documents.

CONFERENCE ORGANIZATION

Organising Committees

Conference Chair

Prof. Amalio Fernández-Pacheco
3DNANO, Institute of Applied Physics, TU Wien

International Advisory Committee

Adekunle O. Adeyeye (Durham University, UK)
Dora Altbir (University Diego Portales, Chile)
Claire Donnelly (Max Planck Institute for Chemical Physics of Solids, Dresden, Germany)
Amalio Fernández-Pacheco (TU Wien, Austria)
Giovanni Finocchio (University of Messina, Italy)
Peter Fischer (Lawrence Berkeley National Lab, USA), chair
Olivier Fruchart (SPINTEC, Grenoble, France)
Denys Makarov (Helmholtz-Zentrum Dresden-Rossendorf, Germany)
Shinichiro Seki (University of Tokyo, Japan)
Bethanie Stadler (University of Minnesota, USA)
Xiuzhen Yu (RIKEN Center for Emergent Matter Science, Japan)

Programme Committee

Dora Altbir (University Diego Portales, Chile)
Andrii Chumak (University of Vienna, Austria)
Amalio Fernández-Pacheco (TU Wien, Austria)
Olivier Fruchart (SPINTEC, Grenoble, France)
Denys Makarov (Helmholtz-Zentrum Dresden-Rossendorf, Germany)
Dieter Suess (University of Vienna, Austria)
Bethanie Stadler (University of Minnesota, USA)

Local Host

3DNANO, Institute of Applied Physics, TU Wien

Conference Contact

3dmag@tuwien.ac.at

KEYNOTE, INVITED AND INAUGURAL SPEAKERS

Inaugural lecture

- Peter Fischer (IL1), LBNL

Keynote speakers

- Stuart Parkin (K1), Max Planck Institute of Microstructure Physics, Halle
- Shunsuke Fukami (K2), Tohoku University
- Denis Sheka (K3), Taras Shevchenko National University of Kyiv
- Claire Donnelly (K4), Max Planck Institute for Chemical Physics of Solids, Dresden
- Dirk Grundler (K5), Ecole Polytechnique Fédérale de Lausanne (EPFL)

Invited speakers

- Sam Ladak (I1), represented by Dr. Joseph Askey, Cardiff University
- Victoria Vega Fernández (I2), University of Oviedo
- Vincent Cros (I3), Laboratoire Albert Fert, CNRS, Thales
- Kai Liu (I4), Georgetown University
- Tristan da Câmara Santa Clara Gomes (I5), INESC-MN
- Lucía Gómez Cruz (I6), Dpto. Física de Materiales, Facultad de Ciencias Físicas, Universidad Complutense de Madrid
- Sabri Koraltan (I7), Technische Universität Wien
- Sol Jacobsen (I8), Norwegian University of Science and Technology, NTNU
- Run-Wei Li (I9), Eastern Institute of Technology, Ningbo
- Ivan Smalyuk (I10), University of Colorado
- Charudatta Phatak (I11), Argonne National Laboratory/Northwestern University
- Saroj Dash (I12), CHALMERS UNIVERSITY OF TECHNOLOGY
- Claas Abert (I13), University of Vienna
- Massimiliano d’Aquino (I14), University of Naples Federico II
- Max Birch (I15), RIKEN Center for Emergent Matter Science
- Karin Everschor-Sitte (I16), University of Duisburg-Essen

SESSION CHAIRS

Session 01
Monday, July 13, 2026
Amalio Fernández-Pacheco
Technische Universität Wien (TU Wien)

Session 02
Monday, July 13, 2026
Olivier Fruchart
SPINTEC, Spintronics and Technology of Components

Session 03
Tuesday, July 14, 2026
Dieter Suess
University of Vienna

Session 04
Tuesday, July 14, 2026
Bethanie Stadler
University of Minnesota

Session 05
Tuesday, July 14, 2026
Naëmi Leo
University of Loughborough

Session 06
Wednesday, July 15, 2026
Oksana Chubykalo-Fesenko
Instituto de Ciencia de Materiales de Madrid, CSIC

Session 07
Wednesday, July 15, 2026
Karin Everschor-Sitte
Universität Duisburg-Essen

Session 08
Wednesday, July 15, 2026
Denys Makarov
Helmholtz-Zentrum Dresden-Rossendorf

Session 09
Thursday, July 16, 2026
Aurelio Hierro Rodríguez
University of Oviedo

Session 10
Thursday, July 16, 2026
Charudatta Phatak
Argonne National Laboratory

Session 11
Thursday, July 16, 2026
Riccardo Tomasello
Politecnico di Bari

Session 12
Thursday, July 16, 2026
Gianluca Gubbiotti
Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche (CNR-IOM), Perugia

Session 13
Friday, July 17, 2026
Peter Fischer
Lawrence Berkeley National Laboratory

Session 14
Friday, July 17, 2026
Claire Donnelly
Max Planck Institute for Chemical Physics of Solids, Dresden

SPONSORS

Sponsor page: https://www.tuwien.at/en/phy/iap/conferences/3dmag-2026/sponsors

Gold sponsors

Durham Magneto Optics

Park Systems

Zurich Instruments AG

Silver sponsors

attocube

European Magnetism Association

HZDR Innovation

IEEE Magnetics Society

Nanoscribe

Quantum Design GmbH

QZabre

Bronze sponsors

Cell Press

Evico Magnetics

PRACTICAL INFORMATION

Venue:

TU Wien, Freihaus building, Wiedner Hauptstraße 8–10 / Operngasse 13–15, 1040 Vienna, Austria.

Lecture hall:

FH 1 Peter Skalicky Hörsaal. TU Wien map: maps.tuwien.ac.at/?q=DC02H03.

Travel information:

https://www.tuwien.at/en/phy/iap/conferences/3dmag-2026/travel-accommodation.

Conference contact:

3dmag@tuwien.ac.at.

Registration desk:

Badge collection and on-site questions are handled at the registration desk in the Freihaus conference area before entering the lecture hall.

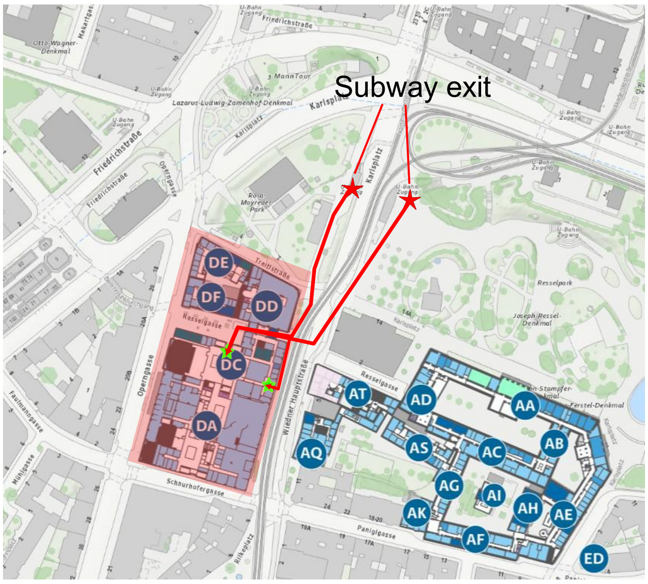
Wi-Fi and local information:

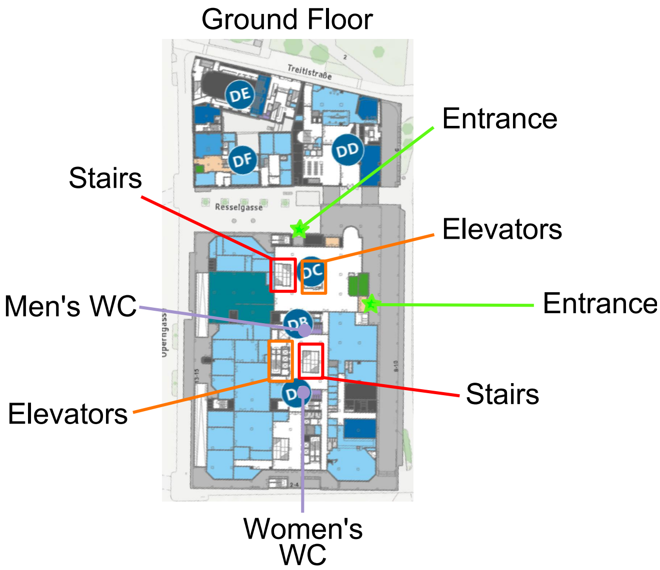
Eduroam is available on campus. Guest Wi-Fi, accessibility and cloakroom/luggage information will be provided at the registration desk when needed.

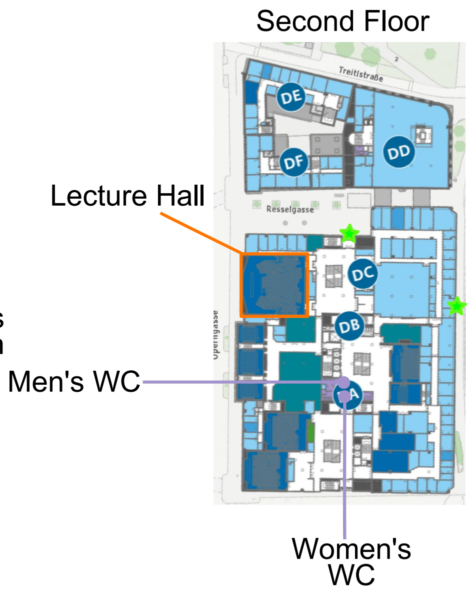
Online updates:

The printed/PDF abstract book is the stable reference document. The website and ConfTool remain the live sources for updates and participant documents.

Lecture hall map







All rooms can be searched for and found using TUW Maps. The room number is composed as follows, using the example of the Lecture Hall DC02H03

- **D**C02H03: the first letter indicates the campus or building complex. In the example, the D indicates the Freihaus campus.
- D**C**02H03: the second letter indicates the wing or building. In the example, the C indicates the main wing of the main building. “A” stands for the green tower, “B” stands for the yellow tower, “C” stands for the red tower
- DC**02**H03: The first two digits indicate the floor. In the example, this is the second floor.
- DC02**H03**: The last two digits indicate the room number, which is determined using a grid. In the example, this is the Lecture Hall

PRESENTER INFORMATION

Presentation Times

Presentation type	Total time	Suggested split
Keynote lecture	40 min	30 min presentation + 10 min discussion
Invited talk	30 min	25 min presentation + 5 min discussion
Oral contribution	20 min	15 min presentation + 5 min discussion

Presentation equipment. Speakers are welcome to use their own laptop. A conference laptop will also be available; speakers wishing to use it should contact the organisers upon registration.

Poster Format and Timing

- Poster format: A0 portrait.
- Tuesday, July 14, 2026: 14:00-15:30 (Poster Session 1 - coffee served; P1-P20).
- Wednesday, July 15, 2026: 14:00-15:30 (Poster Session 2 - coffee served; P21-P39).
- Posters may be mounted from Monday afternoon and remain available until Friday morning unless the organisers announce otherwise.
- The organisation will provide the necessary materials to hang the posters.

STUDENT PRESENTATION PRIZES

- All students are eligible for the 3DMAG 2026 student prizes.
- Voting panel: Keynote speakers, invited speakers, Programme Committee members, International Advisory Committee members, and session chairs.
- Voting basis: Scientific quality, clarity of presentation, response to questions, and overall contribution to the conference discussion.
- Awards: IT products with values of EUR 400, EUR 300, and EUR 200.
- Award timing: The prizes will be presented during the closing ceremony.

PROGRAMME OVERVIEW

TU Wien, Freihaus building, Vienna, Austria

Monday, July 13, 2026

11:00-13:00	Conference Check-in
13:00-13:35	Opening ceremony (including concert)
13:35-14:00	Inaugural lecture (IL1) Peter Fischer
14:00-14:40	Keynote 1 (K1) Stuart Parkin
14:40-15:10	Coffee break
15:10-15:40	Invited 1 (I1) Sam Ladak (represented by Dr. Joseph Askey)
15:40-16:00	Oral 1 (O1) Naëmi Leo
16:00-16:30	Invited 2 (I2) Victoria Vega Fernández (student)
16:30-16:50	Oral 2 (O2) Bethanie Stadler
16:50-17:10	Oral 3 (O3) Rafael Pérez
17:10-18:00	Lab tours

Tuesday, July 14, 2026

09:00-09:40	Keynote 2 (K2) Shunsuke Fukami
09:40-10:10	Invited 3 (I3) Vincent Cros
10:10-10:30	Oral 4 (O4) Krishnanjana Puzhekadavil Joy (student)
10:30-11:00	Coffee break
11:00-11:05	Sponsor 1: Zurich Instruments
11:05-11:35	Invited 4 (I4) Kai Liu
11:35-11:55	Oral 5 (O5) Juliano Denardin
11:55-12:25	Invited 5 (I5) Tristan da Câmara Santa Clara Gomes
12:25-14:00	Lunch
14:00-15:30	Poster Session 1 - coffee served
15:30-15:50	Oral 6 (O6) Eider Berganza
15:50-16:20	Invited 6 (I6) Lucía Gómez Cruz (student)
16:20-16:40	Oral 7 (O7) Daria Gusakova
16:40-17:00	Oral 8 (O8) Robert Kraft (student)
17:10-18:00	Lab tours

Wednesday, July 15, 2026

09:00-09:40	Keynote 3 (K3) Denis Sheka
09:40-10:10	Invited 7 (I7) Sabri Koraltan
10:10-10:30	Oral 9 (O9) Trevor Almeida
10:30-11:00	Coffee break
11:00-11:05	Sponsor 2 : Park Systems
11:05-11:25	Oral 10 (O10) Olha Bezsmertna (student)
11:25-11:55	Invited 8 (I8) Sol Jacobsen
11:55-12:15	Oral 11 (O11) Alexander Edström
12:25-14:00	Lunch
14:00-15:30	Poster Session 2 - coffee served
15:30-16:00	Invited 9 (I9) Run-Wei Li
16:00-16:20	Oral 12 (O12) Giovanni Finocchio

16:20-16:50	Invited 10 (I10) Ivan Smalyuk
17:00-17:20	Conference photo

Thursday, July 16, 2026

09:00-09:40	Keynote 4 (K4) Claire Donnelly
09:40-10:10	Invited 11 (I11) Charudatta Phatak
10:10-10:30	Oral 13 (O13) Nicolas Jaouen
10:30-11:00	Coffee break
11:00-11:05	Sponsor 3: Durham Magneto-Optics
11:05-11:35	Invited 12 (I12) Saroj Dash
11:35-11:55	Oral 14 (O14) Dominik Schramm (student)
11:55-12:15	Oral 15 (O15) Mateusz Gołębiewski
12:25-14:00	Lunch
14:00-14:40	Keynote 5 (K5) Dirk Grundler
14:40-15:10	Invited 13 (I13) Claas Abert
15:10-15:30	Oral 16 (O16) Gianluca Gubbiotti
15:30-16:00	Coffee break
16:00-16:30	Invited 14 (I14) Massimiliano d'Aquino
16:30-16:50	Oral 17 (O17) Matteo Vitali (student)
17:00-18:30	Social activity
18:30-22:00	Conference dinner

Friday, July 17, 2026

09:30-10:00	Invited 15 (I15) Max Birch
10:00-10:20	Oral 18 (O18) Rikako Yamamoto
10:20-10:40	Oral 19 (O20) Volodymyr Kravchuk
10:40-11:10	Coffee break
11:10-11:40	Invited 16 (I16) Karin Everschor-Sitte
11:40-12:00	Oral 20 (O19) Sanjay Ashok
12:00-12:20	Oral 21 (O21) Richard Harrison
12:30-13:00	Closing ceremony

Monday, July 13, 2026
Detailed scientific programme
TU Wien, Freihaus building

11:00-13:00
Conference Check-in

Session 01
Chair: Amalio Fernández-Pacheco *Technische Universität Wien (TU Wien)*

13:00-13:35
Opening ceremony (including concert)

13:35-14:00
IL1. **Advances in 3D nanomagnetism: key breakthroughs, open challenges, and future opportunities**
Peter Fischer
Lawrence Berkeley National Laboratory

14:00-14:40
K1. **2D and 3D Racetrack Memory**
Stuart Parkin
Max Planck Institute of Microstructure Physics, Halle

14:40-15:10
Coffee break

Session 02
Chair: Olivier Fruchart *SPINTEC, Spintronics and Technology of Components*

15:10-15:40
I1. **3D Artificial Spin-ice**
Sam Ladak (represented by Dr. Joseph Askey)
Cardiff University

15:40-16:00
O1. **Deterministic control of internal structure of Bloch points using topological defects in helical nanowires**
Naëmi Leo
Loughborough University

16:00-16:30
I2. **Branch selection at stripe domain bifurcations in reconfigurable magnetic domain wall racetracks**
Victoria Vega Fernández (student)
University of Oviedo

16:30-16:50
O2. **Controlling and Observing Vortex Formation in Magnetic Nanowire: Individual Nanowires and Arrays**
Bethanie Stadler
University of Minnesota

16:50-17:10

O3. Thermal Gradient-Induced Bouncing of Chiral Domain Walls under Applied Current at Cylindrical Nanowire Ends

Rafael Pérez
Institute of Materials Science of Madrid

17:10-18:00

Lab tours

Tuesday, July 14, 2026
Detailed scientific programme
TU Wien, Freihaus building

Session 03
Chair: Dieter Suess *University of Vienna*

09:00-09:40
K2. MRAM and probabilistic spintronics towards three-dimensional magnetic architectures
Shunsuke Fukami
Tohoku University

09:40-10:10
I3. Pt/Co/Al multilayers: a material platform for 3D skyrmionics
Vincent Cros
Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay

10:10-10:30
O4. Three-dimensional control of magnetic cocoons in multilayers employing He+ ions
Krishnanjana Puzhekadavil Joy (student)
Helmholtz Zentrum Berlin, University of Augsburg

10:30-11:00
Coffee break

Session 04
Chair: Bethanie Stadler *University of Minnesota*

11:00-11:05
Sponsor 1: Zurich Instruments

11:05-11:35
I4. 3D magnetic nanowire networks and curvature induced magnetism
Kai Liu
Georgetown University

11:35-11:55
O5. Geometry-stabilized skyrmions and emergent Hall signatures in curved Pt/Co/Ta nanodomes
Juliano Denardin
Physics Department, University of Santiago

11:55-12:25
I5. Magneto-thermoelectric effects in three-dimensional interconnected magnetic nanowire networks
Tristan da Câmara Santa Clara Gomes
INESC Microsistemas e Nanotecnologias (INESC MN)

12:25-14:00
Lunch

Poster Session 1
TU Wien, Freihaus building

14:00-15:30

P1. Focused electron beam induced deposition and characterization of 3D racetrack memory systems
Trevor Almeida
University of Glasgow

P2. Bias-engineered synthetic antiferromagnets hosting sub-20 nm zero-field skyrmions at room temperature
Riccardo Tomasello
Politecnico di Bari

P3. High-resolution two-photon lithography for 3D printing nanomagnets
Joseph Askey
Cardiff University

P4. Conformally coated three-dimensional magnetic nanostructured metamaterials
Alex Roberts (student)
Cardiff University

P5. Domain wall motion in 3D nano-printed iron nanowires
Jakub Jurczyk
Institute of Applied Physics, TU Wien

P6. Atomic Layer Deposition for 3D Nanomagnetic Architectures
Haojie Zhang
Max Planck Institute of Microstructure Physics, Halle, Germany

P7. Exchange bias in bulk nanocomposites
Andrea Bachmaier
Erich Schmid Institute of Materials Science, Austrian Academy of Sciences

P8. 3D heat flux sensor based on anomalous Nernst effect
Kenji Tanabe
Toyota Technological Institute

P9. Role of quadratic and biquadratic coupling in the spin-wave modes of CoFe/Ru/NiFe Artificial Spin Ice structures
Riccardo Fornari (student)
University of Perugia

P10. Skyrmionic cocoons imaged in 3D using HERALDO reconstructions
Jhon Chiliquinga (student)
Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay

P11. Mapping the configuration of thick permanent magnets with pre-edge hard X-ray magnetic tomography
Ginevra Lautizi
Physics of Quantum materials, Max Planck Institute for Chemical Physics of Solids

P12. GHz noise characterization and magnetization reconstruction in a scanning magnetometer: A comparative study using scanning NV and MOKE
Miha Pompe
QZabre AG

P13. Correlative afm-sem-mfm for nanoscale magnetic domain characterization
Marion Wolff (student)
Quantum Design Microscopy GmbH

P14. Comparative studies of magnetic configurations in modulated nanowires
Agustina Asenjo
Instituto de Ciencia de Materiales de Madrid, CSIC

P15. Resonant domain wall dynamics in a three-dimensional magnetic double helix
Imelda Pamela Morales Fernandez (student)
Max Planck Institute for Chemical Physics of Solids

P16. Domain Wall Dynamics in Three-Dimensional Chiral Magnetic Nanostructures
Douveas Iason-Konstantinos (student)
University of Vienna

P17. Controlling Domain Wall Dynamics in Curved Cylindrical Nanowires: From Vortex-Antivortex to Bloch Point Configurations
Roberto Moreno Ortega
Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

P18. Magneto-optical Kerr microscopy on non-planar geometries
Le Zhao
Technische Universität Wien (TU Wien)

P19. Geometric effects on the magneto-optical Kerr effect investigated at 3D non-planar non-curved magnetic thin films
Christian Janzen (student)
Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, Germany

P20. Coherent spin waves in 3D-printed magnonic crystals excited via a microresonator and integrated CPW
Huixin Guo
Technische Universität Wien (TU Wien)

Session 05
Chair: Naëmi Leo *University of Loughborough*

15:30-15:50
O6. Curvature gradient driven domain wall automotion
Eider Berganza
Consejo Superior de Investigaciones Científicas

15:50-16:20
I6. Delayed and Non-Reciprocal Walker Breakdown in Nanowires
Lucía Gómez Cruz (student)
Dpto. Física de Materiales, Facultad de Ciencias Físicas, Universidad Complutense de Madrid

16:20-16:40
O7. Topology of domain wall transformations in magnetic cylinders: micromagnetic study and vector field analysis
Daria Gusakova
SPINTEC, Spintronics and Technology of Components

16:40-17:00

O8. jaxFMM: Fast and accurate stray field evaluation for finite-element micromagnetics

Robert Kraft (student)
Physics of Functional Materials, University of Vienna

17:10-18:00

Lab tours

Wednesday, July 15, 2026
Detailed scientific programme
TU Wien, Freihaus building

Session 06
Chair: Oksana Chubykalo-Fesenko *Instituto de Ciencia de Materiales de Madrid, CSIC*

09:00-09:40
K3. Fundamentals of curvilinear magnetism: geometry-governed effects
Denis Sheka
Taras Shevchenko National University of Kyiv

09:40-10:10
I7. Direct-observation of spin-wave modes on three-dimensional curvilinear nanocaps
Sabri Koraltan
Technische Universität Wien (TU Wien)

10:10-10:30
O9. Direct observation of Néel-type skyrmionic textures in 3D curved magnets under zero-field conditions
Trevor Almeida
University of Glasgow

10:30-11:00
Coffee break

Session 07
Chair: Karin Everschor-Sitte *Universität Duisburg-Essen*

11:00-11:05
Sponsor 2 : Park Systems

11:05-11:25
O10. Magnetic solitons in hierarchical 3D magnetic curvilinear nanoarchitectures
Olha Bezsmertna (student)
Helmholtz-Zentrum Dresden-Rossendorf

11:25-11:55
I8. Functionalizing superconductivity in curvilinear 3D magnetic nanoarchitectures
Sol Jacobsen
Norwegian University of Science and Technology (NTNU)

11:55-12:15
O11. Flexomagnetic Effects in 2D Magnets
Alexander Edström
KTH Royal Institute of Technology

12:25-14:00
Lunch

Poster Session 2
TU Wien, Freihaus building

14:00-15:30

P21. Topological nucleation mechanism of magnetically confined Vortex-Antivortex pairs in weak stripe racetracks
Aurelio Hierro Rodríguez
University of Oviedo

P22. Hopfions in Screw Chiral Magnets
Sandra Chulliparambil Shaju (student)
University of Duisburg-Essen

P23. Observation of magnetic skyrmions in permalloy-rich [Pt/Co/NiFe/Ta] multilayers formed on curvilinear surfaces via scanning transmission X-ray microscopy
Takeaki Gokita (student)
Technische Universität Wien (TU Wien)

P24. Structure and dynamics of complex chiral 3D domain walls in cylindrical geometry.
Oksana Chubykalo-Fesenko
Instituto de Ciencia de Materiales de Madrid, CSIC

P25. Thermodynamic stability and magnetoelectric response of emergent magnetic monopoles in topological magnets
Midori Yamada (student)
The University of Tokyo

P26. Strain control of three-dimensional magnetic nanostructures
José Claudio Corsaletti Filho (student)
Max Planck Institute for Chemical Physics of Solids

P27. A Hall bar on three-dimensional surface fabricated by focused ion beam
Chi Fang
Max Planck Institute of Microstructure Physics

P28. Engineering of rare-earth microwires for biomedical applications
Koplak Oksana
University of Milano-Bicocca

P29. Mapping in-plane stray field components with torsional resonance mode magnetic force microscopy
Jorge Marqués Marchán
Max Planck Institute for Chemical Physics of Solids

P30. Magnetic vector tomography of extended chiral magnets
Polly Mitchell
Max Planck Institute for Chemical Physics of Solids

P31. Physics-informed tomographic reconstruction of chiral magnetic textures
Alexander Setescak (student)
University of Vienna

P32. Geometry-modified domain wall dynamics for 3D racetrack memories
Tiange Dong (student)
Max Planck Institute of Microstructure Physics

P33. Domain-wall membranes in 3d nanomagnetism: a geometric effective theory for dynamics and spin waves
Jacob Mankenberg
Linnaeus University, Kalmar Sweden

P34. Effect of Dimensionality on the Spin Wave Properties on Mix Material Magnonic Crystals
Zhehai Chen
National University of Singapore

P35. The Quantum Spin-Polarized Low-Energy Electron Microscope: Pulsed source, low temperature and angle resolved spectroscopy
Alexander Stibor
Staff Scientist for Quantum Instrumentation, Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley

P36. Towards 3D magnonics: volumetric magnonic directional coupling in high-aspect-ratio YIG microstructures
Hanadi Mortada (student)
Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany.

P37. Dynamic behaviour of magnetic skyrmions in antidot-based DMI-free multilayer structure
Ganna Kharchenko
Central European Institute of Technology (CEITEC), Brno University of Technology, Brno, Czech Republic

P38. Impact of Spin-Diffusion Mechanisms on Magnetization Switching in 3D Perpendicular Shape-Anisotropy Pillars
Daria Gusakova
SPINTEC, Spintronics and Technology of Components

P39. Magnetisation reversal in FeGa 3D nanostructures
Irdi Murataj
Istituto Nazionale di Ricerca Metrologica

Session 08
Chair: Denys Makarov *Helmholtz-Zentrum Dresden-Rossendorf*

15:30-16:00
I9. Strain gradient: a new dimension for magnetic modulation in magnetic thin films
Run-Wei Li
Eastern Institute of Technology, Ningbo

16:00-16:20
O12. Magnetic skyrmion-based devices with novel functionalities
Giovanni Finocchio
University of Messina

16:20-16:50
I10. Dynamics of skyrmions and hopfions in colloidal chiral magnets
Ivan Smalyuk
University of Colorado

17:00-17:20
Conference photo

Thursday, July 16, 2026
Detailed scientific programme
TU Wien, Freihaus building

Session 09
Chair: Aurelio Hierro Rodríguez *University of Oviedo*

09:00-09:40
K4. Keynote lecture
Claire Donnelly
Max Planck Institute for Chemical Physics of Solids, Dresden

09:40-10:10
I11. Design and control of three dimensional magnetic fields and solitons in helical nanostructures
Charudatta Phatak
Argonne National Laboratory/Northwestern University

10:10-10:30
O13. Use of coherence at SEXTANTS beamline for 3D magnetic imaging: status and perspectives with SOLEIL II
Nicolas Jaouen
Synchrotron SOLEIL

10:30-11:00
Coffee break

Session 10
Chair: Charudatta Phatak *Argonne National Laboratory*

11:00-11:05
Sponsor 3: Durham Magneto-Optics

11:05-11:35
I12. Energy-efficient field-free spin-orbit torques in 2D magnetic heterostructures
Saroj Dash
Chalmers University of Technology

11:35-11:55
O14. Self-consistent Magnetic Force Microscope-simulator: paving the way for vector MFM
Dominik Schramm (student)
Technische Universität Wien (TU Wien)

11:55-12:15
O15. Design rules of 3D nanostructures for switchable and localized FMR modes
Mateusz Gołębiewski
Institute of Spintronics and Quantum Information, Faculty of Physics and Astronomy, Adam Mickiewicz University, Poznań, Poland

12:25-14:00
Lunch

Session 11
Chair: Riccardo Tomasello *Politecnico di Bari*

14:00-14:40
K5. 3D magnonics: spin-wave transport in three-dimensional ferromagnetic nano-networks and individual devices, Magnons
Dirk Grundler
Ecole Polytechnique Fédérale de Lausanne (EPFL)

14:40-15:10
I13. Inverse micromagnetics for accurate magnetization reconstruction and magnetic device design
Claas Abert
University of Vienna

15:10-15:30
O16. Anisotropic magnonic band structure in 3D curvilinear magnonic crystal
Gianluca Gubbiotti
Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche (CNR-IOM)

15:30-16:00
Coffee break

Session 12
Chair: Gianluca Gubbiotti *Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche (CNR-IOM), Perugia*

16:00-16:30
I14. Inertial spin-wave dynamics in twisted magnetic nanostrips
Massimiliano d’Aquino
University of Naples Federico II

16:30-16:50
O17. 3D nanoscale control of magnetism in crystalline YIG
Matteo Vitali (student)
Department of Physics - Politecnico di Milano

17:00-18:30
Social activity

18:30-22:00
Conference dinner

Friday, July 17, 2026
Detailed scientific programme
TU Wien, Freihaus building

Session 13
Chair: Peter Fischer *Lawrence Berkeley National Laboratory*

09:30-10:00
I15. Nanosculpted 3D helices of a magnetic Weyl semimetal with switchable non-reciprocal electron transport
Max Birch
RIKEN Center for Emergent Matter Science

10:00-10:20
O18. Geometrical control of topological spin textures in Heusler magnetic nanowires
Rikako Yamamoto
Max Planck Institute for Chemical Physics of Solids

10:20-10:40
O20. Curvature-induced magnetization of altermagnetic films
Volodymyr Kravchuk
Leibniz Institute for Solid State and Materials Research (IFW-Dresden)

10:40-11:10
Coffee break

Session 14
Chair: Claire Donnelly *Max Planck Institute for Chemical Physics of Solids, Dresden*

11:10-11:40
I16. Rethinking linking – Topology in magnetism, water waves and plasmonics
Karin Everschor-Sitte
University of Duisburg-Essen

11:40-12:00
O19. Fractional Hopfions and Bloch Point Pairs in Composite Magnets
Sanjay Ashok
Karlsruhe Institute of Technology

12:00-12:20
O21. Magnetic vector tomography reveals giant magnetofossils are optimised for magnetointensity reception
Richard Harrison
University of Cambridge

12:30-13:00
Closing ceremony

Advances in 3D nanomagnetism: key breakthroughs, open challenges, and future opportunities

Peter Fischer[1,2]

[1] Materials Sciences Division, Lawrence Berkeley National Lab, Berkeley, CA USA
[2] Physics Department, UC Santa Cruz, CA USA
* pjfischer@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. The concept of chirality which requires three dimensions, is essential to understand e.g., fundamental interactions in cosmology and particle physics, the evolution of life in biology, or molecular chemistry, but has recently also attracted enormous interest in the magnetism community. 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.

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. Tsymbal, 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 3D Nano-magnetism, Gianluca Gubbiotti et al 2025 J. Phys.: Condens. Matter 37 143502

2D and 3D Racetrack Memory

Stuart Parkin

Max Planck Institute for Microstructure Physics, Halle (Saale), Germany

stuart.parkin@mpi-halle.mpg.de

Spintronic devices generate and manipulate spin-polarized currents of electrons in atomically engineered heterostructures that allow for novel physical phenomena that make possible spin-valves and magnetic tunnel junction devices. These devices have already had major impact in memory-storage applications in the form of highly sensitive magnetic field sensors that allowed for massive increases in the storage capacity of magnetic disk drives, and, more recently, in the form of a high performance non-volatile magnetic random access memory (MRAM). Beyond these established devices, magnetic racetrack memory has great potential as a highly capacious, solid state, non-volatile memory-storage device that could even replace magnetic hard disk drives[1]. Racetrack memory stores data in the form of chiral magnetic domain walls that are moved by current-induced spin-transfer and spin-obit torques along magnetic nano-wires that form the racetracks. Recently, it has been demonstrated that racetracks can be reduced to nanoscopic dimensions that are needed for real world applications[2]. To date, most work on racetrack memory has relied on 2D forms of racetrack. Even more interesting forms of racetrack memory are based on 3D structures, as originally foreseen[1]. Here we discuss several forms of 3D racetrack memory. First, we discuss the fabrication of ultrathin membranes formed from the racetrack thin film structure that are disposed on surfaces with pre-patterned vertical structures[3,4]. Secondly, we discuss 3D racetrack devices that are printed via a multi-photon super-resolution microscope that we developed[5]. This instrument has a voxel size of just 50 nm with which we can create scaffolds formed from an insulating polymeric material on which we use sputtering techniques to deposit the racetrack structures. These 3D racetracks can be printed in various geometrical forms, including racetracks that have twists, both right-handed or left-handed, and racetracks with curvatures along and across the racetracks. We show that these geometries give rise to novel exchange interactions that strongly influence the current induced motion of chiral domain walls in the 3D racetracks.

1 Parkin, S. S. P., Hayashi, M. & Thomas, L. Magnetic Domain-Wall Racetrack Memory. *Science* **320**, 190–194 (2008). https://doi.org/10.1126/science.1145799

2 Jeon, J.-C., Migliorini, A., Yoon, J., Jeong, J. & Parkin, S. S. P. Multi-core memristor from electrically readable nanoscopic racetracks. *Science* **386**, 315–322 (2024). https://doi.org/10.1126/science.adh3419

3 Gu, K. *et al.* 3D racetrack memory devices designed from freestanding magnetic heterostructures. *Nat. Nanotechnol.* **17**, 1065–1071 (2022).

4 Gu, K. *et al.* Atomically-Thin Freestanding Racetrack Memory Devices. *Adv. Mater.* **37**, 2505707 (2025). https://doi.org/https://doi.org/10.1002/adma.202505707

5 Farinha, A. M. A., Yang, S.-H., Yoon, J., Pal, B. & Parkin, S. S. P. Interplay of geometrical and spin chiralities in 3D twisted magnetic ribbons. *Nature* **639**, 67–72 (2025). https://doi.org/10.1038/s41586-024-08582-8

MRAM and probabilistic spintronics towards three-dimensional magnetic architectures

Shunsuke Fukami[1*]

[1] Tohoku University, Sendai, Japan
* s-fukami@tohoku.ac.jp

The research and development of spintronic technologies has expanded from magnetic sensors, including read heads for hard disk drives, to magnetoresistive random-access memory (MRAM), and is now extending toward exploratory studies for applications in computing and energy harvesting. In this talk, taking MRAM and probabilistic computing, one of the emerging unconventional computing paradigms, as representative examples, I discuss the potential of exploiting the three-dimensional properties of spintronic devices, which have so far been predominantly fabricated from two-dimensional thin-film stacks.

In current MRAM technologies, magnetic tunnel junctions (MTJs) utilizing interfacial perpendicular magnetic anisotropy [1] are employed as memory elements. However, this approach faces increasing challenges in maintaining sufficient thermal stability as device dimensions continue to scale down. We have demonstrated that this issue can be addressed by employing pillar-shaped MTJs that exploit three-dimensional shape magnetic anisotropy [2]. I will show design guidelines for MTJs that combine two-dimensional and three-dimensional magnetic characteristics, focusing on data retention, temperature dependence, and high-speed switching properties [3].

As a second example, probabilistic computing is attracting significant interest as a novel computing paradigm capable of efficiently handling probabilistic algorithms that are difficult to process with conventional deterministic computers. Proof-of-concept demonstrations have been realized using superparamagnetic tunnel junctions, in which the thermal stability of MTJs is intentionally reduced [4]. By introducing recent engineering approaches to MTJs aimed at enhancing computational performance [5-7], I will discuss the prospects and opportunities enabled by three-dimensional device architectures.

These works have been carried out in collatoration with H. Ohno, K. Watanabe, B. Jinnai, J. Igarashi, S. Kanai, W. A. Borders, K. Hayakawa, K. Kobayashi, K. Camsari, and S. Datta, and have been partly supported by JST-ASPIRE, JSPS Kakenhi, and MEXT X-NICS.

[1] S. Ikeda et al., Nat. Mater. **9**, 721 (2010).

[2] K. Watanabe et al., Nat. Commun. **9**, 663 (2018).

[3] J. Igarashi et al., npj Spintronics **2**, 1 (2024).

[4] W. A. Borders et al. Nature **573**, 390 (2019).

[5] K. Hayakawa et al., Phys. Rev. Lett. **126**, 117202 (2021).

[6] S. Kanai et al., Phys. Rev. B **103**, 094423 (2021).

[7] K. Kobayashi et al., Phys. Rev. Appl. **18**, 054085 (2022).

Fundamentals of curvilinear magnetism: geometry-governed effects

Denis D. Sheka[1*]

[1] Taras Shevchenko National University of Kyiv, Ukraine

*sheka@knu.ua

Curvilinear magnetism investigates how curvature and geometry shape the behaviour of magnetic materials [1]. By bending, twisting, or sculpting wires, ribbons, shells, and more complex nanostructures, researchers can tune magnetic responses and unlock new functionalities [2]. This rapidly growing field connects physics,materials science, and engineering, with applications including nanomagnetism,spintronics, skyrmionics, magnonics, and microrobotics, and is recognised as a key driver of next-generation magnetoelectronic technologies.

This talk focuses on the unique phenomena that emerge from geometrically curved magnetic objects, including three-dimensional bent and twisted wires and films. We explore a family of novel geometry-governed effects, encompassing magnetochiral effects and topological patterning, which give rise to theoretically predicted domain wall automotion, unlimited domain wall velocities, chirality symmetry breaking, and mesoscale Dzyaloshinskii-Moriya interactions, among others. Our particular emphasis is on chiral effects, which can be locally driven by exchange mechanisms stemming from local curvature and torsion [1,3], or arising from variations in cross-section [4-5]. Additionally, these effects can be non-locally driven by magnetostatics and supported by topology [6]. We discuss how the non-local symmetry breaking effect has been experimentally validated in the vortex state magnetic cap [7].

[1] D. Makarov, D. Sheka, "Curvilinear Micromagnetism: From Fundamentals to Applications". Topics in Applied Physics. (Springer, Cham, 2022)
[2] G. Gubbiotti et al, J. Phys: Cond Matt **37**, 143502 (2025)
[3] K. Yershov, S. Kondovych, D. Sheka, Phys. Rev B **111**, 184419 (2025)
[4] K. Yershov, D. Sheka, Phys. Rev B **107**, L100415 (2023)
[5] D. Karakuts, K. Yershov, D. Sheka, "Domain Wall Automotion by Cross Section Tailoring in Ferromagnetic Nanostripes", in Functional Magnetic and Spintronic Nanomaterials (2024)
[6] D. Sheka et al , Comm. Phys. **3**, 128 (2020)
[7] O. Volkov et al, Nature Comms, 14, 1491 (2023)

Exploring and controlling three dimensional spin systems

Claire Donnelly[1]

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

Extending spin systems to three dimensions promise significant opportunities for applications, for example providing higher density devices and new functionalities associated with complex topology and greater degrees of freedom [1,2].
In this talk, I will address two main questions: first, can we observe and understand such three-dimensional topological magnetic textures, and second, can we control them?
For the observation and understanding of these three-dimensional textures, we have developed dichroic X-ray tomographic techniques, that open the possibility to map three-dimensional magnetic structures [3], their dynamical responses to excitations [4,5,6], and orientation fields [7,8] – both crystallographic [7], and antiferromagnetic – at the nanoscale. In this way, we observe 3D magnetic solitons which we identify as nanoscale magnetic vortex rings, as well as torons that contain Bloch point singularities [9].
As well as naturally existing within the bulk, we harness the patterning of 3D curvilinear geometries to gain control over local ferroic order and configurations. In this way, not only can new states be realized [10], but we can achieve control over the energy landscape of topological defects [11,12] and their GHz dynamics [13].
This new understanding and control of topological textures in 3D magnetic systems paves the way not only for enhanced understanding of these systems, but also towards the next generation of technological devices.

References

[1] Fernández-Pacheco et al., Nature Communications **8**, 15756 (2017).
[2] C. Donnelly and V. Scagnoli, J. Phys. D: Cond. Matt. **32**, 213001 (2020).
[3] C. Donnelly et al., Nature **547**, 328 (2017).
[4] C. Donnelly et al., Nature Nanotechnology **15**, 356 (2020).
[5] S. Finizio et al., Nano Letters (2022)
[6] M. Di Pietro Martínez, npj Spintronics **3**, 47 (2025)
[7] A. Apseros et al., Nature **636**, 354 (2024)
[8] A. Apseros et al., New Journal of Physics **27**, 103902 (2025)
[9] C. Donnelly et al., Nat. Phys. **17**, 316 (2020)
[10] C. Donnelly et al., Nature Nanotechnology **17**, 136 (2022)
[11] S. Ruiz Gomez et al., Nature Communications **16**, 7422 (2025)
[12] L. Turnbull et al., arXiv:2511.11372
[13] P. Morales Fernández et al., Advanced Materials e00004 (2026)

3D magnonics: spin-wave transport in three-dimensional ferromagnetic nano-networks and individual devices

Dirk Grundler[1*]

[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Materials and Institute of Electrical and Micro Engineering, Lausanne, Switzerland
* dirk.grundler@epfl.ch

In three-dimensional (3D) magnonics one aims at the understanding and mastery of collective spin excitations (spin waves) in magnetically order materials which are patterned on the micron or nano-scale in all three spatial directions on a chip. Beyond creating interesting confinement and localization effects in 3D topographies one can exploit curvature and torsion to engineer magnetic anisotropies and (non-relativistic) spin-orbit coupling. New functionalities are expected for spin waves (magnons), for instance, nonreciprocal transport in preferred directions in 3D devices and networks. At the same time, there are new degrees of freedom to induce chiral spin structures. We report on the creation and exploration of 3D ferromagnetic networks and artificial chiral magnets (ACMs) prepared from the conventional ferromagnetic metal Ni. Using atomic layer deposition (ALD) [1] we prepare 3D tubular woodpiles [2] and 3D tubular screws [3], respectively, from 10 to 30 nm thick conformal Ni shells around polymeric nanotemplates [4]. We explore their static spin configurations [3,5] and spin dynamics in the GHz frequency regime. Ferromagnetic Ni shells on 3D woodpile lattices show incoherent surface magnon modes with unexpectedly high resonance frequencies [2]. They depend decisively on the number of woodpile unit cells. In inductive measurements in fields up to about 1 T we identify an unconventional phase evolution of edge magnon modes when coherently excited by a microwave field [6]. These modes are localized in the curved ferromagnetic nanocaps on the outer side facets of the woodpile superstructures. Hollow Ni screws are found to exhibit zero-field spin spirals giving rise to nonreciprocal magnon transport at room temperature [3]. The studies are conducted by means of spatially resolved inelastic light scattering microscopy and micromagnetic simulations. Controlling toroidal moments and magneto-chiral effects via field-dependent spin orientation and 3D geometrical handedness, we obtain ACMs with programmable nonreciprocity at zero magnetic field. By varying the screw design, outer diameters and screw pitches of the nanotemplates the various Ni shells produced in one-and-the-same ALD process on a large wafer exhibit different static and dynamic properties. Our experiments and findings are a major step in functional 3D nanomagnetism and 3D nanomagnonics based on a mass-production compatible deposition technology. Cooperations with M. Xu, A.J.M. Deenen, H. Guo, M. Hamdi, S. Ladak, K. Lenz, M. Golebiewski, R. Narkowicz, J. Lindner, M. Krawczyk, A. Roberts, J. Askey, V. Lanka, A. van den Berg, C. Donelly, P. Morales-Fernández, E. Zhakina, M. Weigand, and S. Wintz are gratefully acknowledged. Our work is funded by SNSF grant 197360.

[1] M.C. Giordano et al., ACS Appl. Mater. Interfaces **12**, 40443 (2020)

[2] H. Guo et al., Adv. Mater. **35**, 2303292 (2023)

[3] M. Xu et al., Nat. Nanotechn. 21, 58 (2026)

[4] J. Askey et al., Adv. Funct. Mater., e16383, (2025)

[5] A. Roberts et al., https://arxiv.org/abs/2512.13321 (2025)

[6] H. Guo et al., Small **22**, e08983 (2026)

3D Artificial Spin-ice

Sam Ladak[1*]

[1] School of Physics and Astronomy, Cardiff University, United Kingdom
* LadakS@cardiff.ac.uk

In this talk, I will present an overview of work at Cardiff on three-dimensional artificial spin ice (3DASI) systems fabricated using two photon lithography (TPL) and processing [1–3]. Magnetic force microscopy originally enabled direct identification of vertex states in these lattices and real space visualisation of monopole transport across the lattice surface [2]. I will discuss recent advances in the multi-modal characterisation of 3DASI, including nitrogen vacancy (NV) centre scanning magnetometry, transmission X-ray microscopy (TXM) [4] and Brillouin light scattering (BLS). NV magnetometry provides direct access to the stray field signatures of vertex configurations in diamond-bond 3DASI lattices [5]. Monopoles produce strongly divergent fields extending over multiple lattice spacings, whereas ice rule vertices generate structured, topologically constrained stray field textures. BLS measurements further reveal that as-deposited samples and lattices subjected to in plane demagnetising protocols exhibit distinct spin wave spectra. In particular, demagnetised states show a pronounced spectral feature associated with type III monopole vertices, highlighting a dynamic fingerprint of emergent defects. Finally, I will present new synchrotron results demonstrating transmission X-ray microscopy measurements of fully 3D nanostructured spin-ice systems. Together, these results show that multi-modal microscopies, combining real space, stray field and dynamic probes, are essential to fully understand the physics of novel 3DASI systems.

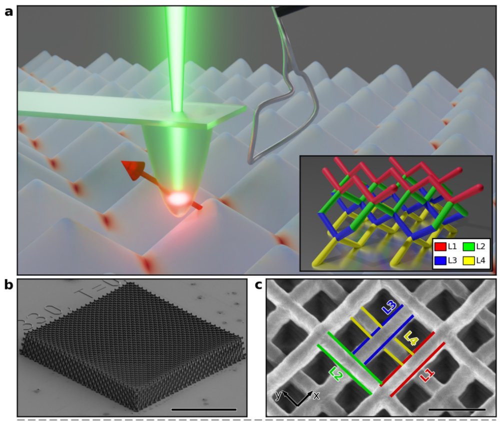


Figure 1. (a) Nitrogen-vacancy centre microscopy upon a 3D artificial spin-ice sample. Inset: Schematic of a diamond-bond 3D Artificial Spin-ice lattice with sublattices coloured red (L1), green (L2), blue (L3) and magenta (L4). (b) Scanning electron microscopy image of experimental lattice. Scale bar indicates 20 μm. (c) High-magnification, top-down SEM of the 3D artificial spin-ice lattice with sub-lattices marked according to the colours in panel a inset.

[1] A. May et al. Communications Physics **2**, 13 (2019)

[2] A. May et al. Nature Communications **12**, 3217 (2021)

[3] A. Van den Berg et al. Communications Physics **6**, 217 (2024)

[4] E. Harding et al. APL Materials **12**, 021116 (2024)

[5] A. Van den Berg et al. arXiv:2511.04877 (2025)

Branch selection at stripe domain bifurcations in reconfigurable magnetic domain wall racetracks

V.V. Fernández[1,2*], A.E. Herguedas-Alonso[1,2], P. Suárez[1], A.G. Casero[1], C. Fernández-González[3], A. Sorrentino[3], R. Valcarcel[3], C. Quiros[1,2], J. I. Martín[1,2], A. Hierro-Rodríguez[1,2], M. Vélez[1,2]

[1]Depto. Física, Universidad de Oviedo, 33007 Oviedo, Spain
[2]CINN (CSIC–Universidad de Oviedo), El Entrego, Spain
[3]ALBA Synchrotron, 08290 Cerdanyola del Vallès, Spain
* fernandezvega@uniovi.es

Magnetic domain-wall racetracks based on stripe domain patterns in materials with weak perpendicular magnetic anisotropy provide a compelling alternative to geometrically confined structures for spintronic technologies [1]. In $NdCo_5$/Py multilayers, the stripe domains act as natural paths that direct the motion of vortex–antivortex (V/AV) textures within the Py layer. The propagation direction can also be controlled, either by magnetic field pulses [1] or by current pulses [2]. A distinctive feature of stripe domain patterns is the presence of bifurcations, that act as nucleation sites for the spin textures [3]. The ability to control which branch of the bifurcation is preferred in each propagation event reveals new insights into spintronic devices. As shown in Fig.1 and due to symmetry considerations, when V/AV pair propagates away from a bifurcation core, the V always runs along the central stripe, whereas the AV moves along the bifurcated outer path. In this study, we investigate the selection of bifurcation branches under applied static transverse magnetic fields using magnetic transmission X-ray microscopy. Statistical analysis of numerous bifurcation events demonstrates that the transverse field lifts the symmetry between branches, enabling both deterministic control and tunable probabilistic behavior. The interplay between saturation magnetic fields applied parallel to the stripe domains and in-plane uniaxial anisotropy will also be studied.

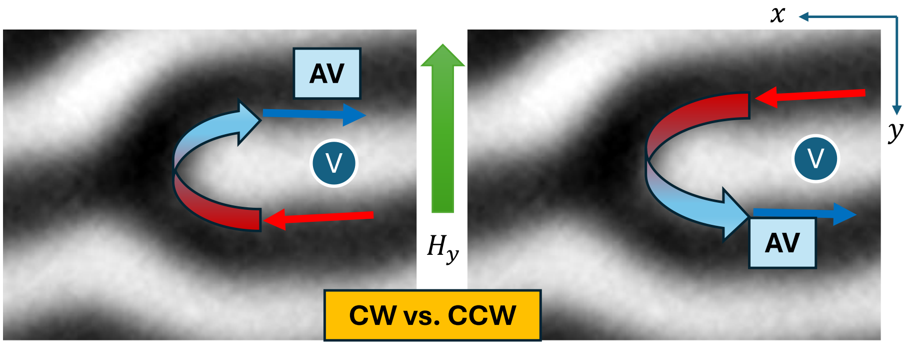


Figure 1. Sketch of Vortex/Antivortex propagation within a stripe bifurcation in a NdCo5/Py multilayer. Note that the selected branch for AV propagation (upper/lower) is directly linked to CW/CCW circulation at the bifurcation core (meron texture).

[1] A. Hierro-Rodríguez, et al., Appl. Phys. Let., vol. **110**, 262402 (2017).

[2] V.V. Fernández, et al., Phys. Rev. Appl. vol. **23**, 014023 (2025).

[3] V. V. Fernández, et al., Journal of Physics: Materials **9**, 015002 (2025).

Pt/Co/Al multilayers: a material platform for 3D skyrmionics

J. J. Chiliquinga-Jacome[1], R. Battistelli[2,3], M. Grelier[1], W. Bouckaert[1], K. Puzhekadavil Joy[3,4], S. Krishnia[1,¤], H. Jaffrès[1], D. Sanz-Hernández[1], F. Büttner[2,3], H. Popescu[4], J. Jurczyk[5], A. Fernandez-Pacheco[5], N. Jaouen[4], N. Reyren[1] and V. Cros[1,*]

[1]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, Palaiseau, France
[2]Helmholtz-Zentrum Berlin, Berlin, Germany
[3]Institüt für Physik, Universität Augsburg, Augsburg, Germany
[4]Synchrotron SOLEIL, L'Orme des Merisiers, Gif-sur-Yvette, France.
[5]Institute of Applied Physics, TU Wien, AustriaTU Wien, Vienna, Austria
[2] University of Vienna, Vienna, Austria
* vincent.cros@cnrs-thales.fr

Pt/Co-based multilayers are a model platform to investigate key interfacial mechanisms in spintronics, including perpendicular magnetic anisotropy, interfacial Dzyaloshinskii–Moriya interaction (DMI), and spin–orbit torques. In this talk, I show that sputtered Pt/Co/Al multilayers provide exceptional tunability of these properties through interface engineering, notably by controlling the Al thickness and the oxidation at the Co/Al interface. We demonstrate record interfacial DMI values for all-metallic systems, an unusual double sign reversal of the interfacial anisotropy attributed to charge redistribution [1], and the emergence of large damping-like and giant field-like torques associated with a strong interfacial Rashba interaction [2,3].

These properties enable the stabilization and efficient manipulation of three-dimensional magnetic textures at room temperature. By engineering multilayers with varying Co thickness, we observe both extended skyrmion tubes and localized skyrmionic cocoons confined to part of the multilayer stack [4-6]. Using patterned tracks and locally engineered structures, we control skyrmion nucleation and motion. Finally, we demonstrate proof-of-concept neuromorphic functionalities, including weighted-sum operations [7], paving the way toward artificial skyrmionic neural networks.

Acknowledgements : This work is supported by EU project SkyANN (reference no. 101135729), by ANR-DFG number BU 3297/4Topo3D) and by ANR-22- EXSP-0002 PEPR SPIN CHIREX and grant no. ANR- 22-EXSP-0007 SPINMAT, and ANR- 22-EXSP-0008 SPINCHARAC.

[1] S. Krishnia *et al*, Phys. Rev. Appl. 24, 024055 (2025)
[2] S. Krishnia *et al*, Nano Letters, 23, 6785 (2024)
[3] A. Pezo *et al*, Phys. Rev. B 112, 214426 (2025)
[4] M. Grellier *et al*, Nature Communications 13, 6843 (2022)
[5] M. Grelier *et al*, Phys. Rev. B 107, L220405 (2023)
[6] J. J. Chiliquinga-Jacome *et al*, arXiv:2601.14889 (2026)
[7] T. Da Camara Santa Clara Gomes *et al*, Nature Electronics 8, 204 (2025)

3D magnetic nanowire networks and curvature induced magnetism

Kai Liu*

Georgetown University, Washington, DC 20057, USA
* kai.liu@georgetown.edu

Three dimensional (3D) nanomagnetic systems provide a fertile ground for implementing neuromorphic computing and for stabilizing unconventional spin configurations. We have recently demonstrated interconnected networks of self-assembled magnetic nanowires (NWs) as a novel platform for neuromorphic computing [1]. These networks comprise multiple distinct transport pathways, each supporting discrete magnetization states. Individual pathways can be selectively addressed, and their magnetic configurations can be electrically modulated via controlled current pulses. As a result, the pathways function analogously to synaptic weights, enabling versatile programmability through targeted switching of specific network segments using pulses of varying amplitude and duration. Leveraging these capabilities, we demonstrate the feasibility of interconnected magnetic NW networks as a reservoir layer within neural network architectures.

Together with Peter Fischer's group we have also explored curvature-induced modification of magnetic configuration in a Co/Pd multilayer thin film with perpendicular magnetic anisotropy (PMA), deposited on an interconnected network of Cu NWs [2]. The overall domain orientation was influenced by the underlying NW-defined curvature and the domains preferentially aligned along the long axis of the NWs. Furthermore, the chirality of the domain walls (DWs) was strongly affected by curvature. In particular, Néel DWs were promoted, and the effective DMI contribution was found to be approximately 1/3 of the intrinsic DMI of the Co/Pd multilayer. We have also investigated magnetic Möbius bands fabricated using two-photon polymerization. Magnetometry and first-order reversal curve (FORC) analysis reveal a strong preference for vortex formation in the vertical section of the band, with vortex polarity intrinsically determined by the band's handedness.

These studies demonstrate the potentials of using 3D nanomagnetic systems for neuromorphic computing and to explore how geometry influences spin configurations across distinct material systems. This work is done in collaboration with D. Bhattacharya, Colin Langton, Bradley J. Fugetta, D. Raftrey, Erin Marlowe, Zhijie Chen, Subhashree Satapathy, Olha Bezsmertna, Andrea Sorrentino, Denys Makarov, Gen Yin and Peter Fischer, and supported in part by the NSF (DMR-2005108, DMR-2320636 and ECCS-2429995).

[1] D. Bhattacharya, C. Langton, M. M. Rajib, E. Marlowe, Z.J. Chen, W. Al Misba, J. Atulasimha, X.X. Zhang, G. Yin, and K. Liu, ACS Appl. Mater. Interfaces, **17**, 20087 (2025).
[2] D. Raftrey, D. Bhattacharya, C. Langton, B. J. Fugetta, S. Satapathy, O. Bezsmertna, A. Sorrentino, D. Makarov, G. Yin, P. Fischer, and K. Liu, ACS Nano, **19**, 31609 (2025).

Magneto-thermoelectric effects in three-dimensional interconnected magnetic nanowire networks

Tristan da Câmara Santa Clara Gomes[1,2*], Nicolas Marchal[1], Flavio Abreu Araujo[1], Joaquin de la Torre Medina[3], Luc Piraux [1]

[1] Institute of Condensed Matter and Nanosciences, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[2] Instituto de Engenharia de Sistemas E Computadores – Microsistemas e Nanotecnologias (INESC MN) Lisbon, Portugal
[3] Instituto de Investigaciones en Materiales/Unidad Morelia, Universidad Nacional Autónoma de México, Morelia, Mexico
* tristan.dacamara@uclouvain.be

3D networks of interconnected magnetic nanowires, nanotubes, and multilayers (Fig. 1) are fabricated by direct electrodeposition into track-etched polymer templates with crossed nanochannels [1,2]. This approach yields flexible polymer–magnetic nanofiber composite films with exceptionally high interconnectivity [3]. The architecture enables in-plane measurements of magneto-thermoelectric properties while confining thermal and electrical currents along the nanofiber axes. These 3D networks exhibit thermopowers comparable to bulk materials for lateral dimensions down to 20 nm [2], and only minor reductions relative to bulk ferromagnetic metals in ferromagnet/Cu multilayer configurations (Fig. 1c) [1]. 3D ferromagnet/Cu multilayer networks, enabling in-plane measurements with negligible contact resistance while enforcing current-perpendicular-to-plane transport through successive layers, exhibit giant magnetoresistance ratios of up to 43% at room temperature. These systems are established as high-performance spin-caloritronic platforms, combining power factors comparable to state-of-the-art thermoelectrics with room-temperature magneto-thermoelectric modulations of up to 34% (≈ 5.5 μV/K), while enabling direct extraction of spin-dependent Seebeck coefficients. Integration into 3D nanowire-based thermocouples further enables magnetically activated thermoelectric switches with infinite magneto-thermopower ratios for thermally powered logic operations [4].

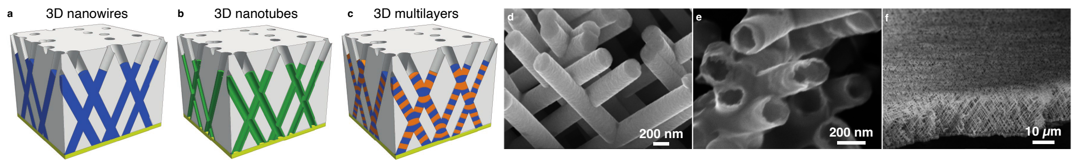


Figure 1. a-c, Schematics of 3D networks made of crossed (a) nanowires, (b) nanotubes and (c) multilayers. d-e, SEM images of (d) a nanowire and (e) nanotube networks after dissolution of the template, showing the branched architecture. f, Low- magnification SEM image illustrating the freestanding macroscopic nanostructured film.

[1] T. d. C. S. C. Gomes *et al.*, Science Advances **5**(3), eaav2782 (2019).

[2] T. d. C. S. C. Gomes *et al.*, Applied Physics Letters **124**, 092406 (2024).

[3] T. d. C. S. C. Gomes *et al.*, Physical Review Research **6**, 023211 (2024).

[4] T. d. C. S. C. Gomes *et al.*, Advanced Materials Technologies **7**, 2101043 (2021).

Delayed and Non-Reciprocal Walker Breakdown in Nanowires

Lucía Gómez Cruz[1,2*], Laura Álvaro Gómez[1], Claudia Fernández González[3], Giuseppe Curci[2], Sandra Ruiz Gómez[3], Lucía Aballe[3], Eva Pereiro[3], Rachid Belkou[4], Jean-Christophe Toussaint[5], Victor Raposo[6], Eduardo Martínez[6], Daria Gusakova[2], Aurélien Masseboeuf[2], Olivier Fruchart[2], Lucas Pérez[1]

[1] Dpto. Física de Materiales, Universidad Complutense de Madrid, Madrid, Spain
[2] Université Grenoble Alpes, CNRS, CEA, SPINTEC, Grenoble, France
[3] ALBA Synchrotron, CELLS, Cerdanyola del Vallès, Barcelona, Spain
[4] SOLEIL Synchrotron, Saint Aubin, France
[5] Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France
[6] Dpto. Física Aplicada, Universidad de Salamanca, Salamanca, Spain
* lugome11@ucm.es

Domain walls (DWs) in magnetic materials can be driven by magnetic fields or electric currents, typically exhibiting two distinct regimes. In the low-driving regime (steady-flow), the DW velocity scales linearly with the applied stimulus and inversely with the damping, α. Above a critical threshold, the system enters the Walker breakdown regime, characterized by the internal magnetization precession of the DW and a sharp reduction of its velocity, which now scales approximately with α. In the case of soft-magnetic thin films, such as permalloy, this process limits DW velocities to around 100 m/s [1]. However, some intrinsic material properties may delay the Walker breakdown, such as the Dzyaloshinskii-Moriya interaction (DMI).

Three-dimensional magnetic nanostructures introduce additional topological degrees of freedom and curvature effects that may have an impact on DW dynamics [2]. Here, we investigate cylindrical permalloy nanowires with a diameter of around 200 nm, which present opposite-azimuthally-magnetized domains with a uniformly-axially-magnetized core, also called vortex state. This magnetic distribution allows to use the Oersted field as a source of magnetic field, controlled by the application of electric current pulses. Using X-ray microscopy techniques, both in statics and with time-resolution, we evidenced DW velocities exceeding 500 m/s. We attribute this high-speed motion to an exchange-spring like coupling between the axial core and the azimuthal periphery, which effectively delays the onset of the Walker breakdown.

To support our experimental observations, we performed micromagnetic simulations. The results reveal that, due to the curvature, there is a chiral-induced non-reciprocal DW motion: depending on the relative orientation of the azimuthal magnetization at the periphery with respect to the direction of propagation, the Walker breakdown can be significantly delayed. Further analysis reveals that dynamics are governed by the creation and annihilation of topological objects at both the surface and in the volume, leading to different regimes. Additionally, we will discuss how these processes show a strong dependence on the damping parameter and relate to the non-reciprocity of spin waves in this system, both observed experimentally and understood by simulations.

[1] Beach, G.S.D. et al., *Dynamics of field-driven domain-wall propagation in ferromagnetic nanowires*, Nat. Mater. 4, 741 (2005)

[2] Fernandez-Pacheco, A. et al., *Three-dimensional magnetism*, Nat. Commun. 8, 15756 (2017)

Direct-observation of spin-wave modes on three-dimensional curvilinear nanocaps

Sabri Koraltan[1]*, Takeaki Gokita[1], Amalio Fernández-Pacheco[1]

[1] TU Wien, Vienna, Austria

*sabri.koraltan@tuwien.ac.at

Spin waves in magnonic systems offer energy-efficient alternatives to conventional electronics~[1], with low-frequency magnetic vortex resonances being particularly relevant for microwave applications~[2]. While planar magnetic vortices have been extensively studied~[2], their dynamics in three-dimensional curvilinear architectures remain largely unexplored. Here, we present the direct experimental observation of vortex core gyration and spin-wave emission on a 3D curvilinear surface[4]. Using a stripline antenna on a SiN membrane, we excite self-assembled polystyrene spheres coated with NiFe, which host a vortex lattice state at remanence. Time-resolved scanning transmission X-ray microscopy (TR-STXM) at BESSY II [4] captures real-space, time-resolved dynamics, revealing complex spin-wave modes due to curvature-induced field gradients. Our results highlight the potential of curvilinear magnetic architectures for next-generation magnonic devices.

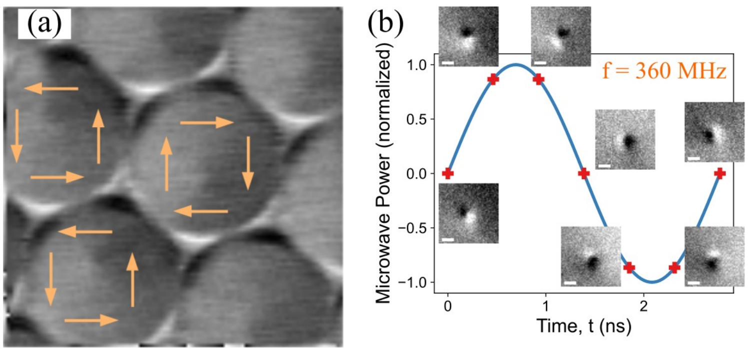


Figure 1. XMCD image of the vortices on spherical nanocaps, and snapshots of the vortex core gyration on curved surfaces as revealed by time-resolved STXM.

[1] Chumak, Andrii V., et al. Nature physics 11.6 (2015): 453-461.
[2] Yu, Haiming, et al. Physics Reports 905 (2021): 1-59.
[3] Koraltan, Sabri, et al. In Preparation (2026).
[4] Koraltan, Sabri, et al. Science Advances 10.39 (2024): eado8635.

Functionalizing superconductivity in curvilinear 3D magnetic nanoarchitectures

Sol H. Jacobsen[1*]

[1] QuSpin Center for Quantum Spintronics,
Norwegian University of Science and Technology NTNU, Trondheim, Norway

* sol.jacobsen@ntnu.no

Harnessing the spin degree of freedom can provide novel functionalities and increased efficiency in computation and sensing. Remarkably, superconducting analogues to conventional spintronic components are predicted to give an energy saving of two orders of magnitude for nanoscale components, even when accounting for the need for cryogenic cooling. In such superconducting spintronic structures, the proximity effect is used to enable low-dissipation spin transport in hybrid systems containing magnetic or normal metal elements. In this talk, we will give a pedagogical introduction to the underlying physics of how geometric curvature gives precise control of the design and manipulation of superconductivity in such archetypal hybrid structures [1-5]. We have recently shown that the geometry can, for example, control the superconducting transition and the direction of Josephson current flow [1], give chirality-dependent ground states in triplet-SQUIDs [2], characterise the compensation quality of a buried antiferromagnetic edge [3], and functionalize a superconducting spin valve with voltage control of the strain (see Fig.1) [4]. Strain and geometry provide different roles, with strain in a superconductor giving additional control of the symmetry of the order parameter, and unlocking the possibility of strain-induced magnetization in a normal metal junction (see Fig.2) [5].

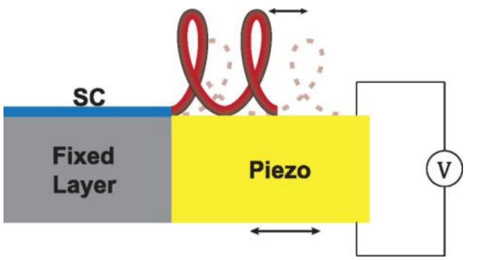


Figure 1. Voltage-controlled superconducting spin valve using ferromagnetic helix [4].

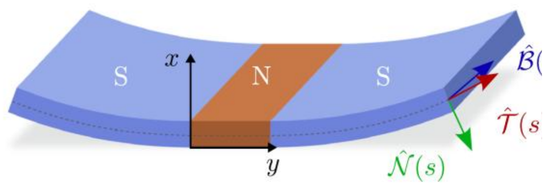


Figure 2. SNS Josephson junction with strained superconductors generates p-wave order and induces magnetization [5].

[1] Salamone et al, *Phys. Rev. B* **104** (2021) L060505 ; **105**, (2022) 134511.

[2] Skarpeid et al, *J.Phys.:Condens.Matter*, **36** (2024) 235302.

[3] Salamone et al, Phys. Rev. B **109**, 094508 (2024).

[4] Salamone et al, *Appl. Phys. Lett.* **125** (2024) 062602.

[5] Heinrich et al, *npj Spintronics* **3**, 18 (2025).

Strain gradient: a new dimension for magnetic modulation in magnetic thin films

Run-Wei Li[1, 2*]

[1] Eastern Institute of Technology, Ningbo
[2] Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences
* rwli@eitech.edu.cn

Strain engineering provides a powerful means to control magnetism, offering promising pathways for flexible sensing technologies in applications such as extended reality and humanoid robotics [1,2]. A fundamental understanding of how mechanical stress influences magnetic properties is essential for advancing high-performance flexible and wearable magnetoelectronic devices [3–6]. However, the complex strain distributions inherent in flexible systems make their regulatory effects on magnetic behavior particularly challenging to unravel [1,7].

Here, we unveil the modulation of magnetic domain structures in multilayers via localized strain gradients [8]. By fabricating microscale periodic wrinkles in flexible Pt/Co/Ta multilayers, we introduce strain gradients with tunable magnitudes and directions. Magnetic force microscopy reveals that both the density and size of skyrmions are synchronously modulated by the in-plane strain gradient profile, enabling significantly broader tunability than achievable with uniform strain. This approach is reversible, cyclable, and transferable across different magnetic multilayer systems. The observed behavior is attributed to strain- and strain-gradient-mediated modulations of the Dzyaloshinskii–Moriya interaction and magnetic anisotropy, as supported by micromagnetic simulations.

In addition, we successfully fabricate Pt/CoFeB multilayers with micro-scale bowl-shaped arrays on elastic substrates using a transfer technique, enabling predefined strain gradient distributions. As a result of this strain patterning, the magnetic domain structures exhibit periodic modulation, with coexistence of circular stripe domains and skyrmions. The nucleation field for skyrmions increases and the corresponding field window expands with the height of the bowl-shaped structures. These findings establish strain gradient as a new route for engineering the performance of flexible magnetoelectronic devices.

[1] H. Yang, S. Li, Y. Wu, ..., Y. Liu, R.-W. Li. Adv. Mater. **36**, 202311996 (2024).

[2] L. Pan, Y. Xie, H. Yang, ..., R.-W. Li. ACS Nano **19**, 5699 (2025).

[3] G. Dai, Q. Zhan, ..., R.-W. Li. *Appl. Phys. Lett.* **100**, 122407 (2012).

[4] P. Sheng, Y. Xie, Y. Bai, B. Wang, ..., R.-W. Li. *Appl. Phys. Lett.* **115**, 242403 (2019).

[5] M. Li, H. Yang, Y. Xie, ..., R.-W. Li, Nano Lett. **23**, 8073 (2023).

[6] X. Bao, H. Yang,..., D. Makarov, R.-W. Li. Adv. Funct. Mater. **34**, 2409844 (2024).

[7] H. Li, Q. Zhan, ..., R.-W. Li. *ACS Nano* **4**, 4403 (2016).

[8] R. Zou, S. Qiu, H. Yang, ..., Y. Xie, ..., R.-W. Li. Adv. Mater. e18161 (2026).

Dynamics of skyrmions and hopfions in colloidal chiral magnets

Ivan I. Smalyukh[a,b,c,d]
[a]Department of Physics, University of Colorado, Boulder, CO, USA.
[b]International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM^2), Hiroshima University, Higashi-Hiroshima, Hiroshima, Japan.
[c]Materials Science and Engineering Program, University of Colorado, Boulder, CO, USA.
[d]Renewable and Sustainable Energy Institute, National Renewable Energy Laboratory and University of Colorado, Boulder, CO, USA

Magnetic monopoles, despite their ongoing experimental search as elementary particles, have inspired the discovery of analogous excitations in condensed matter systems. In chiral condensed matter systems, emergent monopoles are responsible for the onset of transitions between topologically distinct states and phases, such as in the case of transitions from helical and conical phase to A-phase comprising periodic arrays of skyrmions. By combining numerical modeling and optical characterizations, we describe how different geometrical configurations of skyrmions terminating at monopoles can be realized in liquid crystals and liquid crystal ferromagnets. We demonstrate how these complex structures can be effectively manipulated by external magnetic and electric fields. Additionally, we reveal transformations between hopfions, heliknotons and other structures in response to week external electric and magnetic fields. Furthermore, we discuss how our findings may hint at similar dynamics in other physical systems and their potential applications.

Design and control of three dimensional magnetic fields and solitons in helical nanostructures

C. Phatak[1,2], J. Fullerton[1]

[1]Materials Science Division, Argonne National Laboratory, Lemont, IL 60439, USA
[2]Department of Materials Science and Engineering, Northwestern Univeristy, Evanston, IL 60208, USA.

The interplay between geometric topology and magnetic spin topology can lead to novel phenomena such as effective anisotropies, formation and stabilization of intricate 3D spin textures, and emergent 3D magnetic fields consisting of knots [1]. Such effects can be easily studied in 3D nanostructures which can now be easily fabricated using focused electron beam induced deposition method [2]. Amongst them, nanohelices represent an important 3D nanostructure owing to their intrinsic geometric curvature and chirality [3]. Lorentz transmission electron microscopy (LTEM) provides a unique combination to characterize not only the microstructure but also the magnetic domain structure of such nanostructures at a high spatial resolution. In this work, we will present our work on various forms of nanohelices such as interconnected arrays of nanohelices, and helicoids. In interconnected nanohelices, we can create controllable topological stray field patterns by reconfiguring the magnetic state of the nanostructure [4]. By applying external magnetic fields, the magnetization of the nanostructure can be reconfigured, creating corresponding arrangements of magnetic charges in 3D space. These charges lead to unique forms of the emanating stray field localized in the gaps of the nanostructure. Furthermore, we will also discuss the formation of various solitons formed in such arrays during in-situ magnetization reversal. We will also discuss the fabrication of 3D helicoids with varying pitch and its effect on the resulting domain wall formation and the behavior under applied magnetic field. We will discuss the imaging of the stray fields and domain structure using off-axis electron holography and supported by micromagnetic simulations. Imaging of 3D magnetic fields and magnetization also requires advances in methods and algorithms. We will discuss recent work on developing 3D magnetization reconstruction using advanced methods based on machine-learning approaches.

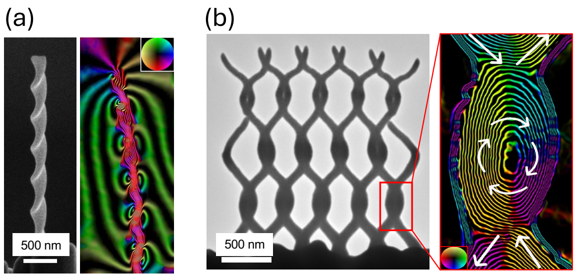


Figure 1.TEM image and projected magnetic induction map of (a) helicoid structures, and (b) interconnected helical nanowire array.

References:
[1] Gianluca Gubbiotti et al, J. Phys.: Condens. Matter 37 143502 (2025).
[2] L. Skoric, et. al., Nano Lett., 20, 184 (2020).
[3] J. Fullerton et al., Nano Lett. 24, 8, 2481–24 (2024).
[4] J. Fullerton et al., Nano Lett. 2025, 25, 13, 5148–5155 (2025).
[5] This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences and Engineering Division.

Energy-efficient field-free spin-orbit torques in 2D magnetic heterostructures

Saroj P. Dash[1*]

[1] Chalmers University of Technology, Gothenburg, Sweden.
*saroj.dash@chalmers.se

Two-Dimensional (2D) van der Waals (vdW) magnetic materials exhibiting non-trivial magnetic interactions provide a new platform for exploring exotic magnetic states and realizing energy-efficient spintronic devices. We demonstrate two complementary approaches achieving field-free, room-temperature magnetization switching with very low power consumption. First, we report the discovery of coexisting ferromagnetic and antiferromagnetic orders in vdW magnet $(Co_{0.5}Fe_{0.5})_{5-x}GeTe_2$ (CFGT) above room temperature, inducing intrinsic exchange bias and canted perpendicular magnetism [1]. This non-trivial magnetic ordering enables deterministic field-free spin-orbit torque (SOT) switching in CFGT/Pt heterostructures. The intrinsic magnetic symmetry breaking eliminates the need for external magnetic fields during switching operations. Second, we exploit unconventional out-of-plane SOTs in heterostructures combining Weyl semimetal $TaIrTe_4$ with perpendicular magnet Fe_3GaTe_2 [2]. Broken crystal symmetry and Berry curvature dipole of $TaIrTe_4$ generate substantial out-of-plane spin polarization or spin Hall conductivity, achieving field-free magnetization switching of Fe_3GaTe_2 at a very low current density. These findings show the potential of 2D vdW heterostructures as a promising platform for next-generation spintronic memory and computing.

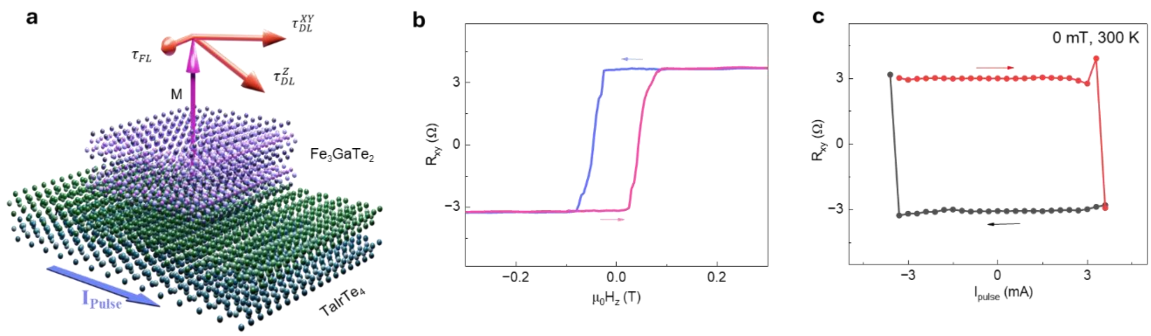


Figure 1. Spin-orbit torque in the $TaIrTe_4/Fe_3GaTe_2$ heterostructure [2]. **b.** Anomalous Hall effect of the $TaIrTe_4/Fe_3GaTe_2$ heterostructure with magnetic field sweep. **c.** Deterministic magnetization switching is achieved without an external magnetic field [2].

References

[1] B. Zhao et al, **Saroj Dash**, Advanced Materials, 2502822 (2025).
https://doi.org/10.1002/adma.202502822
[2] L. Pandey et al, **Saroj Dash**, Nature Communications 16, 8722 (2025).
https://doi.org/10.1038/s41467-025-64109-3

Inverse micromagnetics for accurate magnetization reconstruction and magnetic device design

Claas Abert*

University of Vienna, Vienna, Austria
* claas.abert@univie.ac.at

The accurate determination of magnetization configurations from indirect measurements and the computational design of magnetic device geometries are two central challenges in modern magnetism research. Both can be formulated as inverse problems, where the goal is to find unknown parameters—magnetization textures or device shapes—that best match target observations under micromagnetic constraints. We present a unified computational framework for such inverse micromagnetic problems, built around the open-source libraries NeuralMag and magnum.np [1].

For magnetic device design, we present a level-set-based topology optimization coupled with the adjoint-state method for memory-efficient gradient computation through the time-dependent Landau–Lifshitz–Gilbert equation. The level-set function, parameterized by radial basis functions, implicitly defines material boundaries and is evolved via gradient descent. This is demonstrated through the inverse design of a magnonic spin-wave demultiplexer achieving frequency-selective separation [2].

For magnetization reconstruction from stray-field measurements, we show how physics-informed regularization based on the total micromagnetic energy improves reconstruction fidelity. A fully differentiable forward model in PyTorch enables joint optimization of the magnetization and unknown experimental parameters such as the sensor–sample distance. Applied to nitrogen-vacancy (NV) magnetometry data of $Fe_{3-x}GaTe_2$, this recovers complex chiral spin textures including Néel skyrmions without training data or initial guesses [3].

Finally, we present the extension of this framework to three-dimensional magnetic vector tomography from X-ray magnetic circular dichroism (XMCD) data. By coupling a differentiable XMCD forward model with NeuralMag for micromagnetic energy regularization, we extract accurate 3D magnetization configurations even from sparse or noisy projection data [4].

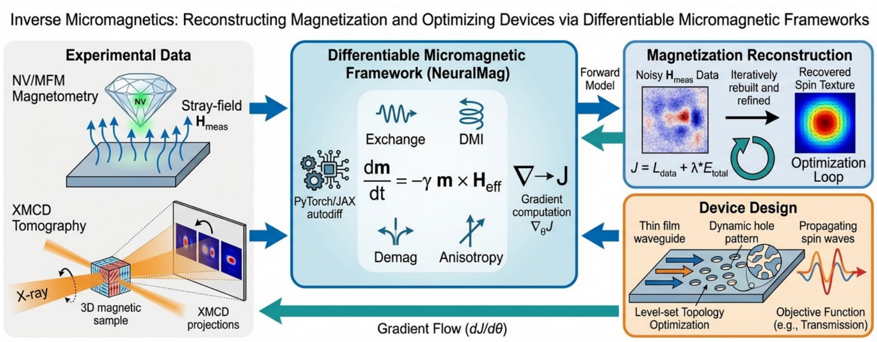


Figure 1. Inverse micromagnetics framework: experimental data are processed through a differentiable micromagnetic model for magnetization reconstruction and device design via gradient-based optimization.

[1] C. Abert et al., npj Comput. Mater. 11, 193 (2025).
[2] A.A. Voronov et al., npj Spintronics 3, 19 (2025).
[3] A. Setescak et al., arXiv:2602.17180 (2026).
[4] A. Setescak et al., 3DMAG 2026 (this conference).

Inertial spin-wave dynamics in twisted magnetic nanostrips

Massimiliano d’Aquino[1*]

[1]University of Naples Federico II, Naples, Italy
* mdaquino@unina.it

The growing ability to exploit the third dimension in the fabrication of magnetic nanoscale systems has allowed overcoming the constraints imposed by traditional flat structures[1]. While thin-film magnetic systems have established the foundation for spintronics and magnonics[2], the transition to three-dimensional (3D) nanomagnetism reveals profound effects arising from curvature, torsion, and topology[3]. In this context, the study of spin-wave propagation in geometrically complex nanostructures—such as twisted magnetic strips—has attracted increasing attention. In addition to exhibiting intricate magnetization textures, these systems enable fundamentally novel dynamical phenomena as a consequence of their inherent spatial asymmetry. Concurrently, the experimental observation of terahertz (THz) nutation arising from magnetic inertia[4], predicted over a decade ago for ferromagnets[5], has opened new avenues in ultrafast magnetism and stimulated extensive research into inertial spin-wave dynamics, following pioneering experiments on planar magnetic nanostructures.

In this presentation, we outline novel dynamical phenomena produced by the excitation of inertial spin-wave dynamics in 3D twisted soft-magnetic nanostrips, where curvature and torsion couple with magnetic inertia to produce THz magnetic oscillations. We show that these inertial effects, enhanced by the underlying 3D geometry, lead to a pronounced nonreciprocal behavior in the spin-wave spectrum[6]. The combination of geometric chirality and inertial dynamics introduces an effective symmetry breaking, positioning these twisted architectures as promising candidates that pave the way to the field of curvilinear THz magnonics.

We present a theoretical treatment[6] that allows quantitative understanding for the onset of geometric (Berry) phase in inertial spin wave dynamics, which is responsible for the aforementioned symmetry breaking. Analytical formulas for dispersion relations and spectral linewidths are derived both in the precessional (GHz) and in the nutational (THz) regimes and offer a complete picture of the influence of each single parameter on the propagation of inertial spin waves. Application to nanostrips with different nontrivial topology such as Möbius and helical strips reveals different wave number quantization rules, enlightening the role of topology in spin-wave dynamics.

[1] G. Gubbiotti Ed., Three-Dimensional Magnonics: Layered, Micro- and Nanostructures, Jenny Stanford Publishing, New York (2019).

[2] V. V. Kruglyak, S. O. Demokritov, and D. Grundler J. Phys. D 43, 264001 (2010).

[3] D. D. Sheka, O. V. Pylypovskyi, O. M. Volkov, K. V. Yershov, V. P. Kravchuk, and D. Makarov, Small 18, 2105219 (2022).

[4] K. Neeraj, N. Awari, S. Kovalev, D. Polley, N. Z. Hagström, S. S. P. K. Arekapudi, A. Semisalova, K. Lenz, B. Green, J.-C. Deinert, I. Ilyakov, M. Chen, M. Bawatna, V. Scalera, M. d’Aquino, C. Serpico, O. Hellwig, J.-E. Wegrowe, M. Gensch, and S. Bonetti, Nat. Phys. 17, 245 (2020).

[5] M.-C. Ciornei, J. M. Rubí, and J.-E. Wegrowe, Phys. Rev. B 83, 020410(R) (2011).

[6] M. d’Aquino, R. Hertel, Phys. Rev. Lett, 135 (2025), 216705.

Nanosculpted 3D helices of a magnetic Weyl semimetal with switchable non-reciprocal electron transport

Max T. Birch[1,*], Yukako Fujishiro[1], Ilya Belopolski[1], Masataka Mogi[2], Yi-Ling Chiew[1], Zhuolin Li[1], Xiuzhen Yu[1], Naoto Nagaosa[1], Minoru Kawamura[1], Yoshinori Tokura[1,2,3]

[1] RIKEN Center for Emergent Matter Science, Wako, Japan.
[2] Department of Applied Physics, The University of Tokyo, Tokyo, Japan.
[3] Tokyo College, The University of Tokyo, Tokyo, Japan.
* maximilian.birch@riken.jp

The emergent properties of materials are governed by the symmetries of their underlying atomic, spin and charge order. Therefore, intrinsic material properties usually constrain the exploration of symmetry-breaking effects. Focused ion beam (FIB) fabrication now enables the structuring of bulk crystals into ultraprecise transport devices [1,2], allowing the study of geometrical symmetry breaking on mesoscopic length scales. In this talk, I will briefly introduce the methodology and rationale behind device fabrication with FIB. I will then highlight our development of the FIB fabrication of three dimensional single crystalline nanostructures [3], with the main example being helical-shaped devices (Figure 1) of the high-mobility Weyl magnet $Co_3Sn_2S_2$ [4]. Lock-in measurements on the helical devices show that the combination of imposed inversion symmetry-breaking geometry and topological ferromagnetism yields non-reciprocal electron transport – or a diode effect – at zero applied magnetic field, exceeding classical self-field expectations by orders of magnitude at low temperatures. We attribute this behaviour to the quasi-ballistic motion of carriers as the mean free path approaches the length scale of the chiral device geometry. Finally, we have shown that current pulses can switch the magnetization of the device. These results highlight the potential of FIB nanosculpting to engineer symmetry and functionality beyond conventional device geometries, including in three dimensions.

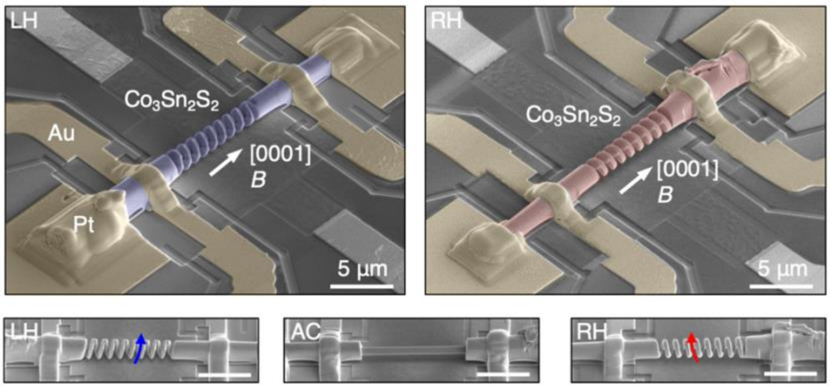


Figure 1. Scanning electron micrographs of the nanosculpted $Co_3Sn_2S_2$ helix devices with left handed (LH) and right handed (RH) chirality, as well as a straight achiral (AC) control sample.

[1] P. J. W. Moll. *Annu. Rev. Condens. Matter Phys.* **9,** 147–162 (2018).

[2] P. J. W. Moll, et al. *Nat. Commun.* **6,** 6663 (2015).

[3] L. A. Turnbull, et al. Preprint at https://arxiv.org/ abs/2511.11372 (2025).

[4] M. T. Birch, et al. *Nat. Nanotechnol.* **21** (2026).

Rethinking linking
Topology in magnetism, water waves and plasmonics

Karin Everschor-Sitte[1*]

[1] Faculty of Physics and CENIDE, University of Duisburg-Essen
* karin.everschor-sitte@uni-due.de

3D magnetism is not a mere extension of 2D. Curvature, confinement, and long-range magnetostatic interactions fundamentally reshape magnetic order, giving rise to intrinsically 3D textures such as hopfions and screw dislocations [1]. Yet their identification and classification remain challenging: visualization strongly depends on representation and viewing angle. Moreover, although such textures can be characterized by the Hopf index, the corresponding local Hopf density is gauge dependent and therefore not uniquely suited for quantitative analysis in finite systems [2].

We show that linking provides a unifying framework to overcome these limitations. By introducing a discrete geometric definition of the Hopf index based on linking [3], we avoid the pitfalls of continuum integral formulas in finite volumes and move beyond homotopy classifications based on spheres. This approach uniquely assigns real-valued Hopf indices to 3D textures and allows to interpret non-integer values as states of mixed topology. For example, the Twiston continuously connects a Hopfion to a Skyrmion tube, see Fig. 1.

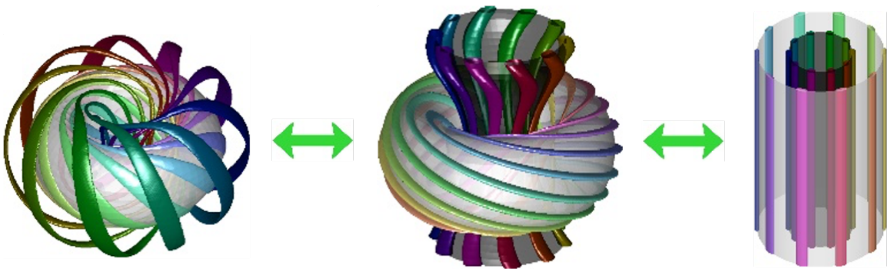


Figure 1. A Twiston with a fractional Hopf index (middle panel) can transform into a Hopfion with Hopf index 1 (left) or Skyrmion tube which has a Hopf index of 0 (right).

Finally, we extend the concept of linking to other physical systems, including plasmonics and water waves, suggesting that linked field configurations may provide a common description across diverse physical platforms.

[1] S. C. Shaju, M. Azhar, and K. Everschor-Sitte, arXiv:2601.10853 (2026).

[2] R. Knapman, M. Azhar, A. Pignedoli, L. Gallard, R. Hertel, J. Leliaert, and K. Everschor-Sitte, Phys. Rev. B **111**, 134408 (2025).

[3] M. Azhar, S. C. Shaju, R. Knapman, A. Pignedoli, and K. Everschor-Sitte, arXiv:2411.06929 (2024).

Deterministic control of internal structure of Bloch points using topological defects in helical nanowires

Naëmi Leo[1,2*], Daniel Wolf[3], Alicia Estela Herguedas Alonso[4,5], Oleksandr Zaiets[3], Jakub Jurczyk[2], Takeaki Gokita[2], John Fullerton[6], Dedalo Sanz-Hernandez[7], Claire Donnelly[8], Andrea Sorrentino[5], Eva Pereiro López[5], Lucia Aballe[5], David Raftrey[9], Peter Fisher[6], Stefan Stanescu[10], Rachid Belkhou[10], Claas Abert[11], Dieter Suess[11], Axel Lubk[3,12], Aurelio Hierro-Rodriguez[4], and Amalio Fernández-Pacheco[2]

[1] Loughborough University, UK; [2] TU Wien, Austria; [3] IFW Dresden, Germany; [4] University of Oviedo, Spain; [5] ALBA Synchrotron, Spain; [6] Argonne National Lab, USA; [7] Laboratoire Albert Fert, France; [8] MPI Dresden, Germany; [9] Lawrence Berkeley Lab, USA; [10] Synchrotron SOLEIL, France; [11] Vienna University, Austria; [12] TU Dresden, Germany.
* n.leo@lboro.ac.uk

Bloch points are three-dimensional singularities in magnetization that play a key role in topological transformations of spin textures [1]. Using a geometrical approach, here we demonstrate deterministic control of the internal magnetic structure of Bloch point. This is achieved by creating a chirality interface between two three-dimensional double-helix nanowires of opposite helicity, which form a kinked, non-collinear structure (see Figure 1). A saturating magnetic field nucleates head-to-head or tail-to-tail configurations at the chirality interface, leading to the formation of a Bloch point in the vicinity of the chirality interface, marked (*) below. Combining advanced experimental tomography techniques, including transmission electron microscopy (TEM) and x-ray magnetic circular dichroism (XMCD), with micromagnetic simulations, we confirm that domain walls containing circulating Bloch points are reliably nucleated with predefined polarity and circulation [2]. These Bloch points also have a hyperbolic character, with a helicity angle ≠90°. Due to the combination of tailored geometry and the robustness of the initialization field protocol, our approach thus facilitates future 3D spintronic device architectures containing Bloch points with controlled properties.

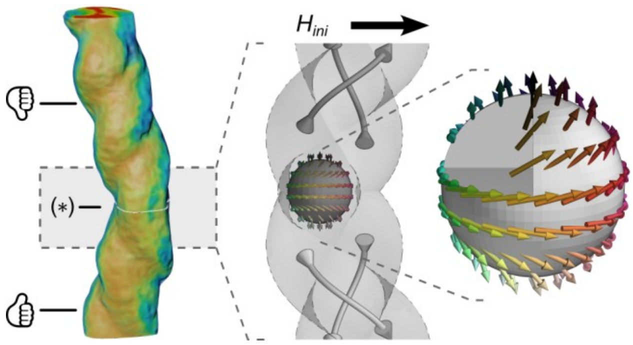


Figure 1. Interfacing two helical nanowires of opposite handedness at position (*) allows for the controlled nucleation of a Bloch point after saturation with a transverse field H_{ini}.

[1] E. Feltdkeller, «Mikromagnetisch stetige und unstetige Magnetisierungs-konfigurationen», Z. Angew. Phys. **19** 530 (1965). «Continuous and Singular Micromagnetic Configurations», IEEE Trans. Magn. **53** 1 (2017)

[2] «Deterministic control of internal structure of Bloch points using topological defects in helical nanowires", N. Leo *et al.*, in preparation.

Controlling and Observing Vortex Formation in Magnetic Nanowire: Individual Nanowires and Arrays

Beth Stadler[1,2*], Roman Kolisnyk[1], Anthony Afful[1], Biazid Moghal[1], Pang-Hsiao Liu[2]

[1] Electrical & Computer Engineering, University of Minnesota, Minneapolis, MN USA
[1] Chemical Engineering & Materials Science, University of Minnesota, Minneapolis, MN USA
* stadler@umn.edu

Magnetic nanowires have predictable switching fields (H_N) based on the formation of vortex domain walls at the ends. There is a well-known relationship between the fields and the radius (*r*) of the nanowire [1,2]:

$$H_N = \frac{k\,A}{\mu_o\,M_s\,r^2} \quad (1)$$

where k is a constant, A is the anisotropy constant and $\mu_o\ M_s$ is the saturation magnetization of the nanowire material. This predictable behaviors enable magnetic nanowires and nanobars to be used as reconfigurable barcodes in arrays [3], as bio-barcodes and nanowarmers (eg: rewarming cryopreserved organs) when free floating [4,5], and as heating agents with controllable areal heat based on the amplitude of an applied alternating magnetic field [2].

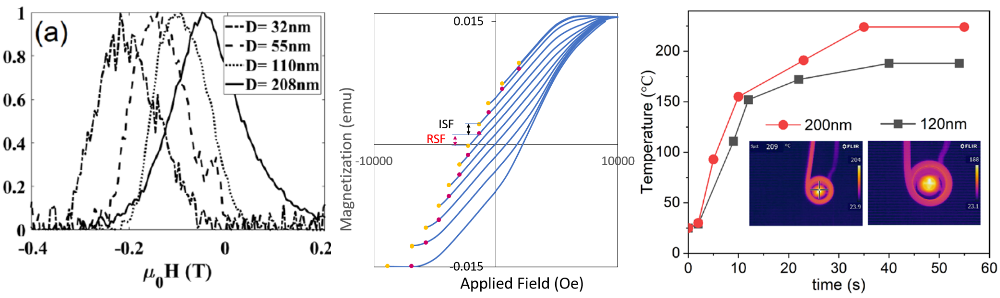


Figure 1. a) Barcodes [4] of magnetic nanowires using irreversible switching field (ISF in (b)) where full FORC curve (b) is not needed [6]. c) Specific heating of magnetic nanowires using the amplitude of an alternating magnetic field [2].

This paper will focus on the control, measurement, and observation (using magneto-optical garnets) of vortex formation in magnetic nanowires and nanobars, both in arrays and free-floating. Interestingly, two trends of vortex domain wall switching are observed, one the agrees with the long-standing relationship above, and one that does not.

[1] J.A. Fernandez-Roldan, D. Serantes, R.P. del Real, M. Vazquez, O. Chubykalo-Fesenko Appl. Phys. Lett. **112**, 212402 (2018).
[2] Y. Chen, B.J.H. Stadler International Journal of Hyperthermia **40**, 2223371 (2023).
[3] J. Um, Y. Zhang, W. Zhou, M.R. Zamani Kouhpanji, C. Radu, R. Franklin, B.J.H. Stadler *ACS Applied Nano Materials* **4**, 3557-3564 (2021).
[4] MR Zamani Kouhpanji, A. Ghoreyshi, P. B. Visscher, BJHS, *Sci. Rep.* **10**, 15482 (2020).
[5] D. Shore, A. Ghemes, O. Dragos-Pinzaru, Z. Gao, Q. Shao, A. Sharma, J. Um, I. Tabakovic, J.C. Bischof, B.J.H. Stadler. *Nanoscale* **11**, 14607-14615 (2019).
[6] BJHS, MR Zamani Kouhpanji, A. Stankiewicz, *IEEE Trans. Magnetics* **59,** 1 (2022).

Thermal Gradient-Induced Bouncing of Chiral Domain Walls under Applied Current at Cylindrical Nanowire Ends

E. Saugar[1], J. Marqués-Marchan[2], S. Catalano[3], A. Asenjo[1], M. Foerster[4], M.A. Niño[4], M. Vazquez[1], F. Casanova[5], A. Fraile-Rodríguez[6], R. P. del Real[1], O. Chubykalo-Fesenko[1] and C. Bran[7]
[1]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain
[2] Max Planck Institute for Chemical Physics of Solids,Dresden, Germany
[3] Materials Physics Center, CSIC-UPV/EHUDonostia - San Sebastian, Spain
[4]ALBA Synchrotron Light Facility, CELLS Barcelona, Spain
[5]CIC nanoGUNE BRTA, Donostia-San Sebastián, Basque Country, Spain
[6]Dept. Física de la Materia Condensada, Universidad de Barcelona, Barcelona, Spain
[7]INMA, CSIC-Universidad de Zaragoza, Zaragoza, Spain
* rafael.perez@icmm.csic.es

Cylindrical geometries in nanomagnetism provide advantages for next-generation spintronics due to curvature-induced effects. Unlike planar structures, cylindrical nanowires exhibit chiral spin textures and complex, fast-moving domain walls[1]. Simulations indicate that Bloch-point domain walls in highly magnetized nanowires may surpass the magnonic velocity limit under applied fields because of their 3D conical structure[2].

Despite advances in theoretical modeling, experimental evidence of DW dynamics in 3D cylindrical nanostructures under applied current remains scarce, primarily due to the challenges associated with real-time observation at the nanoscale of very fast objects. Only a few studies have successfully imaged DW motion in such geometries[3, 4]. In some of them[5], quite high current density has been reported as a requirement to induce domain wall.

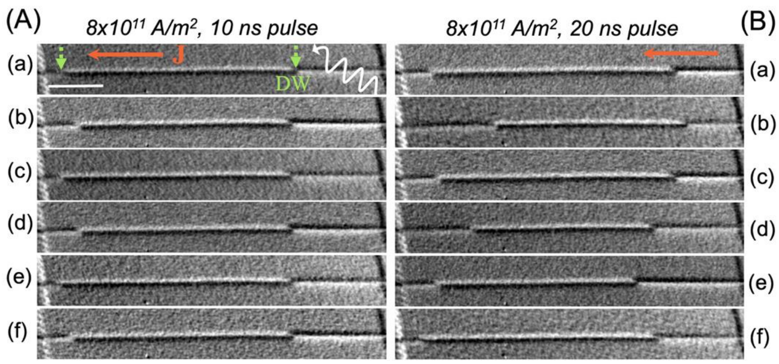


Figure 1. DWs movement under high amplitude current pulses. XMCD-PEEM series of images taken after a pulse applied repeatedly for (A) 10 ns and (B) 20 ns, respectively.

In this work[6], using XMCD-PEEM, we examined domain-wall dynamics in cylindrical nanowires under ns current pulses. Low current densities move domain walls and saturate the nanowire, but higher currents cause them to rebound from wire ends, with rebound distance increasing with pulse duration. Modelling shows spin-transfer torque dominates at low currents, while its competition with thermal gradient governs higher-current behaviour.

[1] A. Fernández-Pacheco et al., Nat Commun, **8**, 15756 (2017)
[2] F. Tejo et al., Nanoscale, **16**, 10737–10744 (2024)
[3] C. Bran et al., Nanoscale, **15**, 8387–8394 (2023)
[4] S. Ruiz-Gómez et al., Nanoscale, 12, 17880–17885 (2020)
[5] M. Schöbitz et al., Phys Rev Lett, 123, 217201 (2019)
[6] C. Bran et al., Adv. Funct. Mater., accepted (2026)

Three-dimensional control of magnetic cocoons in multilayers employing He^+ ions

K. Puzhekadavil Joy[1,2,*], R. Battistelli[1,2], S. Wittrock[1], K. Litzius[2], S. Collin[3], J. Chilinquinga[3], M. Schneider[4], M. Weigand[1], S. Wintz[1], B. Pfau[4], V. Cros[3], N. Jaouen[5], N. Reyren[3], F. Büttner[1,2]
[1]Helmholtz-Zentrum Berlin, Germany, [2]University of Augsburg, Germany,
[3]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, Palaiseau, France,
[4]Max Born Institute, Berlin, Germany,
[5]SOLEIL Synchrotron, Gif-sur-Yvette Cedex,France
* krishnanjana.puzhekadavil_joy@helmholtz-berlin.de

Skyrmionic cocoons are prolate-shaped three-dimensional spin textures realized in the interior of Pt/Co/Al magnetic multilayers [1-2]. Their nucleation so far occurs randomly throughout the multilayer stack. Achieving spatial control is crucial for potential device applications.

Here, we demonstrate controlled nucleation of these 3D spin textures in both lateral and vertical dimensions using He^+ ion irradiation. The irradiated multilayers were investigated with Scanning transmission x-ray microscopy (STXM) at BESSY II. By tuning the He^+ acceleration energy from 5 keV to 30 keV, we controlled the ion penetration depth from the topmost layers to the full thickness of the multilayer stack (~ 290 nm). While 5 keV irradiation suppresses the formation of skyrmionics cocoons in the exposed region, 30 keV irradiation enables their deterministic nucleation within the irradiated areas (Figure 1).

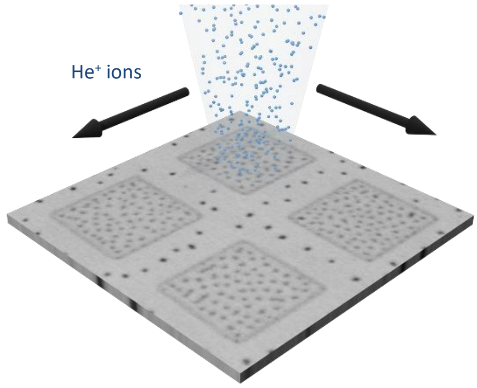


Figure 1 : Multilayer irradiated with He^+ ions of energy 30 keV. Different squares are exposed to ions of varying doses.

Quantitative analysis of the magnetic depth profile using X-ray magnetic circular dichroism reveals that the vertical extent of the cocoons can be tailored by varying the ion energy and dose. The magnetization in the irradiated regions exhibits a non-monotonic dependence on ion dose, highlighting the complex ion-multilayer interactions. These effects are attributed to ion-induced interlayer mixing, which modifies key magnetic parameters such as magnetic anisotropy.

Our results provide a pathway toward deterministic three-dimensional spin texture engineering and help bridge the gap between fundamental 3D spintronics and future device applications.

This work is supported by by ANR-DFG number BU 3297/4-1 (Topo3D), by ANR-22- EXSP-0002 PEPR SPIN CHIREX and grant no. ANR- 22-EXSP-0008 PEPR SPIN SPINCHARAC) and by EU project SkyANN (reference no. 101135729)

[1] M. Grellier *et al.*, *Nat Commun*. **13**, 6843 (2022); Ibid, *Phys. Rev. B*. **107**, L220405 (2023).
[2] J.J. Chiliquinga-Jacome *et al.*, *arXiv:2601.14889 (2026)*

Geometry-stabilized skyrmions and emergent Hall signatures in curved Pt/Co/Ta nanodomes

Juliano C. Denardin[1,2,4*], Denilson Toneto[3], Juan L. Palma[2,3], Marcio A. Correa[4], Matheus Gamino[4], Simón Oyarzún[1,2]

[1] Physics Department, USACH, Santiago, Chile
[2] Center of Nanoscience and Nanotechnology (CEDENNA), Santiago, Chile.
[3] CIIMAT, Central University of Chile, Santiago, Chile
[4] Department of Physics (DFTE), UFRN, Natal, RN, Brazil
* juliano.denardin@usach.cl

Magnetic skyrmions in heavy-metal/ferromagnet multilayers are promising information carriers for next-generation spintronic and neuromorphic technologies owing to their topological protection and nanoscale dimensions [1]. Here, we introduce controlled three-dimensional curvature by depositing Pt/Co/Ta multilayers onto ordered anodic aluminum oxide nanodomes with diameters ranging from 100 to 250 nm. This curved geometry maintains perpendicular magnetic anisotropy while reshaping the local balance between anisotropy, exchange, and dipolar interactions [2].

A combined experimental and micromagnetic approach, integrating Hall effect measurements, Hall-derived first-order reversal curve (FORC) analysis, magnetometry, and magnetic force microscopy (MFM), is used to resolve magnetization reversal pathways, pinning mechanisms, and spatially confined magnetic textures. MFM imaging reveals robust stabilization of Néel-type skyrmions at remanence across all dome diameters, evidencing curvature-driven confinement (see Fig.1).

The Hall response exhibits pronounced nonlinearity and memory effects, reflecting the presence of multiple metastable magnetic states and field-tunable transitions between them. These features provide the key ingredients for physical reservoir computing, enabling short-term memory and nonlinear signal transformation within a compact magnetic platform. Our results demonstrate that curvature-engineered multilayers constitute a scalable route to three-dimensional nanomagnetism, offering simultaneous control over skyrmion stability, emergent transport signatures, and functional responses relevant for spintronic and neuromorphic computing architectures.

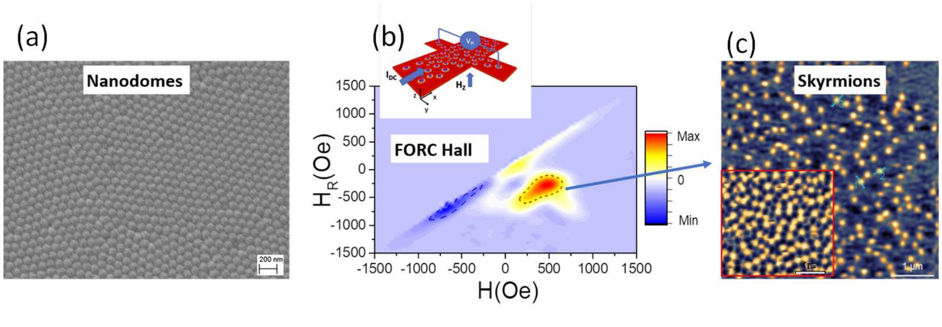


Figure 1. (a) SEM image of 100 nm nanodomes. (b) FORC Hall diagram of nanodomes and (c) arrays of skyrmions nucleated at 500 Oe and stabilized at ZF (inset).

[1] T. Yokouchi, et.al. Sci. Adv. **8**, eabq5652 (2022).

[2] F. Tejo, et. Al. ACS Appl. Mater. Interfaces **12**, 47 (2020).

Curvature gradient driven domain wall automotion

Eider Berganza[1]*, Felipe Tejo[2], Guilherme H. R. Bittencourt[3], Vagson L. Carvalho-Santos[4], Oksana Chubykalo-Fesenko[1], Agustina Asenjo[1]

[1] Instituto de Ciencia de Materiales de Madrid-CSIC. Sor Juana Ines de la Cruz 3, 28049 Madrid
[2] Universidad Central de Chile, Escuela de Ingeniería, Santiago de Chile, Chile.
[3] Instituto Federal de Santa Catarina, R. Aloísio Stoffel, 89885-000, São Carlos, SC, Brasil
[4] Universidade Federal de Vicosa, Departamento de Física, Avenida Peter Henry Rolfs s/n, 36570-000, Vicosa, MG, Brasil.
*eider.berganza@csic.es

Curvature and geometry have significant implications in nanomagnetism, leading to the appearance of intriguing novel phenomena. (1) While theory suggests that geometrical curvature gives rise to domain-wall automation (2) –the spontaneous movement of a magnetic domain wall without the continuous application of an external driving force– experimental validation this phenomenon has remained elusive. We address this gap using permalloy spiral-shaped magnetic nanostructures. By initializing head-to-head and tail-to-tail domain walls in an *onion state*, we show that curvature acts as an attractive potential that pulls domain walls toward the spiral's center, by measuring depinning fields via Magnetic Force Microscopy with in-situ applied magnetic field (Fig. 1). Our combined experimental, analytical, and simulation-based approach proves that curvature gradient is a very useful geometrical parameter for the control of domain wall dynamics which has relevant implications for the realization of low-energy spintronic devices. (3)

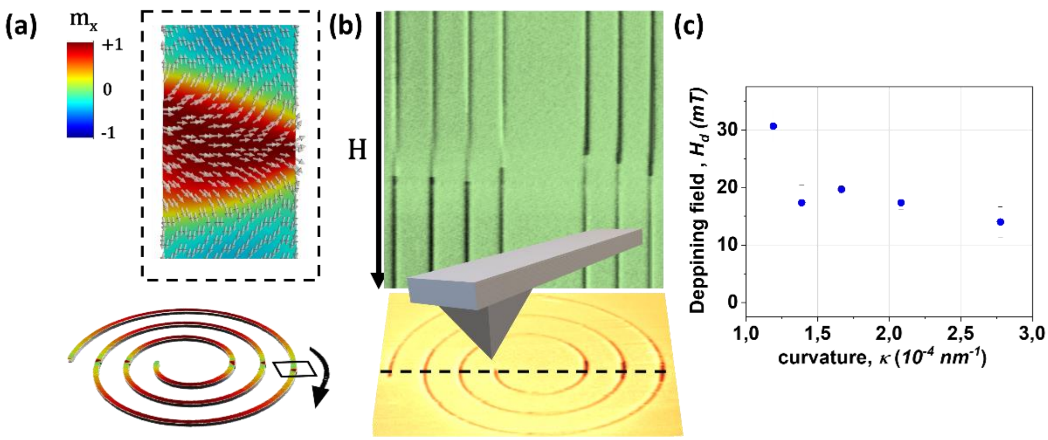


Figure 1. (a) Permalloy Archimedean spiral showing magnetic onion-state with transversal DW in micromagnetic simulations. **(b)** Standard Magnetic Force Microscopy images, showing onion states, with Advanced modes displaying depinning fields of the DWs on the marked line. **(c)** Experimentally obtained depinning of DWs versus the local curvature of the position where they are hold within the spiral.

[1] D. Makarov, et al. Curvilinear Micromagnetism: From Fundamentals to Applications, Springer International Publishing, 2022.

[2] K. V Yershov et al. Phys. Rev. B, **98,** 060409(R) (2018)

[3] E. Berganza, Small **21**, 12, 2407084 (2025)

Topology of domain wall transformations in magnetic cylinders: micromagnetic study and vector field analysis

Lucia Gomez-Cruz[1,2], Mouad Fattouhi[1], Anais Fondet[1], Giuseppe Curci[1], Natalia Boscolo-Meneguolo[1], Laura Alvaro Gomez[2], Ioan-Lucian Prejbeanu[1], Lucas Perez[2], Christophe Thirion[3], Edgar Bonet[3], Jean-Christophe Toussaint[3], Aurelien Masseboeuf[1], Olivier Fruchart[1], Daria Gusakova[1*]

[1] Université Grenoble Alpes, CNRS, CEA, SPINTEC, Grenoble, France
[2] Dpto. Fisica de Materiales, Universidad Complutense de Madrid, Madrid, Spain
[3] Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France
* daria.gusakova@cea.fr

Cylindrical magnetic nanowires are three-dimensional systems in which magnetization may be manipulated by spin-polarized currents or current-induced Oersted fields in view of three-dimensional storage devices design. Recently, different types of such physical systems involving cylindrical shape have been studied in our laboratories: (a) 3D Perpendicular Shape-Anisotropy Pillars [1], (b) nanowires with chemical modulations [2], (c) azimuthally-magnetized nanowires [3].

To simulate non-trivial 3D micromagnetic textures of such systems and the impact of current on their dynamics we have developed the multi-physics finite element C++ software *feeLLGood* which is suitable for irregular or curved geometries [4]. In addition to conventional micromagnetism considering magnetization, the code includes the self-consistent calculation of the spin dynamics of conduction electrons, which give rise to STT and SOT-induced effects. We also developed a portfolio of post-processing tools for the topological analysis based on 2D/3D vector field singularities, and conversion tools from micromagnetic output to experimental contrast. All three are particularly suited for the proper understanding of 3D spintronic systems.

Here we review the dynamics of each system (a), (b), (c) in term of non-trivial topology of 3D magnetic texture and vector field analysis. Indeed, in contrast to flat 2D magnetic systems, fully 3D geometry allows the formation of volume singularities such as, for example, Bloch Points (BP). According to physical ingredients, these textures may be either the lowest energy solutions or dynamically-induced objects. Moreover, we evidence that the interplay between volume topological objects (BP itself) and induced surface objects (vortex and antivortex pairs) is a key feature in the magnetization dynamics of 3D nanomagnets, which cannot be described either purely as 3D (bulk) nor 2D (surface).

We discuss physical origins, topological conservation laws and the consequence of complex interplay between volume and surface topological objects in cylindrical geometries.

[1] N. Boscolo-Meneguolo *et al.*, Phys. Rev. B **112**, 014448 (2025)

[2] L. Alvaro-Gomez *et al.*, Phys. Rev. Res. **7**, 023092 (2025)

[3] L. Gomez Cruz, submitted.

[4] https://feellgood.neel.cnrs.fr/

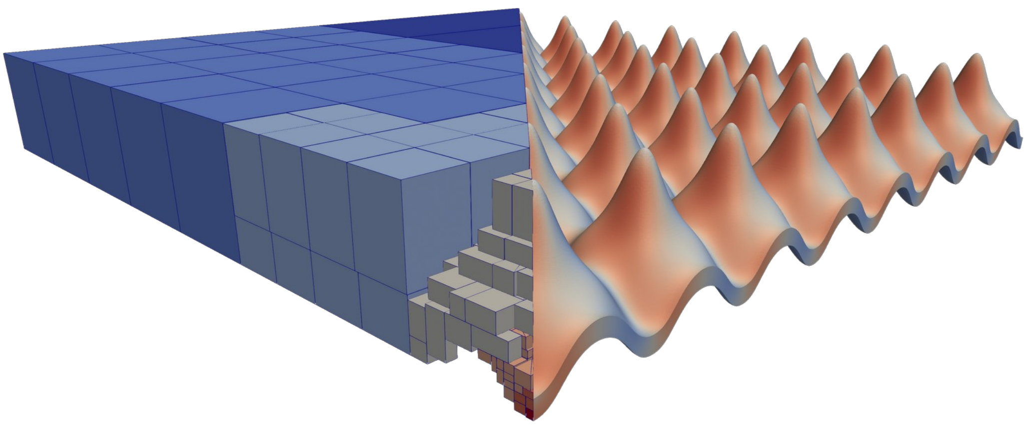
jaxFMM: Fast and accurate stray field evaluation for finite-element micromagnetics

Robert Kraft[1,2*], Florian Bruckner[1], Dieter Suess[1], Claas Abert[1]

[1] Physics of Functional Materials, University of Vienna, Vienna, Austria
[2] Vienna Doctoral School in Physics, University of Vienna, Vienna, Austria
* robert.kraft@univie.ac.at

The design of novel magnetic devices and materials relies heavily upon the insights gained from micromagnetic simulations. Applications rapidly increase in both size and complexity, resulting in unprecedented computational complexity and simulations with runtimes that are no longer feasible. Here, the long-ranged stray field is especially challenging, even more so in the case of irregular meshes encountered in finite-element simulations: The cost for computing the stray field scales quadratically with the number of vertices in the mesh and efficient FFT-based approaches are only available for regular grids. However, the Fast Multipole Method (FMM) offers linear scaling, can be parallelized efficiently and is capable of dealing with highly irregular meshes. We introduce jaxFMM [1], an open-source implementation of the FMM written in JAX [2], with additional routines for stray-field evaluation. With jaxFMM, stray fields of systems with millions of vertices can be quickly evaluated on just one GPU - such as the mesh in Fig. 1, where jaxFMM enabled dispersion calculations which previously were not feasible. Furthermore, the code is very concise and easy to use, also runs on CPUs and has access to JAX features such as automatic differentiation – therefore it is ready for future applications in inverse-design or machine-learning tasks.

Figure 1. jaxFMM far-field hierarchy (left) of the bottom center corner in a finite-element mesh with 33 million elements (right)



[1] https://gitlab.com/jaxfmm/jaxfmm

[2] https://github.com/jax-ml/jax

Direct observation of Néel-type skyrmionic textures in 3D curved magnets under zero-field conditions

Trevor P. Almeida[1]*, Kayla Fallon[1], Danian A. Dugato[2], Wesley B. F. Jalil[2], András Kovács[3], Rafal Dunin-Borkowski[3], Stephen McVitie[1] and Flavio Garcia[2]

[1]SUPA, School of Physics and Astronomy, University of Glasgow, G12 8QQ, UK.
[2]Centro Brasileiro de Pesquisas Físicas (CBPF), Rio de Janeiro-RJ, Brazil.
[3]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Jülich, Germany.

Stabilizing magnetic textures under zero-field conditions is a critical issue in a range of spintronic and biomedical applications. Herein, we apply colloidal lithography to produce nanocaps (~ 500 nm diameter) of multi-layered Pt/Co(t)/Pt with varying Co thickness (t) to explore a range of chiral spin textures [1]. A phase diagram constructed using micromagnetic simulations showed the ground state in relation to effective radial anisotropy constant (K_{radial}) and interfacial Dzyaloshinskii-Moriya interaction (iDMI), varying from vortex, planar ring, stripe, radial state and skyrmionics states (Fig. 1a). The K_{radial} resulting in skyrmionic states corresponded to 2 nm thick Co layers and was examined experimentally using electron holography. The nanocap curvature provides a tilt angle required for electron holography to be sensitive to the in-plane magnetic component, ϕ_m, of Néel-type skyrmions. The phase image (Fig. 1b) and magnetic induction map (Fig. 1c) confirms the presence of a single Néel-type skyrmion (labelled 'sk') and is consistent with that observed from Néel skyrmions in thin films [2,3]. Some nanocaps with 2 nm thick Co layers are observed to comprise two skyrmions, whilst nanocaps with 1.5 nm thick Co layers are consistent with stripe domain states. This works provides fundamental insight into the impact of geometric curvature on controlling ground states and iDMI, allowing effective engineering of skyrmionic configurations without the need to apply fields at room temperature.

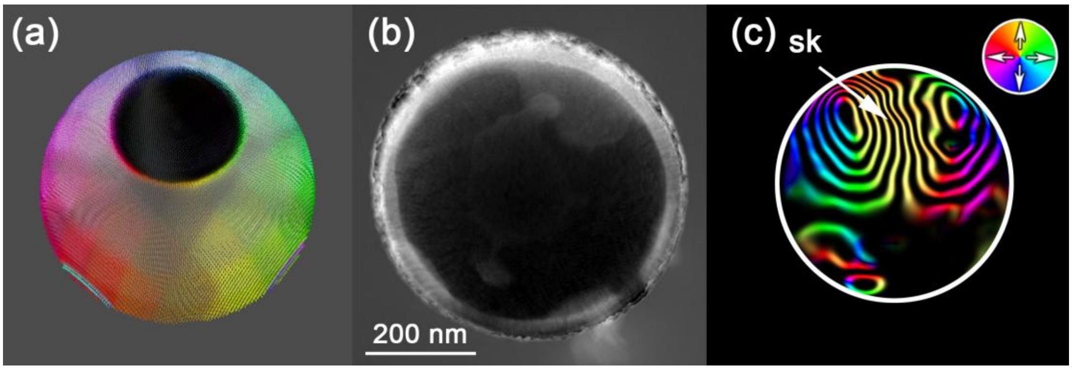


Figure 1. (a) Micromagnetic simulation; (b) electron holography phase image and (c) associated reconstructed magnetic induction map of a multi-layered [Pt(1 nm)/Co(2 nm)/Pt(1nm)]×10 nanocap confirming the presence of a single Néel-type skyrmion (labelled 'sk'). The contour spacing is 0.157 rad, and the direction of magnetic induction is indicated by the colour wheel (inset) [1].

1. Dugato, D. et al, *Nano Lett.* **25 (22)**, 8901–8908 (2025).
2. Denneulin, T. et al, *Ultramicroscopy* **220**, 113155 (2021).
3. Fallon, K. et al, *Phys. Rev. B* **100**, 214431 (2019).

Magnetic solitons in hierarchical 3D magnetic curvilinear nanoarchitectures

Olha Bezsmertna [1*], Rui Xu[1], Oleksandr V. Pylypovskyi[1], David Raftrey[2,3], Andrea Sorrentino[4], Jose A. Fernandez-Roldan[1], Ivan Soldatov[5], Daniel Wolf[5], Axel Lubk[5], Rudolf Schäfer[5], Peter Fischer[2,3], and Denys Makarov[1]

[1] Zentrum Dresden-Rossendorf e.V., Dresden, Germany
[2] University of California Santa Cruz, Santa Cruz CA, USA
[3]Lawrence Berkeley National Laboratory, Berkeley CA, USA
[4]Alba Light Source, Cerdanyola del Vallès 08290, Spain
[5]Leibniz Institute for Solid State and Materials Research, Dresden, Germany

* o.bezsmertna@hzdr.de

Curvilinear magnetism is an emerging field investigating how shape of the sample modifies magnetic responses [1]. Coupling between geometry and magnetic lattice is often established via magnetostatics. In particular, it can lead to non-local symmetry breaking in 3D samples [2], and asymmetries in geometric shapes lead to magnetic symmetry breaking [3]. Here, we fabricate large arrays of magnetic nanostructures and analyse magnetic phenomena [4]. We utilize advanced Anodized Aluminum Oxide (AAO) templates to create large-scale, highly-periodic 3D nanomembranes of 50-nm-thick permalloy of a nanoflower shape (see Fig. 1a). These nanoflowers host a variety of magnetic textures, and the ground state of the nanoflower is the magnetic vortex shifted from the origin (see Fig. 1b). This asymmetric state is formed due to the interaction of surface and volume magnetostatic charges. These ordered arrays of magnetic architectures of complex shape enable further research in nonlinear magnetization dynamics, 3D magnonics [5] and curvilinear spintronics.

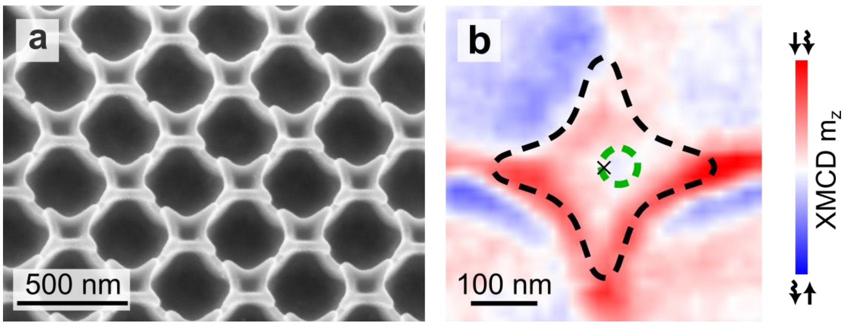


Figure 1. (a) tilted view scanning electron microscopy (SEM) image of 50-nm-thick Permalloy ($Fe_{80}Ni_{20}$) nanoflowers; (b) magnetic vortex shifted from the center (lowest energy state)

[1] D. Makarov et al., *Springer Nature*, Vol. 146 (2022)

[2] D. D. Sheka et al., *Communications Physics*, 3(1), 128 (2020)

[3] O. M. Volkov et al., *Nature Communications*, *14*(1), 1491 (2023)

[4] O. Bezsmertna et al., *Nano Letters 24, 15774–15780 (2024)*

[5] G. Gubbiotti at al., Nano Letters 26 (4), 1561-1568 (2026)

Flexomagnetic Effects in 2D Magnets

Alexander Edström[1*], *Silvia Picozzi*[2,3], *Paolo Barone*[3], *Massimiliano Stengel,*[4,5]

[1]*Department of Applied Physics, School of Engineering Sciences, KTH Royal Institute of Technology, AlbaNova University Center, 10691 Stockholm, Sweden*
[2]*Department of Materials Science, University of Milan-Bicocca, Milan, Italy*
[3]*Consiglio Nazionale delle Ricerche CNR-SPIN, Italy*
[4]*Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus UAB, 08193 Bellaterra, Spain, 08010 Barcelona, Spain*
[5]*ICREA - Instituciò Catalana de Recerca i Estudis Avançats, Barcelona, Spain*
*aleeds@kth.se

Curvature has become a powerful means of engineering complex magnetic phase diagrams, including chiral and topological spin states [1,2]. Intriguing predictions were made from micromagnetic modeling and followed by notable experimental advances. However, achieving a realistic, material-specific description from first-principles has been difficult due to the loss of translational symmetry. Overcoming this difficulty is particularly important when going to the nano- or atomic scale, as encountered in 2D magnetic Van der Waal's monolayers, such as CrI_3 or $MnPX_3$, which exhibit high mechanical flexibility and a natural tendency to ripple.

In earlier work, we used relativistic density-functional theory (DFT) to study flexomagnetic coupling in ferromagnetic monolayers, showing that curvature-induced Dzyaloshinskii–Moriya interactions (DMI) can stabilize non-collinear states such as spin cycloids [3]. Although these interactions can arise as purely geometric, non-relativistic effects, we found that spin–orbit coupling (SOC) strongly modifies their curvature dependence, giving rise to qualitatively new magnetic behavior.

Building on this framework, we now extend the analysis to Néel antiferromagnets within the same D_{3d} class of monolayer magnets, focusing on the linear flexomagnetic effect—where curvature induces a magnetization proportional to its magnitude. We develop a first-principles methodology to compute the linear flexomagnetic tensor for monolayer systems, using $MnP(S/Se)_3$ as prototypical examples. With this tensor fully characterized, we demonstrate how curvature combined with external magnetic fields can generate and control complex spin textures.

Acknowledgements

We acknowledge support from the Swedish Research Council, ÅForsk, the Göran Gustafsson foundation, Swedish e-Science Research Center (SeRC), and the Wallenberg foundations (KAW) through WISE, and computational resources provided by the National Academic Infrastructure for Supercomputing in Sweden (NAISS).

[1] D. Sheka, A Perspective on Curvilinear Magnetism. Applied Physics Letters **118** (2021) 230502.
[2] R. Hertel, Curvature Induced Magnetochirality. SPIN **3** (2013) 1340009.
[3] A. Edström, D. Amoroso, S. Picozzi, P. Barone, M. Stengel, Curved Magnetism in CrI_3. Physical Review Letters **128** (2022) 177202.

Magnetic skyrmion-based devices with novel functionalities

Giovanni Finocchio[1*], Dimitris Kechrakos[2], Andrea Meo[3], Francesca Garesci[4], Anna Giordano[1], Mario Carpentieri[3], Riccardo Tomasello[3]

[1]Department of Mathematical and Computer Sciences, Physical Sciences and Earth Sciences, University of Messina, Italy
[2]Physics Laboratory, School of Pedagogical and Technological Education, Athens, Greece
[3]Department of Electrical and Information Engineering, Technical University of Bari, Italy
[4]Department of Engineering, University of Messina, Italy
*giovanni.finocchio@unime.it

Magnetic skyrmions have great potentials in addressing the challenges of packing density, power-efficiency and transmission speed in information processing and storage. Here, we implement state-of-the-art micromagnetic simulations to study in detail the dynamics of current-driven skyrmions in FM and SAF multilayer nanoring and propose devices with novel functionalities. In the first part, we implement skyrmions in FM nanorings and demonstrate [1] three applications for electrical pulse generation, namely a "clock" with tuneable frequency, an alternator based on engineered anisotropy gradient, and an energy harvester exploiting existing thermal gradients. We show how to precisely tune the frequency and amplitude of the output electrical signals by varying the material parameters, the sample geometry and the number of skyrmions, and we examine the device functionality under realistic conditions of temperature and material defects. In the second part, we improve the previous concepts by implementing synthetic antiferromagnet (SAF) nanorings [2], that suppress the detrimental Skyrmion Hall Effect and can be efficiently downscaled while they can support higher skyrmion velocities. As an outcome, generated electrical pulses in the GHz regime become feasible in SAF nanorings. Furthermore, skyrmions are shown to exhibit comparable performance to Neel domain walls in SAF nanorings as long as their mutual repulsions remain weak. Finally, we introduce a novel skyrmionic three-phase AC alternator based on a SAF nanoring, which operates in the GHz regime and demonstrate an optimized functionality

(a) **(b)**

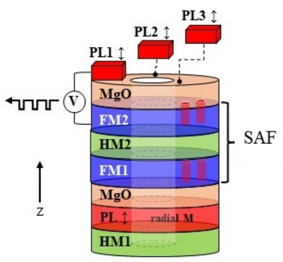


Figure 1. (**a**) Energy harvesting by a gradient-driven skyrmion on a FM nanoring and a Faraday coil, (**b**) Sketch of a SAF nanoring device for skyrmion-based electrical pulse generation.

[1] D. Kechrakos, V. Puliafito, A. Riveros, J. Liu, W. Jiang, M. Carpentieri, R. Tomasello, G. Finocchio, Phys. Rev. Applied, **20**, 044039 (2023)
[2] D. Kechrakos, A. Meo, F. Garesci, M. Carpentieri, A. Giordano, R. Tomasello, G. Finocchio, J. Phys. D: Appl. Phys. **58** (2025) 11500

Use of coherence at SEXTANTS beamline for 3D magnetic imaging: status and perspectives with SOLEIL II

Jhon J. Chiliquinga-Jacome[1], Matthieu Grelier[1], Marisel Di Pietro Martínez[2,3], Alexis Wartelle[4], G. Beutier[5], Horia Popescu[6], Vincent Cros[1], Nicolas Reyren[1], and Nicolas Jaouen[6,]*

[1]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, 91767, Palaiseau, France

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

[3]International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM2),Hiroshima University, Hiroshima 739-8526, Japan

[4]Univ. Grenoble Alpes, Inst NEEL, F-38042 Grenoble, France

[4]Université Grenoble Alpes, CNRS, Grenoble INP, SIMaP, 38000 Grenoble, France

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

* nicolas.jaouen@synchrotron-soleil.fr

Non-collinear spin textures in ferromagnetic ultrathin films have attracted renewed interest, driven by the possibility of finely engineering magnetic interactions—most notably the interfacial Dzyaloshinskii–Moriya interaction (i-DMI) in multilayer systems. This enables the stabilization of complex chiral spin textures such as chiral magnetic domain walls, spin spirals, and magnetic skyrmions. We have recently demonstrated that circular dichroism in resonant x-ray scattering (REXS) is a powerful approach to determine domain wall characteristics, namely their type (Néel or Bloch) and sense of rotation (chirality) in ferromagnetic and antiferromagnetic multilayers [1–3]. We will show how angular-dependent circular dichroism measurements in REXS allow us to retrieve three-dimensional information on chiral magnetic textures [4], supported by quantitative REXS simulations [5].

In the second part, we will focus on recent results obtained using x-ray Fourier transform holography (FTH). Several experiments performed at the SEXTANTS beamline illustrate its capability to image magnetic materials with element selectivity and spatial resolution down to a few tens of nanometers in two dimensions [6]. The current status of the sample environment (magnetic field, electric field, femtosecond laser excitation, temperature control) as well as developments in 2D detector systems will be presented. We will also describe recent advances enabling three-dimensional reconstruction of magnetic textures using tomographic FTH [7].

Finally, we will discuss the respective limitations and complementarity of REXS and FTH approaches. In particular, we address the intrinsic limitations of REXS in scattering geometry for magnetic imaging at the current SOLEIL storage ring, and outline the perspectives opened by SOLEIL II, especially in view of the expected increase in coherent flux at the SEXTANTS beamline for 3D magnetic imaging.

This work is supported by EU project SkyANN (reference no. 101135729), by ANR-DFG number BU 3297/4-1 (Topo3D) and by ANR-22- EXSP-0002 PEPR SPIN CHIREX and grant no. ANR- 22-EXSP-0008 PEPR SPIN SPINCHARAC).

[1] J.-Y. Chauleau et al., Phys. Rev. Lett 120, 037202 (2018)

[2] W. Legrand et al., Science Adv. 4, eaat0415 (2018).

[3] C. Léveillé et al., Phys. Rev. B., 104(6), L060402 (2021).

[4] E. Burgos-Parra, et al. Scientific Reports 13, 11711 (2023).

[5] S. Flewett et al., Phys. Rev. B 103 (18), 184401 (2021).

[6] H. Popescu et al., J. Synchr. Radiation, 26(1) 280 (2019).

[7] M. Di Pietro Martinez et al., Phys. Rev. B 107(9), 094425 (2023).

Self-consistent Magnetic Force Microscope-simulator: paving the way for vector MFM

Dominik Schramm[1*], Claas Abert[2], Jakub Jurczyk[1], Sabri Koraltan[1], Amalio Fernández Pacheco[1]

[1] TU Wien, Vienna, Austria
[2] University of Vienna, Vienna, Austria
* dominik.schramm@tuwien.ac.at

The rapid emergence of complex three-dimensional magnetic states—such as vortices, skyrmions, chiral domain walls, and other non-collinear spin textures—together with increasingly intricate sample topographies, demands characterization techniques with true vector sensitivity. Conventional Magnetic Force Microscopy (MFM), while widely accessible and highly versatile, predominantly probes information related to the out-of-plane (z) component of the magnetic stray field. However, a comprehensive understanding of modern 3D magnetic systems requires access to all three spatial components of the magnetic interaction.

To support the development of vector-resolved MFM concepts, we present an advanced, self-consistent MFM simulator capable of quantitatively predicting the response of non-conventional MFM configurations. The simulator enables systematic exploration of the expected signal using a wide range of magnetic tip geometries, material parameters, and magnetic states.

A central feature of the framework is its fully micromagnetic and self-consistent treatment of both tip and sample. The magnetization states of tip and sample are calculated within the same micromagnetic model, explicitly accounting for their mutual interaction. This approach provides quantitative insight into tip-induced perturbations, enabling identification of tip designs that maximize signal while minimizing disturbance of fragile magnetic configurations.

Beyond planar systems, the simulator establishes a versatile platform for investigating MFM imaging of non-planar and fully three-dimensional nanostructures. It allows quantitative prediction of MFM contrast arising from complex spin textures and spatially varying stray fields, thereby guiding the optimization of next-generation vector MFM techniques for the reliable characterization of advanced 3D magnetic materials and devices.

Design rules of 3D nanostructures for switchable and localized FMR modes

Mateusz Gołębiewski[1*], Krzysztof Szulc[1,2], Maciej Krawczyk[1]

[1] Adam Mickiewicz University, Poznań, Poland
[2] Polish Academy of Sciences, Poznań, Poland
* mateusz.golebiewski@amu.edu.pl

We investigate ferromagnetic-resonance (FMR) mode localization in three-dimensional (3D) magnetic nanoarchitectures, pushing magnonics beyond conventional planar geometries. Using large-scale micromagnetic simulations, we systematically study two representative classes of 3D nanostructures: (i) scaffold-like networks of ferromagnetic nanowires and (ii) gyroids – periodic chiral architectures characterized by triple-junction connectivity. We uncover a surface-localization effect of FMR modes that is strongly tunable with the orientation of the external magnetic field, revealing a mechanism for controllable mode switching in 3D geometries [1].

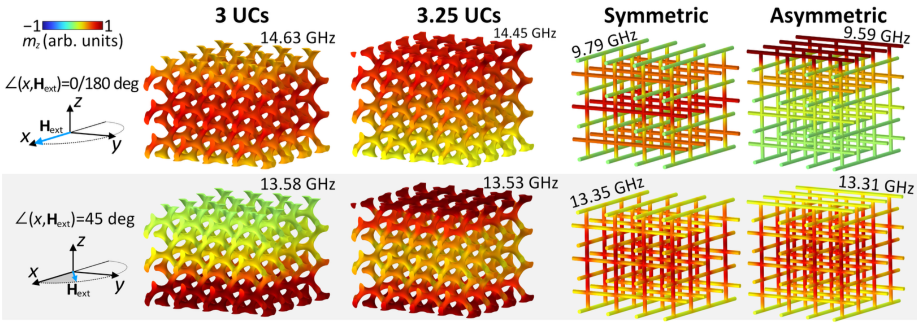


Figure 1. Dynamic magnetization (m_z) distribution for representative FMR modes in a gyroid (left; UC – unit cell) and a scaffold structure (right) under two in-plane orientations of the external magnetic field: 0° (top) and 45° (bottom). The maps highlight field-orientation–controlled localization and redistribution of the mode intensity across struts/nanorods.

Figure 1 shows the emergence of localized magnetization dynamics. While demagnetizing fields explain the general preference for perpendicular nanorods, they do not account for the systematic displacement of the mode profile and the appearance of surface-localized states under specific field configurations. Our simulations identify exchange-mediated coupling as the key driver: field-aligned nanorods increase the local magnetic energy in neighboring rods via exchange interactions, which biases the excitation toward rods that are adjacent to a single field-aligned counterpart – here, near the surface. This exchange-driven "neighbor asymmetry" naturally produces field-rotation-controlled switching between distinct localized states. By comparing multiple geometric parameters, we extract practical design rules for the onset of the effect. These results provide guidance for engineering 3D magnonic nanostructures with programmable, field-controlled high-intensity FMR modes, with direct relevance to enhanced FMR readout, and device concepts where tunability of localized excitations are advantageous.

The research leading to these results was funded by the National Science Centre of Poland, Projects No. UMO-2020/39/I/ST3/02413 and No. UMO-2023/49/N/ST3/03032. M.G. also received funding from the AMU Foundation in Poznań (2024/2025) and from the Foundation for Polish Science (FNP).

[1] M. Gołębiewski, K. Szulc and M. Krawczyk, Acta Materialia **283**, 120499 (2025).

Anisotropic magnonic band structure in 3D curvilinear magnonic crystal

G. Gubbiotti[1]*, O. Bezsmertna[2], O. V. Pylypovskyi[2], R. Xu[2], S. Chiroli[3], F. Zighem[3], C. Fernandez Gonzalez[4], A. Sorrentino[4], D. Raftrey[5,6], D. Wolf[6], A. Lubk[6], P. Fischer[5-6], D. Faurie[3], and D. Makarov[2]

[1] CNR-Istituto Officina dei Materiali (IOM), Perugia, Italy
[2] Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
[3]LSPM-CNRS, Université Sorbonne Paris Nord, Villetaneuse, France
[4]Alba Light Source, MISTRAL beamline, Barcelona, Spain
[5]Department of Physics, University of California, Santa Cruz, United States
[6]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, United States
[7] Leibniz Institute for Solid State and Materials Research, Dresden, Germany
*gubbiotti@iom.cnr.it

Curvilinear magnetic nanostructures enable control of magnetization dynamics through geometry-induced anisotropy and chiral interactions, as well as magnetic field modulation. In this work, we report a curvilinear magnonic crystal based on large-area square arrays of truncated nanospikes fabricated by conformal coating of 3D hierarchical templates with permalloy thin films. [1] Brillouin light scattering spectroscopy reveals an anisotropic band structure when the magnetic field is applied along the [10] and [11] crystal directions. Multiple dispersive and folded Bloch-type spin-wave modes are observed as well as nondispersive modes that exhibit direction-dependent frequency shifts and intensity asymmetries along lattice principal axes. Finite element micromagnetic simulations indicate that curvature-induced variations of the demagnetizing field govern the magnonic response, enabling the identification of modes propagating in nanochannels and others localized on nanospike apexes or along the ridges connecting adjacent nanospikes. This work establishes 3D hierarchical templates as a versatile platform for curvature-engineered magnonics.
G. G. acknowledges the support of the PETASPIN Association.

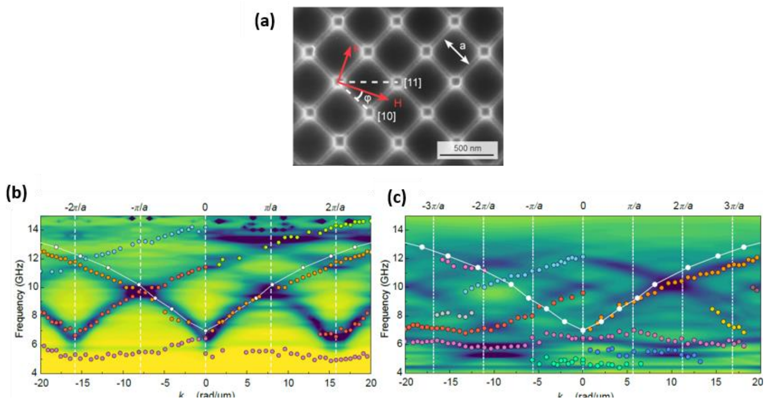


Figure 1. (a) Top view of the large-area square arrays of 3D truncated nanospikes template covered by 30 nm thick permalloy film. Experimental spin-wave band structure measured by Brillouin ligh scattering spectrowsocpy when the magnetic field is applied along the (a) [10] and (b) [11] directions. The white symbols correspond to the dispersion of a planar 30 nm-thick reference film. The colored background represents simulated dynamic magnetization amplitudes. Vertical dashed lines indicate positions of the Brillouin zones.

[1] G. Gubbiotti et al, Nano Lett. 26, 1561 (2026).

3D nanoscale control of magnetism in crystalline YIG

Matteo Vitali[1*], Valerio Levati[1], Andrea Del Giacco[1], Nicola Pellizzi[1], Raffaele Silvani[2], Luca Ciaccarini Mavilla[2], Marco Madami[2], Irene Biancardi[1], Davide Girardi[1], Matteo Panzeri[1], Piero Florio[1], Maria Cocconcelli[1], David Breitbach[3], Philipp Pirro[3], Ludovica Rovatti[4], Nora Lecis[4], Federico Maspero[1], Riccardo Bertacco[1], Giacomo Corrielli[5], Roberto Osellame[5], Valeria Russo[6], Andrea Li Bassi[6], Silvia Tacchi[7], Daniela Petti[1], Edoardo Albisetti[1]

[1] Department of Physics, Politecnico di Milano, Milano, Italy
[2] Department of Physics and Geology, Università di Perugia, Perugia, Italy
[3] RPTU University Kaiserslautern-Landau, Kaiserslautern, Germany
[4] Department of Mechanical Engineering - Politecnico di Milano, Milano, Italy
[5] Istituto di Fotonica e Nanotecnologie (IFN-CNR), Milano, Italy
[6] Department of Energy - Politecnico di Milano, Milano, Italy
[7] CNR-IOM c/o Department of Physics and Geology, Università di Perugia, Perugia, Italy
*matteo.vitali@polimi.it

The outstanding magnetic properties of Yttrium Iron Garnet (YIG) make it an ideal candidate for spin-wave (SW) based data processing applications, enabling highly energy-efficient information transmission. Unfortunately, manipulate crystalline YIG

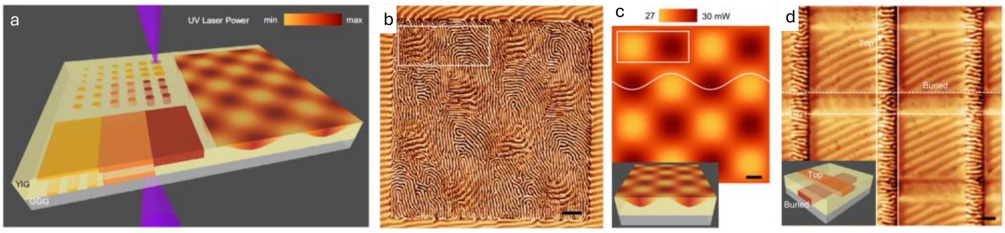


Figure 1. a) Sketch of the laser patterning process, the PMA can be tuned through the volume of the YIG, and the laser can patter also through the substrate. b), c) MFM measurement (b) on an area irradiated with spatially variable laser power (c), in which magnetic domains change dimensions due to the tuned anisotropy. Scale bars 5μm. The depth of the modified YIG volume is tuned through the laser power (inset of (c)). d) MFM measurement on rectangular uniformly irradiated areas, which are patterned both through the top and bottom surface of the YIG. Scale bar 2 μm. All panels are adapted from [1]

magnetic properties through conventional nanofabrication is challenging, and mostly limited to material removal and 2D capabilities. In our recent work [1] we present a magnetic nanopatterning technique based on a single step irradiation with a focused UV laser, following a phase nanoengineering approach [2]. The irradiation induces a stable enhancement of the perpendicular magnetic anisotropy (PMA), while preserving the structural quality of a 1μm thick single crystal YIG. Irradiated areas show distinctive magnetic stripe domains which differ from the ones of the pristine YIG (Fig. 1b, d), and whose dimensions can be controlled through the laser power. The spatial localization of the anisotropy modulation can be tuned down to the nanoscale and in the third dimension through the YIG volume. Exploiting various anisotropy profiles we demonstrate tuning of SWs bandstructure and localization, ultimately realizing proof-of-concept magnonic crystals [1].

[1] V. Levati, M. Vitali, et al., Nat Commun **16**, 9602 (2025)

[2] V. Levati, D. Girardi, et al., Adv. Mater. Technol. **8**, 2300166, (2023)

Geometrical control of topological spin textures in Heusler magnetic nanowires

Rikako Yamamoto[1,2*], Luke Turnbull[1,2], Marisel Di Petro Martinez[1,2], Jeffrey Neethirajan[1], José Claudio Corsaletti Filho[1], Simone Finizio[3], Tim Butcher[3,4], Igor Beinik[5], Dieter Suess[6], Praveen Vir[1], Chandra Shekar[1], Claudia Felser[1], Claas Abert[6], and Claire Donnelly[1,2]

[1]MPI-CPfS, Dresden, Germany
[2]WPI-SKCM2, Higashi-Hiroshima, Japan
[3]PSI, Villigen, Switzerland
[4]MBI, Berlin, Germany
[5]MAX-IV, Lund, Sweden
[6]University of Vienna, Vienna, Austria
* Rikako.Yamamoto@cpfs.mpg.de

Nontrivial topological spin textures, such as magnetic skyrmions and antiskyrmions, have garnered significant attention due to their unique properties and promising applications in spintronic devices [1,2]. Among these, antiskyrmions are particularly intriguing because of their anisotropic winding configurations and potential for directionally selective dynamics, originating from anisotropic Dzyaloshinskii–Moriya interactions (DMI) [3,4]. Despite intense interest, controlled nucleation and stabilization of antiskyrmions remain challenging, as competing magnetic interactions often lead to energetic degeneracy among different topological states, hindering deterministic formation.

Here, we demonstrate a geometry-based route to nucleate and stabilize antiskyrmions in $Mn_{1.4}PtSn$, a Heusler compound known to host anisotropic DMI. By introducing geometrical confinement anisotropy through the fabrication of nanowires oriented at different angles relative to the crystallographic axes, we engineer the magnetic energy landscape. Using X-ray magnetic dichroic ptychography, we directly image the magnetic configurations of individual nanowires with high spatial resolution. The measurements reveal that the interplay between the intrinsic crystalline anisotropy and engineered geometrical confinement promotes preferential nucleation of antiskyrmions within specific nanowire orientations. The observed stabilization is robust across multiple nanostructures, demonstrating a confinement-driven mechanism.

Our results establish an experimentally accessible strategy for the engineered nucleation of antiskyrmions through nanoscale structural design, highlighting the critical interplay between crystallographic symmetry and geometrical confinement. Beyond the specific material system, this geometry-based approach provides a general and scalable pathway to tailor topological spin textures in confined geometries, opening new opportunities for integrating anisotropic topological objects into functional nanoscale spintronic devices.

[1] N. Nagaosa and Y. Tokura, Nature Nanotechnology 8, 899 (2013).

[2] S. Koraltan *et al.*, arXiv:2601.16575

[3] A. K. Nayak *et al.*, Nature 548, 561 (2017).

[4] K. Karube *et al.*, Nature Materials 20, 335 (2021).

Fractional Hopfions and Bloch Point Pairs in Composite Magnets

Sanjay Ashok[1*], Nicolai Bechler[1], Jan Masell[1]

[1] Karlsruhe Institute of Technology, Karlsruhe, Germany
* sanjay.ashok@kit.edu

Hopfions are three-dimensional magnetization textures classified by their topological winding number called Hopf index [1]. A doughnut shaped magnetic hopfion has an integer Hopf index. Hopfion-like textures beyond the standard doughnut topologies [2] with non-integer Hopf indices have thus far been elusive in three spatial dimensions. Our theoretical work aims to fill this gap.

In our work, we demonstrate that hopfions with fractional Hopf index, called fractional hopfions [3], are stable in composite magnets comprised of two slabs with opposite sign of DMI (see Fig. 1). We further distinguish the role of Bloch-, Neel- and Antiskyrmion-type DMI in composite magnets and their effect on the winding [4]. In addition to the spatially continuous and elongated fractional hopfions, we study the appearance of Bloch point pairs [4, 5] within Neel and Antiskyrmion-type composite materials. We also predict the range of external magnetic field and uniaxial anisotropy where these textures can be found. Our work demonstrates that composite magnets are promising material platforms to study three dimensional topological structures with tunable and fractional topological winding.

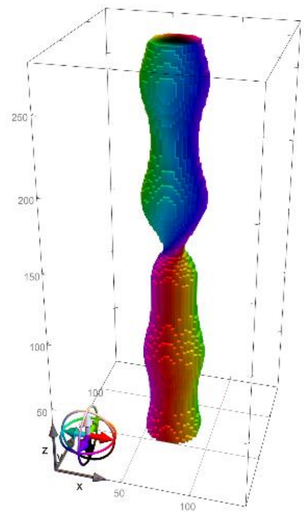


Figure 1: Fractional hopfion as a twisted skyrmion string in a composite magnet comprised of two slabs with opposite sign of DMI.

[1] F. Zheng et al., Nature **623**, 718-723 (2023).

[2] R. Knapman et al., Communications Physics **7**, 151 (2024).

[3] X. Z. Yu et al., Advanced Materials **35**, 2210646 (2023).

[4] S. Ashok and J. Masell, in preparation.

[5] M. Lang et al., Scientific Reports **13**, 6910 (2023).

Curvature-induced magnetization of altermagnetic films

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

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

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

The obtained results are generalized for the case of planar g-wave altermagnets.

[1] K.V. Yershov, O. Gomonay, J. Sinova, J. van den Brink, and V.P. Kravchuk, Phys. Rev. Lett. **134**, 116701 (2025).

Magnetic vector tomography reveals giant magnetofossils are optimised for magnetointensity reception

Richard J Harrison[1*], Sergio Valencia[2], Jeffrey Neethirajan[3], Claire Donnelly[3], Marina Raboni Ferreira[3], Lourdes Marcano[4], Liao Chang[5], Pengfei Xue[5], Zhaowen Pei[5], Emilie Ringe[1], Po-Yen Tung[1], Charan Kuppili[6], Simone Finizio[7], Radu Abrudan[2], Burkhard Kaulich[8], Benedikt Daurer[8], Luis Carlos Colocho Hurtarte[8], and Majid Kazemian[8]

(1) University of Cambridge, U.K.
(2) Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany
(3) Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
(4) University of Oviedo, Oviedo, Spain
(5) Peking University, Beijing, China
(6) Canadian Light Source, Saskatoon, Canada
(7) Paul Scherrer Institute, Villigen, Switzerland
(8) Diamond Light Source, Didcot, U.K.
* rjh40@cam.ac.uk

Giant magnetofossils are unusual, micron-sized biogenic magnetite particles found in sediments dating back at least 97 million years. Their distinctive morphologies are the product of biologically controlled mineralisation, yet the identity of biomineralising organism, and the biological function they serve, remain a mystery. It is currently thought that the organism exploited magnetite's mechanical properties for protection. Here we explore an alternative hypothesis, that it exploited magnetite's magnetic properties for the purpose of magnetoreception. We present a three-dimensional magnetic vector tomography study of a giant magnetofossil and assess its magnetoreceptive potential. Our results reveal a single magnetic vortex that displays an optimised response to spatial variations in the intensity of Earth's magnetic field. This magnetic trait may have conferred an evolutionary advantage to mobile marine organisms, providing an upper age limit on the development of navigational magnetoreception and raising the possibility that earlier evidence of this sense may yet be preserved in the fossil record. More broadly, this work provides a blueprint for assessing the morphological and magnetic evidence for putative biogenic iron oxide particles, which are a key component in the search for early life on Earth and Mars.

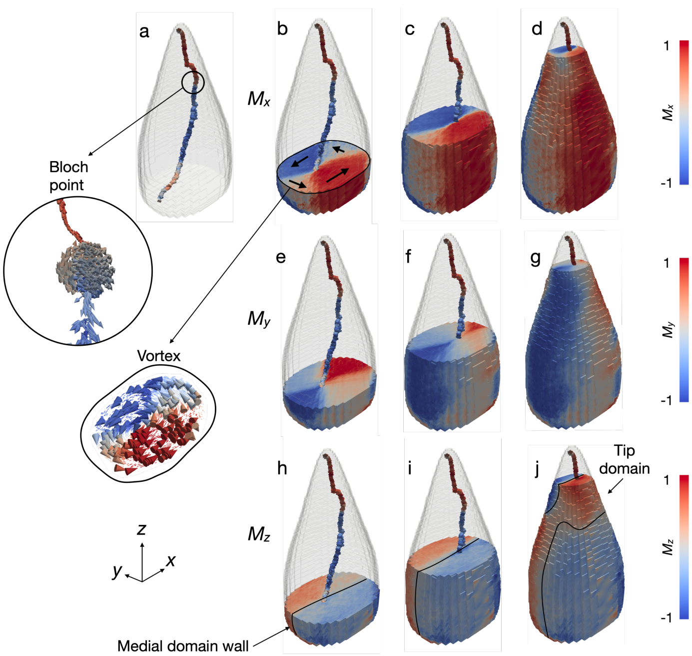


Figure 1. 3D nanotomography of a giant magnetofossil, showing the internal vortex magnetic structure and Bloch point.

Focused electron beam induced deposition and characterization of 3D racetrack memory systems

Trevor P. Almeida[1]*, Keir Edgar[1], Sameh Okasha[1], Aurys Silinga[1], András Kovács[2], Rafal Dunin-Borkowski[2] and Stephen McVitie[1]

[1]SUPA, School of Physics and Astronomy, University of Glasgow, G12 8QQ, UK.
[2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Jülich, Germany.

The volumetric storage density and performance of racetrack (RT) memory systems have the potential to be revolutionized by expanding to complex 3D architectures [1]. Conventional lithography methods are not well suited for complex 3D nanofabrication and focused electron beam induced deposition (FEBID) offers an ideal method for the growth and study of complex magnetic structures that can help transform the field of 3D RT memory [2]. This work presents the FEBID of 3D iron RT nanocircuits on MEMS-based *in-situ* transmission electron microscopy (TEM) chips for the purpose of imaging their current-induced DW motion. Translating the SEM beam using stream files [3] allowed for fabrication of cornered (Fig. 1a) and curved (Fig. 1b) iron RTs over the biasing contacts with favourable domain wall (DW) pinning sites. The electron energy loss spectroscopy (EELS) chemical analysis shown in Fig. 1c confirmed the RTs exhibit a relatively high iron purity core (74%), oxide shell (19.3%) and residual carbon dispersed throughout (6.7%). Electron holography was performed and revealed DWs are positioned at the intended geometric pinning sites of the RT corners (Fig. 1d) and curve apexes (Fig. 1e). Comparison of the electron holography data to micromagnetic simulations verified the DWs as vortex-type. This work provides a solid foundation to study the current-induced DW motion in complex 3D RT systems, taking them into a brand-new realm of understanding.

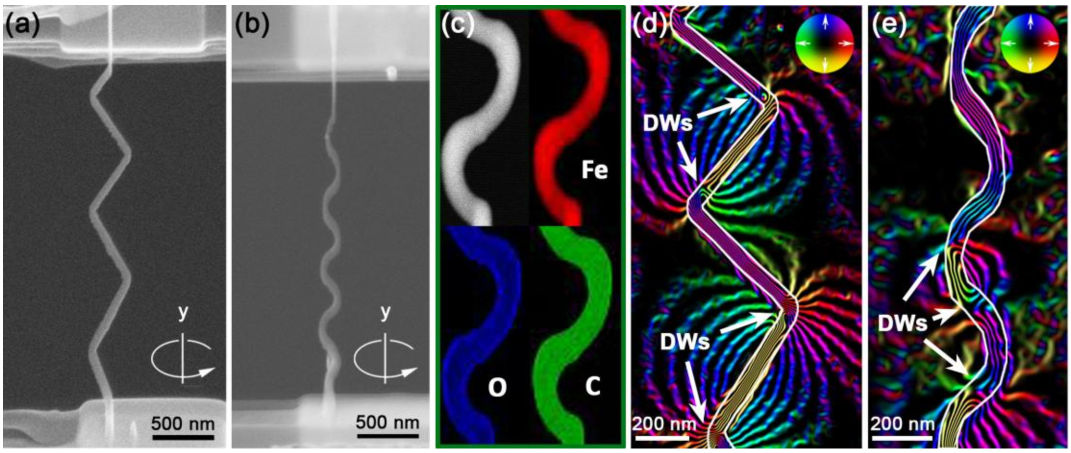


Figure 1. (a,b) Scanning electron microscope images of (a) cornered; and (b) curved iron RTs connected to biasing contacts on the MEMS-based nanochips. (c) HAADF image and EELS chemical maps displaying the elemental distribution of Fe, O and C. (d,e) Magnetic induction maps of the (d) cornered; and (e) curved RTs. The contour spacings are 0.21 rad and the direction of magnetic induction is denoted by the colour wheel (top inset).

[1] Gu, K. Et al. *Nat. Nanotechnol.* **17**, 1065–1071 (2022).

[2] Silinga, A. et al, *Microsc. Microanal*. **31**, ozaf043 (2025).

[3] Skoric, L. et al. *Nano Lett*. **20**, 184−191 (2020).

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

Emily Darwin[1], Riccardo Tomasello[2], Reshma Peremadathil Pradeep[1], Mario Carpentieri[2], Giovanni Finocchio[3] and Hans J Hug[1,4]

[1]Empa, Swiss Federal Laboratories for Materials Science and Technology, 8600, Dübendorf, Switzerland.
[2]Dept. of Electrical and Information Engineering, 70126, Politecnico di Bari, Bari, Italy.
[3]Dept. of Mathematical and Computer Sciences, 98122, University of Messina, Messina, Italy.
[4]Department of Physics, 4001, University of Basel, Basel, Switzerland.
* riccardo.tomasello@poliba.it

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 [1-2].

We 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 fabricated by magnetron sputtering and characterized using high-sensitivity quantitative magnetic force microscopy combined with micromagnetic simulations [3].

With zero external field, the SAF bias system stabilizes ferromagnetically coupled skyrmions in the FM multilayer system and antiferromagnetically coupled skyrmions in the SAF multilayer system. This is confirmed by micromagnetic simulations. In both systems, the skyrmions are polarity controllable via a preparatory field application. 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. The bias concept provides a scalable and materials-agnostic pathway toward zero-field operation, size reduction, and polarity control of chiral spin textures, advancing the integration of compensated skyrmions into energy-efficient spintronic devices.

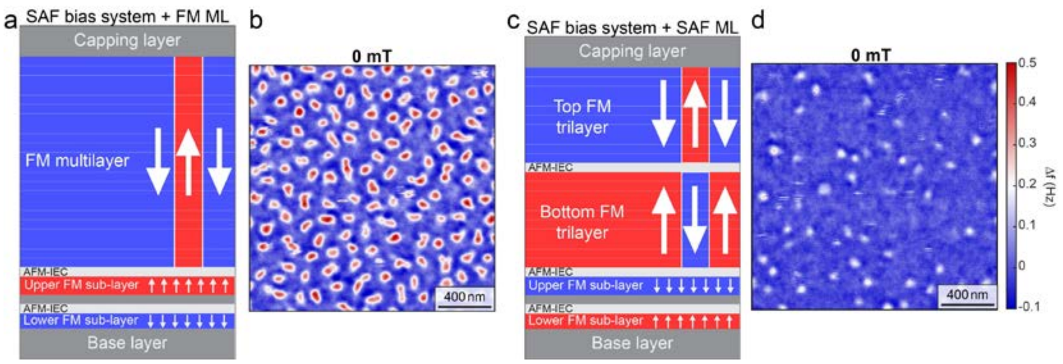


Figure 1. Schematic of FM ML (a) with SAF bias layer and SAF multilayer (c) with SAF bias layer with the corresponding zero-field MFM data (b and d, respectively).

[1] R. Juge, et al., Nat. Comm. 13, 1 (2024).

[2] E. Darwin, et al., Sci. Rep. 14, 95 (2024).

[3] E.Darwin et al. (under review 2026).

High-resolution two-photon lithography for 3D printing nanomagnets

Joseph Askey[1], Matthew Hunt[2], Lukas Payne[1], Arjen van den Berg[1], Ioannis Pitsios[3], Alaa Hejazi[4], Wolfgang Langbein[1], Sam Ladak[1*]

[1]School of Physics and Astronomy, Cardiff University, Cardiff, CF24 3AA, UK.
[2]Huntleight Healthcare Ltd, Cardiff UK.
[3]VitreaLab GmbH, Vienna, Austria.
[4]Taibah University – Faculty of Science and Arts, Janada Bin Umayyah Road, Medina 42353, Kingdom of Saudi Arabia
[2] University of Vienna, Vienna, Austria
* ladaks@cardiff.ac.uk

Three-dimensional (3D) nanomagnets are versatile systems for studying unconventional spin textures and domain walls [1], realising GHz spin-wave frequencies [2] as well as tuning the spin-wave dispersions [3], and are especially important platforms for advanced applications in high-storage density memory devices [4]. The fabrication of such systems necessitates advancements in high-resolution 3D printing technologies and deposition [5]. Two-photon lithography (TPL) is a promising route to realising such systems, however with resolutions typically limited to approximately 200 nm and feature sizes above 100 nm using infra-red excitation wavelengths [6]. In this talk, the high-resolution TPL system developed in Cardiff University is presented. Sub-100 nm magnetic nanostructures are demonstrated, as well as the direct visualisation of domain wall pinning within these systems using scanning probe microscopy [7]. Finally, recent advancements in high-resolution TPL fabrication are discussed.

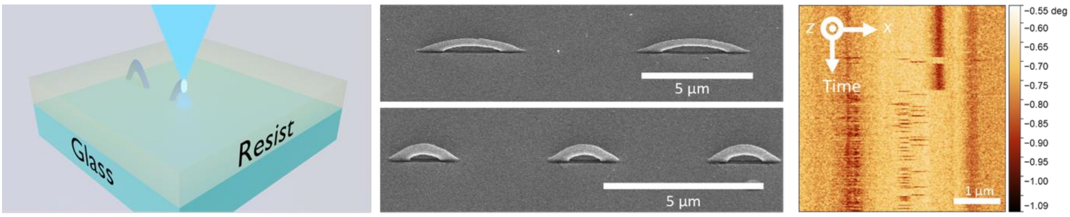


Figure 1. Sub-100 nm 3D magnetic nanowires fabricated via TPL, and domain wall pinning characterised using MFM.

[1] S. Ruiz-Gómez, *et al.* *Nat. Commun.*, **16**, 7422 (2025).

[2] H. Guo, *et al*. *Adv. Mater.*, **35**, 2303292 (2023)

[3] M. Gołębiewski, *et al.* Phys. Rev. Applied, **19**, 064045 (2023)

[4] S. Parkin, SH. Yang. *Nature Nanotech.,* **10**, 195–198 (2015)

[5] J. Askey, *et al.* *Adv. Funct. Mater.,* e16383 (2025)

[6] A. May, *et al.* *Commun. Phys.,* **2**, 13 (2019).

[7] J. Askey, M. Hunt, et al. Nanoscale, 16, 17793-17803 (2024)

Conformally coated three-dimensional magnetic nanostructured metamaterials

Alexander Roberts[1*], Huixin Guo[2], Joseph Askey[1], Vani Lanka[1], Arjen van den Berg[1], Dirk Grundler[2,3] and Sam Ladak[1]

[1] School of Physics and Astronomy, Cardiff University, Cardiff, United Kingdom
[2] Institute of Materials, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[3] Institute of Electrical and Micro Engineering, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
* RobertsA70@cardiff.ac.uk

Three-dimensional (3D) magnetic nanostructures offer unprecedented opportunities for data storage, neuromorphic computing applications and the engineering of emergent spin-textures [1]. However, the fabrication of ultra-dense nanonetworks with controllable configurations remains challenging. Here we leverage recent advances in atomic layer deposition (ALD) of ferromagnets [2] to fabricate conformally coated Ni nanotubes arranged in a woodpile geometry with lattice spacings ranging from 800 to 1200 nm, realised by a combination of two-photon lithography and ALD. Magnetic force microscopy (MFM) reveals that these woodpiles exhibit both axial and chiral states with distributions across the top-layer of the structure which can be controlled by varying both the number of nanotubes stacked in Z (*N*) and the lattice spacing between these constituent nanotubes. Further micromagnetic simulations demonstrate that the observed chiral configurations are not intrinsic to the nanotubes themselves but are rather imprinted via coupling of the spin textures in the 3D nanonetwork and the planar sheet film.

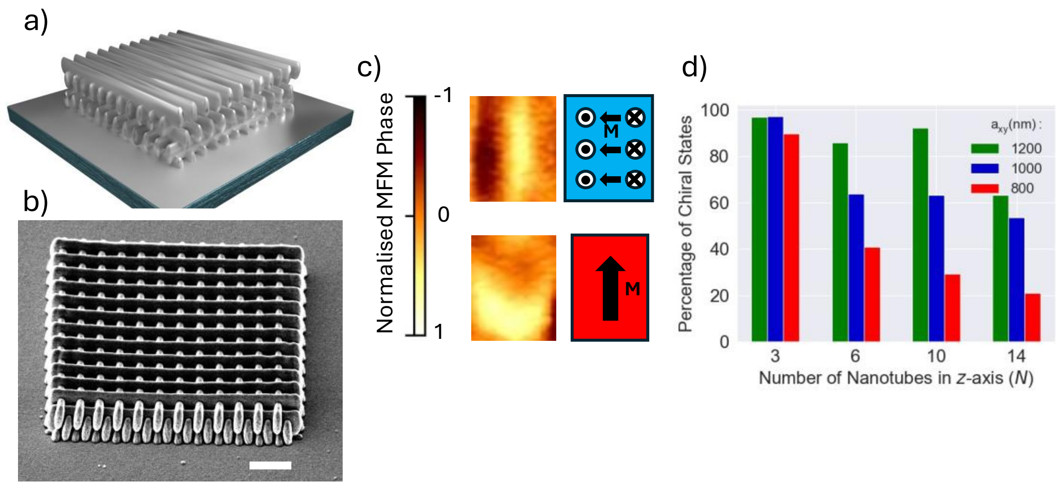


Figure 1: a) Schematic of an fcc woodpile lattice, illustrating the conformal nature of the Ni coating deposited via ALD and the continuous layer this forms with the sheet film. b) Scanning electron microscope image of a 3D ferromagnetic woodpile structure, where the scale bar represents 2 µm. c) Example MFM images demonstrating contrast indicative of a chiral state (top) and an axial state (bottom), with schematics representing the direction of the magnetisation. d) Percentages of top-layer chiral configurations for woodpiles of varying *N* and lattice spacings observed via MFM, illustrating the geometrically tuneable nature of the spin-textures in 3D ferromagnetic woodpile nanostructured metamaterials.

[1] A. Fernández-Pacheco et al, Nat Commun. 8, 15756 (2017).

[2] H. Guo et al, Adv. Mater. 35, 2303292 (2023).

Domain wall motion in 3D nano-printed iron nanowires

Jakub Jurczyk[1*], David Da Wei Stockinger[2], Daniel Wolf[3], Axel Lubk[3], Heinz Wanzenboeck[2], Amalio Fernández-Pacheco[1],

[1] Institute of Applied Physics, TU Wien, Vienna, Austria
[2] Institute of Solid State Electronics, TU Wien, Vienna, Austria
[3]Institute for Solid State Research, Leibnitz Institute for Solid State and Materials Research, Dresden, Germany
* jakub.jurczyk@tuwien.ac.at

Rapid development of nano-manufacturing methods, like two photon lithography and focused electron beam induced deposition (FEBID) enabled the possibility of applying 3D functional structures in various field, including magnonics and spintronics [1]. Especially the latter technique is known for 3D printing of functional nanostructures with unparalleled spatial resolution [2]. FEBID facilitates focused beam of electrons from scanning electron microscope (SEM) to locally dissociate molecules of precursor adsorbed on the substrate's surface [2]. For application in magnetism four compounds have been used frequently: $Co_2(CO)_8$, $Fe(CO)_5$, $Fe_2(CO)_9$, and $HFe_3Co(CO)_{12}$ [2, 3].

In this contribution, we report on high-purity, high-fidelity three-dimensional nanostructures fabricated by focused electron beam induced deposition (FEBID) using $Fe(CO)_5$ as a precursor. By optimizing the growth conditions, we achieve metallic nanowires with high iron content confirmed by electron energy loss spectroscopy (EELS) and a saturation magnetisation approaching the bulk value, as determined by off-axis electron holography. The magnetic behaviour of individual nanowires was investigated using dark-field magneto-optical Kerr effect (MOKE) measurements. We find that the scaling of the switching field with nanowire dimensions is consistent with a dominant shape anisotropy. Furthermore, dedicated studies on L-shaped nanowires demonstrate domain-wall conduit behaviour, where domain-wall propagation fields are lower than the nucleation fields required to generate additional domain walls. These results highlight the potential of high-purity FEBID-grown nanostructures for spintronic applications.

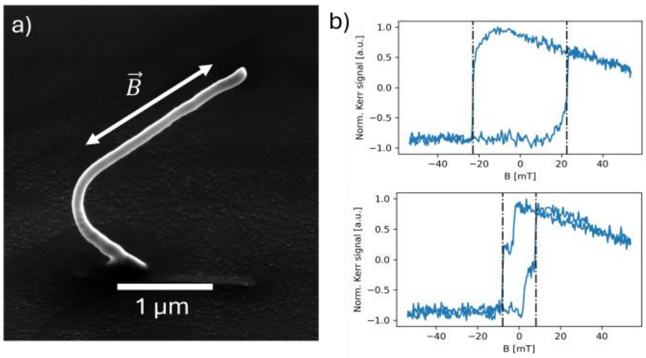


Figure 1. a) SEM image of an iron L-shaped nanowire deposited with FEBID; the arrow marks the direction of magnetic field during MOKE measurement. b) hysteresis loops for two magnetisation reversal mechanisms: domain nucleation (upper) and domain wall propagation (lower).

[1] Gubbiotti G. et al, J. Phys.: Condens. Matter, **37**, 143502, (2025)

[2] Reisecker, V. et al., Advanced Functional Materials, **34(46)**, 2407567, (2024)

[3] Barth, S. et al. Journal of Materials Chemistry C, **8(45),** 15884, (2020)

Atomic Layer Deposition for 3D Nanomagnetic Architectures

Haojie Zhang*, Chi Fang, Stuart Parkin*

Max Planck Institute for Microstructure Physics, Halle, Germany
* haojie.zhang@mpi-halle.mpg.de; stuart.parkin@mpi-halle.mpg.de

Three-dimensional (3D) nanomagnetism is moving beyond planar thin-film stacks toward curved and high-aspect-ratio magnetic architectures, where geometry, interfaces, and nanoscale confinement jointly define anisotropy, domain topology, and magnetization dynamics. A key fabrication challenge is the realization of conformal, thickness-controlled, and interface-sharp multilayers on non-planar templates while preserving functional magnetic properties such as perpendicular magnetic anisotropy, interlayer exchange, and low damping.

Here, we present a process and characterization framework based on atomic layer deposition (ALD)[1,2] for depositing metallic and oxide layers that form the basis of spintronic heterostructures on 3D structures. Leveraging ALD's self-limiting surface chemistry, we target precise thickness control and high conformality across complex topographies, enabling the deposition of functional films with controlled interface formation and minimized intermixing. To connect film growth to magnetic functionality, we combine detailed structural and magnetic metrology. For 3D architectures, we further evaluate the spatial uniformity of magnetization reversal and geometry-induced magnetic effects. The resulting ALD-enabled multilayer platform aims to support 3D nanomagnetic building blocks relevant to curvilinear magnetism, topological spin textures, and magnetization dynamics in confined geometries, where reproducible interface engineering over 3D structures is essential.

[1] Angewandte Chemie International Edition, 59(39):17172-17176, (2020)

[2] Adv. Mater. Interfaces 9, 2200013E, (2022)

Exchange bias in bulk nanocomposites

Michael Zawodzki[1], Stefan Wurster[1], Heinz Krenn[2], Andrea Bachmaier[1*]

[1] Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Leoben, Austria
[2] Institute of Physics, University of Graz, Graz, Austria
* andrea.bachmaier@oeaw.ac.at

The exchange bias effect is used for a variety of technological applications, such as magnetic read heads [1]. So far, it has mainly been investigated in thin films and 2D structures [2]. Studies on exchange bias in bulk materials are rare [3,4]. With severe plastic deformation it is possible to process bulk nanocomposites based on powder blends, which allows for a large variety of phase combinations and to overcome the 2D limitation of exchange-biased materials.

In this study, ferromagnetic (Fe, Ni or FeNi-alloys) and antiferromagnetic (NiO) phases were deformed to investigate the exchange bias and its characteristics in bulk samples with a 3D interfacial network. The influence of microstructure on the exchange bias and the magnetic properties of the novel nanocomposites are studied by magnetometry measurements in combination with microstructural characterization. Depending on the composition and the deformation parameters, different final microstructures are obtained. Magnetic coupling between the ferromagnetic/antiferromagnetic phases and exchange bias are observed for all deformed composites. Elevated deformation temperatures are the key to achieve ferromagnetic and antiferromagnetic phases with a homogeneous distribution and a strong reduction of the phase sizes in the nanocrystalline regime. It is shown that the amount of applied strain and the morphology of the phases has an influence on the magnetic properties and the magnitude of the exchange bias.

[1] I.R. McFadyen, E.E. Fullerton, M.J. Carey, MRS Bulletin **31**, 379–383 (2006)

[2] T. Blachowicz, A. Ehrmann, Coatings **11** 122 (2021).

[3] E. Menéndez, J. Sort, V. Langlais, et al., Journal of Alloys and Compounds **434–435**, 505–508 (2007).

[4] I.J. McDonald, M.E. Jamer, K.L. Krycka et al., ACS Applied Nano Materials **2**, 1940–1950 (2019)

3D heat flux sensor based on anomalous Nernst effect

Kenji Tanabe[1*], Hiroto Imaeda[1], Tsunehiro Takeuchi[1], and Hiroyuki Awano[1]

[1] Toyota Technological Institute, Nagoya, Japan
* tanabe@toyota-ti.ac.jp

Heat flux sensors (HFS) have attracted significant interest for their potential in managing waste heat efficiently. A recently proposed HFS, which works on the basis of the anomalous Nernst effect (ANE), offers several advantages in its simple structure leading to easy fabrication, low cost, and reduced thermal resistance [1]. However, enhancing sensitivity through traditional material selection is now challenging due to a small number of materials satisfying the required coexistence of a large transverse thermopower and low thermal conductivity. In this study, by utilizing composite structures and optimizing the device geometry, we have achieved a substantial improvement in the sensitivity of an ANE-based HFS[2].

We developed composite structures comprised of a plastic substrate with an uneven surface and three-dimensional (3D) uneven Tb-Co films, fabricated using nanoimprint techniques and sputtering (Fig. 1(a-b)). This approach resulted in a sensitivity that is approximately three times greater than that observed in previous studies (Fig. 1(c)). Importantly, this method is independent of the material properties and can significantly enhance the sensitivity. Our findings could lead to the development of highly sensitive HFS devices and open avenues for the fabrication of 3D devices.

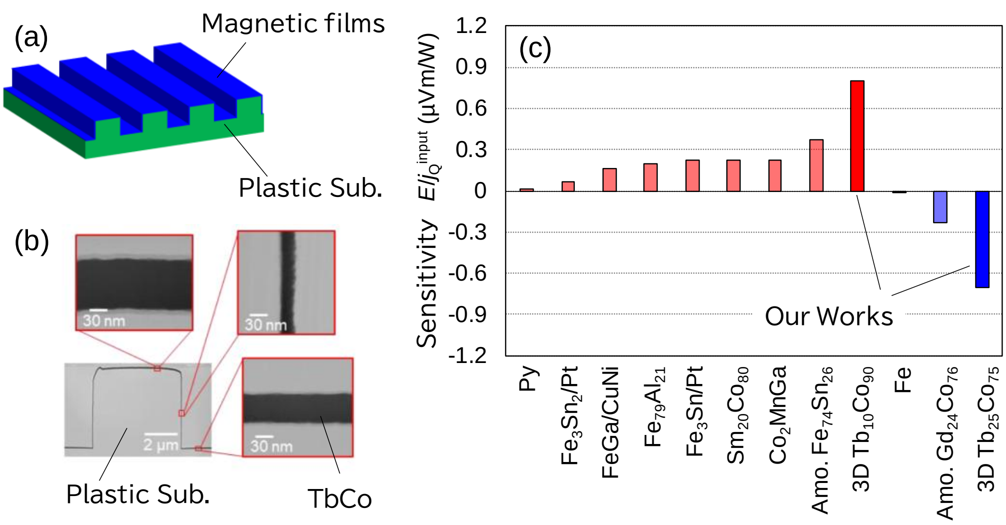


Figure 1. (a) Schematic diagram of the 3D sample structure. (b) Cross-sectional transmission electron microscope image of the sample surface. (c) Summery of sensitivity for ANE-type HFS. The dark red and blue indicate the results when using the 3D structure. The difference in color means the sign of the sensitivity.

[1] W. Zhou and Y. Sakuraba, Applied Physics Express **13**, 043001 (2020).

[2] H. Imaeda, K. Tanabe et al., Applied Physics Letters **125**, 044101 (2024).

Role of quadratic and biquadratic coupling in the spin-wave modes of CoFe/Ru/NiFe Artificial Spin Ice structures

Riccardo Fornari[1,3]*, Mohammad Tomal Hossain[2], Raffaele Silvani[3], Vinayak Shantaram Bhat[2], Sultana Rawnak[3], M. Benjamin Jungfleisch[3], and Gianluca Gubbiotti[3]*

[1] Dipartimento di Fisica e Geologia, Università degli studi di Perugia, Perugia, Italy
[2] Department of Physics and Astronomy, University of Delaware, Newark, Delaware, USA
[3] CNR-Istituto Officina dei Materiali (IOM), Perugia, Italy
*riccardo.fornari@dottorandi.unipg.it
*gubbiotti@iom.cnr.it

Artificial spin ices (ASI) are engineered metamaterials composed of arrays of elongated nanomagnets coupled through dipolar interactions and exhibiting collective magnetic behavior. Due to the geometrical arrangement of the nanoelements, magnetic frustration emerges because the dipolar interactions among neighboring elements cannot be simultaneously minimized. This leads to several emergent phenomena and makes ASI systems promising candidates for reconfigurable magnonic devices. Here, we investigate the static and dynamical properties of exchange-coupled CoFe(15 nm)/Ru(0.6 nm)/NiFe(15 nm) continuous trilayers and square-lattice ASI systems by vibrating-sample magnetometry and Brillouin light-scattering spectroscopy. Experimental data are interpreted through micromagnetic simulations performed with MuMax3, enabling accurate modeling of interfacial magnetic interactions and direct comparison with measurements. By combining experiments and simulations, we identify and quantify the quadratic and biquadratic interlayer coupling terms governing the magnetic behavior of the systems. We analyze magnetization reversal processes together with the frequencies, spatial profiles, and phase relations of the spin-wave modes in the CoFe and NiFe layers. Unlike monolayer ASI systems dominated by shape anisotropy, the strong RKKY interaction in our structures promotes mutually perpendicular layer magnetizations and drives alignment along the hard axis of the nanoelements.

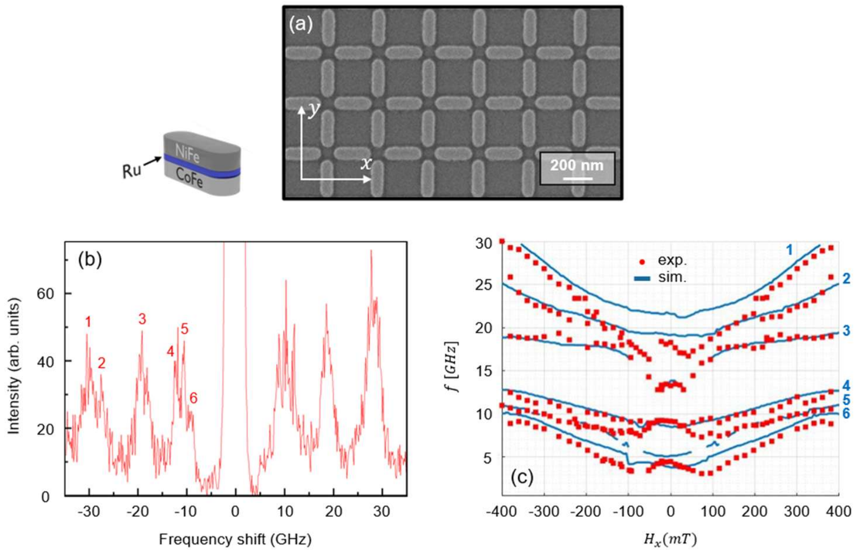


Figure 1. (a) SEM image of the CoFe/Ru/NiFe square lattice ASI sample along with the coordinate axes. (b) Exemplary BLS spectra acquired at $H_x = 360\ mT$ in which the experimental peaks have been labeled numerically. (c) Comparison between simulated and experimentally obtained field dependence of the modes for the exchange-coupled ASI. The simulated curves were labeled for direct comparison with the experimental data.

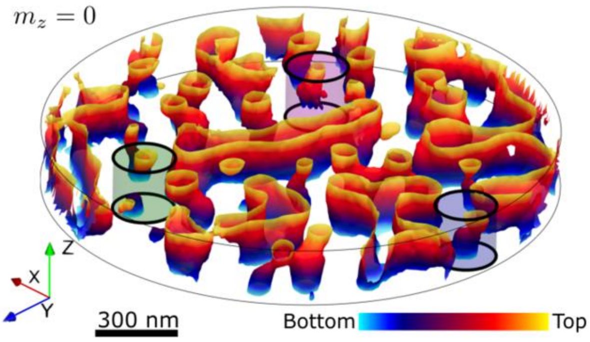
Skyrmionic cocoons imaged in 3D using HERALDO reconstructions

Jhon J. Chiliquinga-Jacome[1,*], Matthieu Grelier[1,2], Riccardo Battistelli[3,4], William Bouckaert[1], Krishnanjana Puzhekadavil Joy[3,4], Sophie Collin[1], Florian Godel[1], Marisel Di Pietro Martínez[5,6], Claire Donnelly[5,6], Felix Büttner[3,4], Horia Popescu[7], Vincent Cros[1], Nicolas Reyren[1], Nicolas Jaouen[7]
[1] Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, 91767, Palaiseau, France
[2] Present address: Spin-ion Technologies, 91120, Palaiseau, France
[3] Helmholtz-Zentrum Berlin, 14109 Berlin, Germany
[4] University of Augsburg, Augsburg, Germany
[5] Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[6] International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM2)
[7] Synchrotron SOLEIL, L'Orme des Merisiers, 91190, Saint Aubin, France
* jhon.chiliquinga-jacome@cnrs-thales.fr

Three-dimensional magnetic textures are central to emerging spintronic technologies, but direct access to their internal magnetization structure remains experimentally challenging. In particular, skyrmionic cocoons [1][2], which are vertically confined chiral textures in magnetic multilayers, require depth-resolved imaging techniques.

Here, we report full 3D vector reconstruction of skyrmionic cocoons in aperiodic Pt/Co/Al multilayers (figure) using HERALDO soft X-ray tomography [3] using a back-propagation algorithm [4]. By combining two orthogonal slit references and dual-axis tilting while keeping the sample to applied field orientation constant, we access in-plane and depth-resolved components of the magnetization. The reconstruction achieved a spatial resolution of about 30 nm (Fourier shell correlation, ½-bit criterion). The 3D maps reveal that worm domains extend throughout the multilayer thickness, while cocoons are vertically localized and appear in misaligned pairs. Their non-vertical alignment and apparent size variations across projections could be attributed to the grains distribution and pinning effects created in the sample. Micromagnetic simulations initialized from the reconstructed state confirm the overall cocoon structure while highlighting resolution-limited smearing of fine details.

These results highlight the strength of HERALDO vector tomography for imaging complex 3D chiral textures and pave the way for systematic investigations in future spintronic devices.



This work is supported by EU project SkyANN (reference no. 101135729), by ANR-DFG number BU 3297/4-1 (Topo3D) and by ANR-22- EXSP-0002 PEPR SPIN CHIREX and grant no. ANR- 22-EXSP-0008 PEPR SPIN SPINCHARAC).

[1] M. Grelier, *et al. Nat. Commun.* **13**, 6843 (2023)
[2] M. Grelier, *et al*, *Phys. Rev. B* **107**, L220405 (2023)
[3] J. J. Chiliquinga-Jacome et al., arXiv:2601.14889 (2026)
[4] M. Di Pietro Martínez*et al*, *Phys. Rev. B* **107**, 094425 (2023)

Mapping the configuration of thick permanent magnets with pre-edge hard X-ray magnetic tomography

Ginevra Lautizi[1*], Maik Kahnt [2], Joerg Strempfer[3], Doga Gursoy[3], Pedro Mercado Lozano[3], Claire Donnelly[1]

[1] Physics of Quantum materials, Max Planck Institute for Chemical Physics of Solids
[2] MAX IV Laboratory, Lund University
[3] Advanced Photon Source, Argonne National Laboratory
* Ginevra.Lautizi@cpfs.mpg.de

In recent years, there has been growing interest in three-dimensional, unconfined magnetic systems, due to the prospect for complex magnetic configurations in the bulk, with system-representative sizes and application-relevant behaviour, such as micro-energy harvesting and automobiles [1].
Until now, imaging of magnetic systems has been limited to samples of a few micrometres in size, with insight into thicker systems having been gained through surface-sensitive techniques. However, thinning magnetic materials changes the magnetic behaviour, so imaging at the nanoscale in system-representative samples is necessary. Here, we demonstrate that the transmission imaging of magnetic samples up to 50 µm thick, an order of magnitude thicker than previously possible [2]. We used spectroscopic hard X-ray magnetic circular dichroism to image $Nd_2Fe_{14}B$, one of the most used permanent magnets [3]. For thicknesses above 30 µm, we observed the appearance of surface localised domains (Fig. 1). These domains have been previously observed in surface-sensitive optical measurements of similar samples [4]. By tilting the sample, it is possible to see how these domain structures do not form a single domain across the thickness, but instead vary through the thickness. This demonstration of pre-edge hard X-ray magnetic imaging opens the door to the investigation of bulk-like materials. The next step is to combine phase imaging with magnetic tomography [5] for the first 3D imaging of magnets thicker than 5 µm. This will provide an insight into the internal nanoscale magnetic configuration of truly bulk systems.

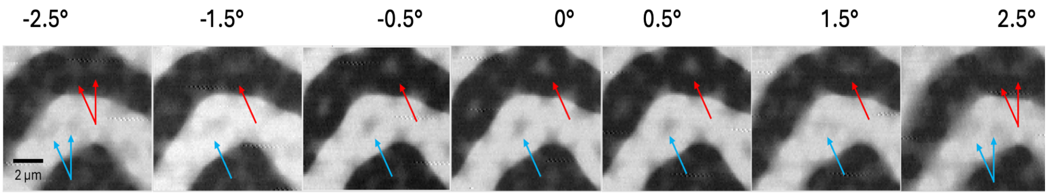


Figure 1. Tilt series of XMCD images showing surface localised domains in a 35 µm thick $Nd_2Fe_{14}B$ sample. At normal incidence, bright and dark surface domains appear within the dark and bright regions, respectively. When tilting the sample, the domain split into two different features (see arrows), demonstrating that they have a 3D structure. Unpublished.

[1] Bodduluri, M. T. et al. *MikroSystemTechnik 2019; Congress* 1–4 (2019).

[2] Neethirajan, J. et al. Phys. Rev. X 14, 031028 (2024).

[3] Coey, J. M. D. *J. Magn. Magn. Mater.* **248**, 441–456 (2002).

[4] Schaefer, Handbook of Magnetism and Magnetic Materials (2020).

[5] Donnelly, C. *et al. Nature* **547**, 328–331 (2017).

GHz noise characterization and magnetization reconstruction in a scanning magnetometer: A comparative study using scanning NV and MOKE

Miha Pompe[1*], Björn Josteinsson[1], Simon Josephy[1],
Andrea Morales[1], Zhewen Xu[1], Gabriel Puebla Hellmann[1]

[1] QZabre AG, Zürich, Switzerland
* miha@qzabre.com

Correlative magnetic microscopy combining complementary techniques provides powerful insights into domain structure and dynamics in magnetic thin films. We demonstrate multimodal characterization of BiYIG by integrating magneto-optical Kerr effect (MOKE) microscopy with scanning nitrogen-vacancy (NV) magnetometry in a single experimental platform (QZabre QSM) [1,2]. This approach enables direct comparison of magnetization distributions obtained from polar MOKE with quantitative stray field maps acquired via ODMR, achieving spatial resolution down to ~50 nm [3]. Complementary T_1 relaxometry measurements reveal localized magnetic noise at GHz frequencies, manifesting as 10-20% relaxation time reduction at domain walls due to thermally-driven spin fluctuation. Inverse Fourier transformation of the ODMR stray field data yields full vector magnetization reconstruction, exposing subtle in-plane magnetization components near domain boundaries that remain inaccessible to polar MOKE. Quantitative analysis of domain wall profiles reveals characteristic widths of 450-650 nm and magnetic field gradients of 4-10 mT/µm. This integrated multimodal methodology enables simultaneous characterization of static magnetization textures and dynamic magnetic excitations, providing a comprehensive framework for investigating complex magnetic phenomena in nanostructured materials.

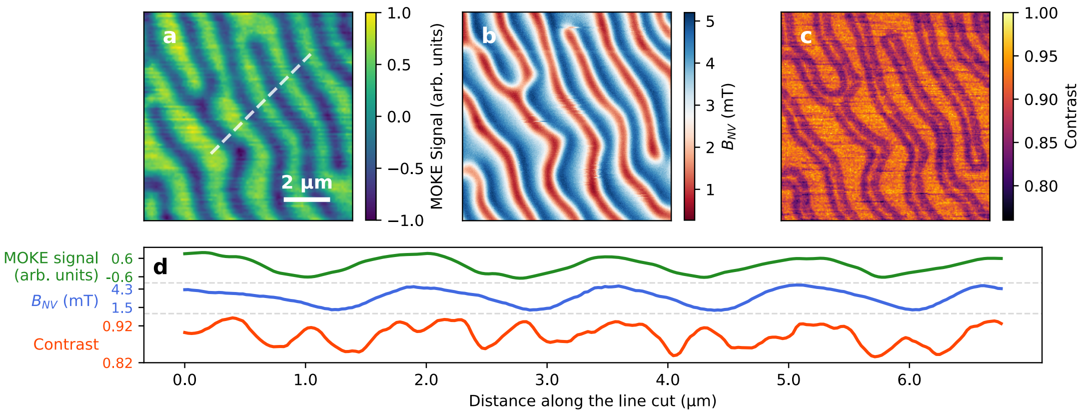


Figure 1. Multimodal imaging of BiYIG domains showing (a) MOKE, (b) ODMR stray field map, and (c) T1 relaxometry. (d) Line profiles reveal domain contrast in MOKE and ODMR with reduced T_1 at domain walls.

[1] Kazakova et al, J. Appl. Phys. **125**, 060901 (2019).

[2] Kimel et al, J. Phys. D: Appl. Phys. **55**, 463003 (2022).

[3] Degen, Appl. Phys. Lett **92**, 243111 (2008).

Correlative afm-sem-mfm for nanoscale magnetic domain characterization

Sebastian Seibert[1], Lukas Stühn[1], Hajo Frerichs[1], Darshit Jangid[1], Christian Schwalb[1], Marion Wolff[1*]

[1] Quantum Design Microscopy GmbH, Pfungstadt, Germany
* wolff@qd-microscopy.com

Magnetic domains and domain walls (DWs) play a critical role in data storage, spintronics, and nanoelectronic devices. While scanning electron microscopy (SEM) provides high-resolution imaging, it lacks direct magnetic sensitivity. Magnetic Force Microscopy (MFM), a magnetic mode of atomic force microscopy (AFM), enables mapping of long-range magnetic interactions, but precise positioning on nanoscale features and reliable correlation with SEM data remain.

We present a fully integrated correlative AFM–SEM approach that enables structural, topographical, and magnetic characterization within a single vacuum environment and coordinate system. SEM is used for rapid localization of micro- and nanoscale features,

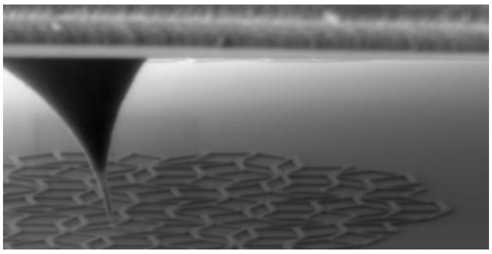


Figure 1. SEM Profile View of the FEBID tip engaged on the NiFe nanorod structure.

including domain walls, followed by AFM topography and MFM lift-mode imaging of the identical region of interest. Eliminating sample transfer ensures accurate data correlation, reduces contamination risk, and improves workflow efficiency.

A key feature is real-time SEM-based visualization of the cantilever, enabling precise tip positioning. This allows controlled lift-height optimization, balancing signal strength and spatial resolution while preventing tip–sample damage.

The approach is demonstrated on hard disk media, NiFe nanorod arrays, and FIB-patterned cobalt structures. In each case, direct correlation of SEM structure, AFM topography, and MFM phase contrast enables reliable nanoscale magnetic characterization.

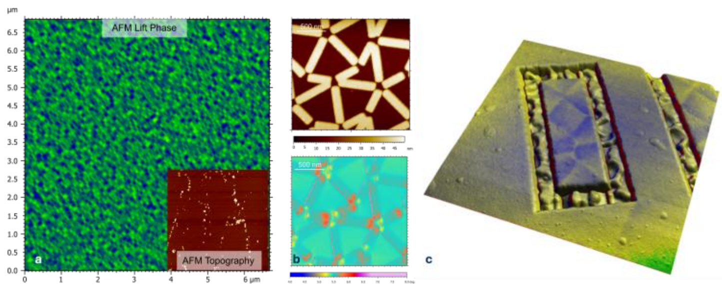


Figure 2. (a) MFM measurements on a hard disk with the corresponding topography. (b) Topography and MFM measurement of artificial spin-ice. (c) 3D representation of the topography and MFM signal (color-coded) of FIB-patterned cobalt layer.

Comparative studies of magnetic configurations in modulated nanowires

João Fradet[1], Cristina Bran[2], Luis Alfredo Rodriguez[3], Victor Vega[4], D. Reyes[3], Yolanda Álvarez[4], Eider Berganza[1], Javier García[4], Victor Prida[4], Christophe Gatel[3], Etienne Snoeck[3], Manuel Vázquez[1], Oksana Fesenko[1], Agustina Asenjo[1]*

[1] Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain
[2] INMA, CSIC-Universidad de Zaragoza, Zaragoza, Spain
[3] CEMES-CNRS, Toulouse, France
[4] Universidad de Oviedo, Oviedo, Spain
* aasenjo@icmm.csic.es

Understanding and controlling magnetic domain configurations in curved structures is essential for advancing technologies such as 3D magnetic recording and spintronics. Cylindrical nanowires, influenced by geometry-induced effects, offer a compelling alternative to planar nanostripes for dynamic applications. Their geometry stabilizes non-conventional magnetic textures, including Bloch point domain walls and vortex or skyrmion tubes [1]. Particularly promising are modulated cylindrical nanowires, where variations in magnetization or diameter promote complex configurations and domain-wall dynamics [2].

Magnetic imaging techniques have progressed remarkably, providing unprecedented nanoscale insight. Beyond improved sensitivity and spatial resolution, key goals now include quantifying magnetic moments and achieving full 3D imaging of domain-wall structures and

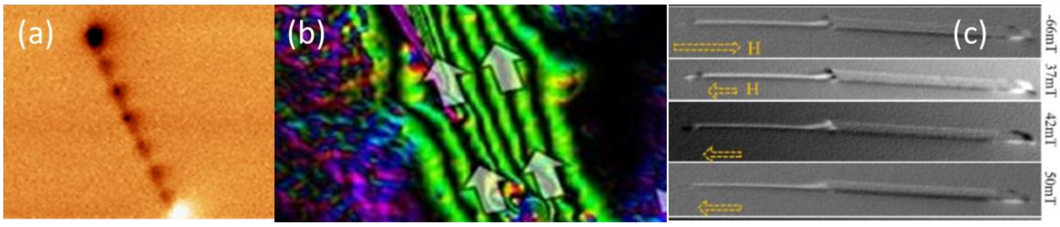


Figure 1. (a) MFM and (b) Electron Holography images of FeCo/Cu modulated nanowire. (c) XMCD-PEEM images of CoFe bisegmented nanowire after applying magnetic fields.

its dynamics [3]. While Magnetic Force Microscopy (MFM) is widely used in thin-film studies, its applicability to 3D systems is limited but still valuable for studying magnetization reversal processes [4]. In contrast, recent tomographic techniques based on XMCD and electron holography enable volumetric reconstruction of magnetic textures [5,6]. In this work, we show how combining complementary imaging techniques enables a comprehensive understanding of magnetization configurations and processes in FeCo-based modulated cylindrical nanowires under in-situ applied magnetic fields [4,7].

[1] E. Berganza et al., Materials (Basel). **14**(19):5671 (2021)
[2] C. Bran et al., Nanoscale,**15**, (2023) 8387-8394
[3] C. Bran et al., Adv. Funct. Mater., accepted (2026)
[4] J. Fradet et al., Nanoscale **17**, 18202-18210 (2025)
[5] C. Donnelly et al., Nature **547**, 328–331 (2017).
[6] E. Snoeck et al., Nano Lett. **8** (12) 4293–4298 (2008)
[7] L.A. Rodriguez et al., Chap 15, Magnetic Nano- and Microwires, Design, Synthesis, Properties and Applications, 3rd Edition, Editor: M. Vázquez, ISBN: 9780443365348 (2026)

Resonant domain wall dynamics in a three-dimensional magnetic double helix

Pamela Morales-Fernández[1,2], Iason Konstantinos-Douveas[3], Claas Abert[3], Elina Zhakina[1], Sandra Ruiz-Gómez[1,4], Claudia Fernández-González[1,4], Luke Alexander Turnbull[1,5], Sebastian Wintz[6], Markus König[1], Simone Finizio[6,7], Markus Weigand[6], Naëmi Leo[8], Dieter Suess[3,9], Aurelio Hierro-Rodríguez[10], Amalio Fernández-Pacheco[2], Claire Donnelly[1,5]

[1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[2]Institute of Applied Physics, TU Wien, Vienna, Austria
[3]Faculty of Physics, University of Vienna, Vienna, Austria
[4]ALBA Synchrotron Light Source, CELLS, Barcelona, Spain
[5]International Institute for Sustainability with Knotted Chiral Meta Matter, Japan
[6]Helmholtz Zentrum Berlin for Materials and Energy, Berlin, Germany
[7]Swiss Light Source, PSI, Villigen, Switzerland
[8]Loughborough University, Loughborough, United Kingdom
[9]Research Platform Mathematics-Magnetism-Materials, University of Vienna, Austria
[10]Physics Department, Oviedo University, Oviedo, Spain.
* Pamela.MoralesFernandez@cpfs.mpg.de

Three-dimensional (3D) magnetic nanostructures promise exciting opportunities beyond the physics of planar systems, with prospects for new topological textures [1], curvilinear effects [2], non-reciprocal dynamics [3] and ultrafast texture motion [4]. Yet, investigating dynamics in complex 3D nanogeometries has remained challenging due to limitations in fabrication and characterization. Our approach combines direct 3D nanoprinting [5] with lab-based magnetic imaging to explore magnetic states and coupling regimes in a cobalt nano double helix [6] and employ time-resolved X-ray microscopy [7] to uncover oscillatory resonant dynamics. Micromagnetic simulations reveal the nature of the observed resonances and further predict higher-frequency excitations that can be systematically tuned via geometric parameters: by precisely engineering the double helix geometry, the magnetostatic coupling between domain walls can be directly controlled, enabling precise tuning of resonant frequencies. This geometry-driven approach promises an alternative to conventional tuning mechanisms based on tailored anisotropies, DC bias, or external magnetic fields in conventional resonators. Our results [8] establish a platform for geometrically programmed magnetization dynamics in complex 3D nanoarchitectures.

[1] S. Castillo-Sepúlveda et al., Phys. Rev. B **104**, (2021).
[2] S. Ruiz-Gómez et al., Nat Commun **16**, 7422 (2025).
[3] M. Xu, P. Morales-Fernández et al., Nat. Nanotechnol. (2025).
[4] R. Hertel, J. Phys.: Condens. . Matter **28**, 483002 (2016).
[5] L. Skoric et al., Nano Lett. **20**, 184 (2020).
[6] C. Donnelly et al., Nat. Nanotechnol. **17**, 136 (2022).
[7] M. Weigand et al., Crystals **12**, 8 (2022).
[8] P. Morales-Fernández et al., Under review (2026).

Domain Wall Dynamics in Three-Dimensional Chiral Magnetic Nanostructures

Iason-Konstantinos Douveas[1*], Pamela Morales Fernandez[2], Claire Donnelly[2], Claas Abert[1]

[1] University of Vienna, Vienna, Austria
[2] Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
* iason-konstantinos.douveas@univie.ac.at

We present a micromagnetic study of domain wall (DW) dynamics in three-dimensional chiral magnetic nanostructures subject to external magnetic fields. Using finite-element simulations, we systematically explore how DW behavior is governed by structural parameters such as helix pitch, diameter, and chirality. To bridge simulation and experiment, we implement X-ray magnetic circular dichroism (XMCD) contrast simulations, enabling direct qualitative comparison with experimental measurements[1]. Our approach using a reduced-scale model for broad parameter space exploration yields a comprehensive picture of DW dynamics in curved three-dimensional geometries. These results provide fundamental insight in magnetization dynamics in complex nanostructures.

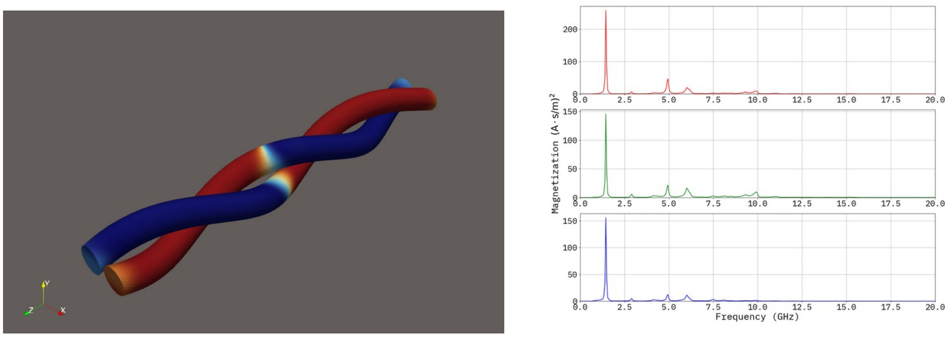


Figure 1. a) Double Helix with a locked Domain Wall in the center of the structure. b) Excitation spectrum of the magnetization.

[1] C. Donnelly et al., "Complex free-space magnetic field textures induced by three-dimensional magnetic nanostructures," *Nat. Nanotechnol.*, vol. 17, pp. 136–142, 2022, doi: 10.1038/s41565-021-01027-7

Controlling Domain Wall Dynamics in Curved Cylindrical Nanowires: From Vortex-Antivortex to Bloch Point Configurations

D. Alvarez García-Largo[1] G. H. R. Bittencourt[2], V. L. Carvalho-Santos[2], D. Altbir[3] , O. Chubykalo-Fesenko[4] and R. Moreno[4]*

[1]Facultad de ciencias físicas, Universidad Complutense de Madrid, Madrid, Spain.
[2]Departamento de Física, Universidade Federal de Viçosa, 36570-900 Viçosa, Brazil.
[3]Universidad Diego Portales, CEDENNA, Santiago, Chile.
[4]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain.
**roberto.m.o@icmm.csic.es*

Mastering magnetic domain wall (DW) dynamics in elongated nanostructures, such as cylindrical nanowires (NWs), is fundamental for the development of next-generation 3D magnetic devices. In this context, curvilinear magnetism has emerged as an effective strategy to tune magnetic properties through geometric design.

In this work, we employ micromagnetic simulations to investigate the dynamical response of complex DWs under the action of external magnetic fields beyond the standard transversal type, specifically focusing on vortex–antivortex (VAV) and Bloch point (BP) configurations [2]. We first study the dynamics of these DWs in straight cylindrical nanowires, identifying their distinct chiral dynamical behaviors. Subsequently, we introduce structural curvature by modeling arc-shaped NW geometries. Our findings reveal that curvature exerts a significant influence on the VAV DW dynamics, inducing back-and-forth oscillations coupled with rotation, similar to previously observed transversal DW behaviors [3,4]. In contrast, the BP DW demonstrates a remarkable "curvature-blind" response; its dynamical behavior in bent nanowires remains virtually identical to that observed in straight geometries, maintaining stable, high-velocity propagation [5]. These results provide critical insights for 3D magnonic and spintronic applications, demonstrating that curvature can be utilized as a selective degree of freedom to modulate DW mobility and functionality depending on the specific magnetic configuration

[1] D. D. Sheka Appl. Phys. Lett. 118, 230502 (2021)

[2] R. Moreno et al JMMM 542 168495 (2020).

[3] R. Moreno et al Phys. Rev B 96 184401 (2016).

[4] G. H . R. Bittencourt et al Phys. Rev. B 106 (9), 094410 (2020).

[5] GHR Bittencourt et al J. Appl. Phys.135, 063906 (2024)

Magneto-optical Kerr microscopy on non-planar geometries

Le Zhao[1*], Alexander Rabensteiner[1], Miguel Ángel Cascales-Sandoval[1], Naëmi Leo[1,2], Sabri Koraltan[1], and Amalio Fernández-Pacheco[1,†]

[1] Institute of Applied Physics, TU Wien, Wiedner Hauptstraße 8-10, 1040 Vienna, Austria
[2] Department of Physics, Loughborough University, Epinal Way, Loughborough LE11 3TU, United Kingdom
* le.zhao@tuwien.ac.at
† amalio.fernandez-pacheco@tuwien.ac.at

The rapid development of three-dimensional (3D) nanomagnetism has drawn increasing interest in recent years [1]-[4]. Accessing magnetic contrast on non-planar facets requires experimental approaches that are compatible with height variations while remaining sensitive to different magnetization orientations. In this work, we develop an extended depth-of-field magneto-optical Kerr effect (MOKE) microscopy scheme tailored for magnetic structures with non-planar geometries [5]. The approach combines focal-plane scanning with a dedicated image-stitching strategy, enabling the reconstruction of domain images that are simultaneously sharp and spatially consistent across the full field of view. The recent developments toward applying this strategy to complex three-dimensional nanostructures are also discussed.

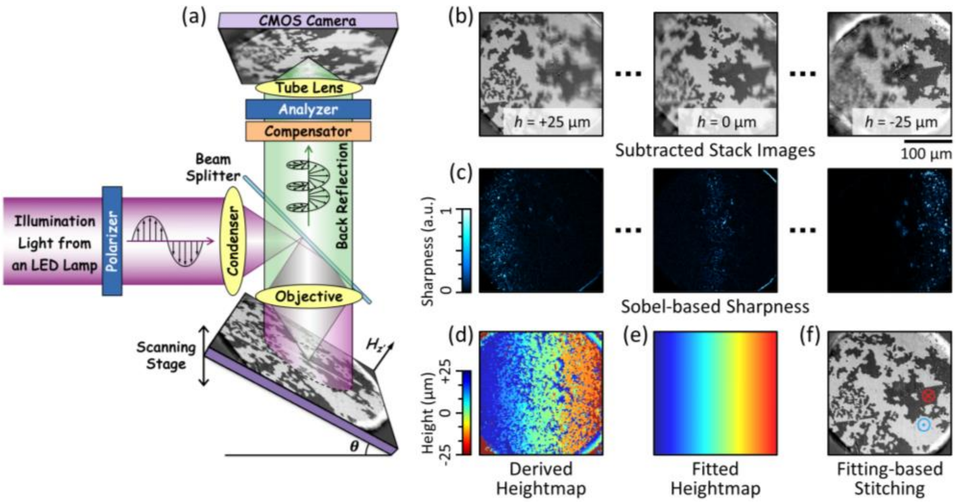


Figure 1. (a) Schematic illustration of the home-built MOKE microscope used for extended depth-of-field imaging. (b) Representative background-subtracted images acquired at different focal heights. (c) Sharpness evaluation of each subtracted image. (d) Heightmap obtained based on sharpness analysing. (e) Continuous two-dimensional height profile obtained by fitting the discrete height information in (d). (f) Final reconstructed all-in-focus domain image. Figures (b-f) share the same scale bar.

[1] A. Fernández-Pacheco et al., Nat. Commun. **8**, 15756 (2017).

[2] P. Fischer et al., APL Mater. **8**, 010701 (2020).

[3] R. Streubel et al., J. Appl. Phys. **129**, 210902 (2021).

[4] G. Gubbiotti et al., J. Phys.: Condens. Matter **37**, 143502 (2025).

[5] L. Zhao et al., arXiv:2601.08059 (2026).

Geometric effects on the magneto-optical Kerr effect investigated at 3D non-planar non-curved magnetic thin films

Christian Janzen[1*], Florian Ott[1], Bhavadip B. Rakholiya[1], Arno Ehresmann[1]

[1] Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, Germany
* christian.janzen@uni-kassel.de

Magnetic thin film systems with complex three-dimensional geometries provide new opportunities for tailoring magnetic properties through shape, curvature, topology, as well as chirality and are therefore promising for the discovery and study of novel magnetic effects [1]. These 3D microstructures can, in principle, be magnetically characterized using MOKE-based measurement devices intended for conventional planar material systems, like a Kerr microscope [2]. However, the interpretation of data is not trivial because the MOKE depends on the local reflection geometry [3]. To address this challenge, we investigate non-planar non-curved 3D magnetic geometries both experimentally and theoretically. By systematically varying geometric parameters, we analyze how the local surface tilt affects the polarization state of the incident and reflected light with respect to the surface normal of the sample, as well as the overall optical path in the system. Magneto-optical calculations, based on [4-6], have been performed to characterize MOKE in magnetic multilayer systems with arbitrary surface normal with respect to the plane of incidence. Further, simulations of simple optical setups have been performed to investigate the effects of the associated surface tilt on the optical path of light in the system. Additional contributions to the change in light polarization have been identified when accounting for the image-forming optics of the measurement device (cf. Fig 1. (A), (B)). With this, the magnetic and non-magnetic contributions to the observed signal can be deconvolved. By studying the influence of geometrical parameters that effectively change the locally perceived initial polarization of the incident light as well as the angle of incidence (cf. Fig. 1 (D)), we deepen the understanding of Kerr-microscopic signals measured on non-planar nanomagnetic systems as a basis for 3D curved systems.

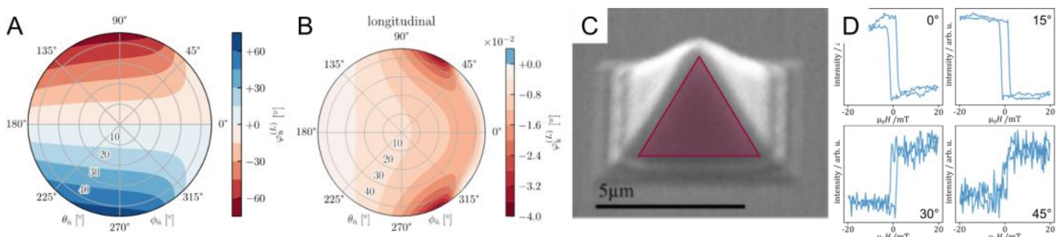


Figure 1. Non-magnetic rotation (A) and magnetic Kerr-rotation (B) of an electric field vector reflected at a magnetic thin film depending on surface normal tilt regarding the azimuthal and polar angle; SEM micrograph of a ferromagnetic micro-pyramid (C) with wall-specific magnetization reversal curves (D) depending on the initial polarization of the light.

[1] G. Gubbiotti, J.Phys.: Condens. Matter, **37**, 143502, (2025).
[2] C. Janzen, INTERMAG Short papers, Rio de Janeiro, 1-2, (2024).
[3] I. Soldatov, IEEE Magnetics Letters, **12**, 1–4, (2021).
[4] J. Hamrle, PhD thesis Université Paris Sud- Paris XI, (2003).
[5] E. Waluschka, Optical Engineering, **28.2**, 280286, (1989).
[6] R. A. Chipman, Optical Engineering, **34.6**, 1636–1645, (1995).

Coherent spin waves in 3D-printed magnonic crystals excited via a microresonator and integrated CPW

Huixin Guo[1*], Kilian Lenz[2], Mateusz Gołębiewski[3], Mingran Xu[1], Ryszard Narkowicz[2], Jürgen Lindner[2], Maciej Krawczyk[3], and Dirk Grundler[1]

[1]École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
[2]Helmholtz-Zentrum Dresden–Rossendorf (HZDR), Dresden, Germany
[3]Adam Mickiewicz University, Poznań, Poland
* guohuixin233@gmail.com

Three-dimensional (3D) magnonic crystals are attractive for energy-efficient information processing because their magnonic band structure can be engineered and tuned, enabling advanced wave-based functionalities and microwave signal transport in all three spatial directions on a chip. However, coherent excitation and reliable readout of spin-wave modes in fully connected 3D architectures remain challenging. Here we demonstrate two complementary routes to coherently access magnon modes in additively manufactured Ni woodpile magnonic crystals fabricated by two-photon lithography followed by conformal atomic layer deposition of Ni [1]. In a narrowband approach (Fig. 1a), an entire 3D crystal is embedded in a planar microwave microresonator and measured by ferromagnetic resonance (FMR) at discrete radiofrequency (RF) signals at 14.26 and 23.85 GHz [2]. Angle-dependent spectra reveal multiple coherent modes with symmetry fingerprints consistent with the woodpile lattice, including robust edge-type excitations localized at curved nanocaps that exhibit a distinct phase evolutionunder uniform microwave excitation. In a broadband approach (Fig. 1b), the 3D crystals are integrated onto coplanar waveguides (CPWs) for RF excitation, while micro-focused Brillouin light scattering (μ-BLS) provides spatially resolved detection on selected structural levels. This scheme reveals frequency- and field-dependent level selectivity, including suppressed microwave-driven signals on upper layers under specific conditions. Together, these results establish practical device pathways for coherent 3D magnonics, spanning resonator-enhanced spectroscopy and on-chip waveguide excitation with local optical readout. This work was supported by the SNSF (grant No. 197360).

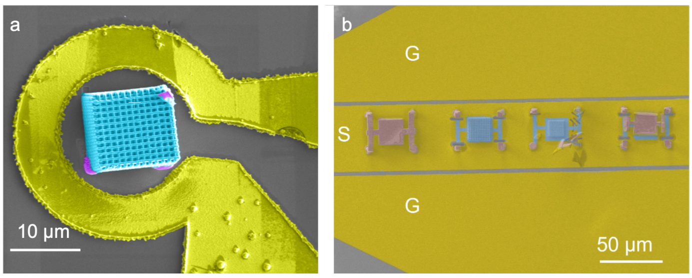


Figure 1. (a) Scanning electron microscopy image of a 3D Ni woodpile crystal (blue) placed in a planar microresonator (yellow) for FMR (scale bar: 10 μm). (b) Optical image of woodpile crystals integrated on the signal line of a CPW for broadband RF excitation and local μ-BLS readout (scale bar: 50 μm).

[1]. H. Guo, et al., Advanced Materials **35**, 2303292 (2023).

[2]. H. Guo, K. Lenz, M. Gołębiewski, et al., Small **22**, no. 7 (2026).

Topological nucleation mechanism of magnetically confined Vortex-Antivortex pairs in weak stripe racetracks

Aurelio Hierro-Rodriguez[1,2*], Victoria Vega Fernández[1,2], Salvador Ferrer[3], María Vélez[1,2]

[1] Depto. Física, Universidad de Oviedo, Oviedo, 33007, Spain
[2] CINN (CSIC-Universidad de Oviedo), El Entrego, 33940, Spain
[3] ALBA Synchrotron, Cerdanyola del Vallès, 08290, Spain
* hierroaurelio@uniovi.es

The magnetic racetrack idea represents one of the most paradigmatic approaches towards the implementation of high-density high-efficiency spintronic devices [1,2]. In this context, using magnetic systems that allow for magnetic-based stabilization of the propagation tracks is desirable, as it enables full reconfigurability. Multilayers with weak perpendicular magnetic anisotropy (wPMA) and stripe domains fulfil this requirement, allowing for a controlled propagation of Vortex-Antivortex pairs [3]. However, a precise understanding of texture formation at stripe domain bifurcations is mandatory to control their behaviour. Here, we employ micromagnetic simulations of a $Ni_8Fe_2/NdCo_5/Ni_8Fe_2$ 40/80/40 nm heterostructure with wPMA to study the texture nucleation process, identifying Bloch lines, merons, and Bloch point dipoles. We demonstrate that a topological transformation between the Bloch point dipole and the Vortex-Antivortex pair is essential to understand the confined guiding phenomenon, basal for the use of these systems as reconfigurable magnetic texture racetrack devices [4].

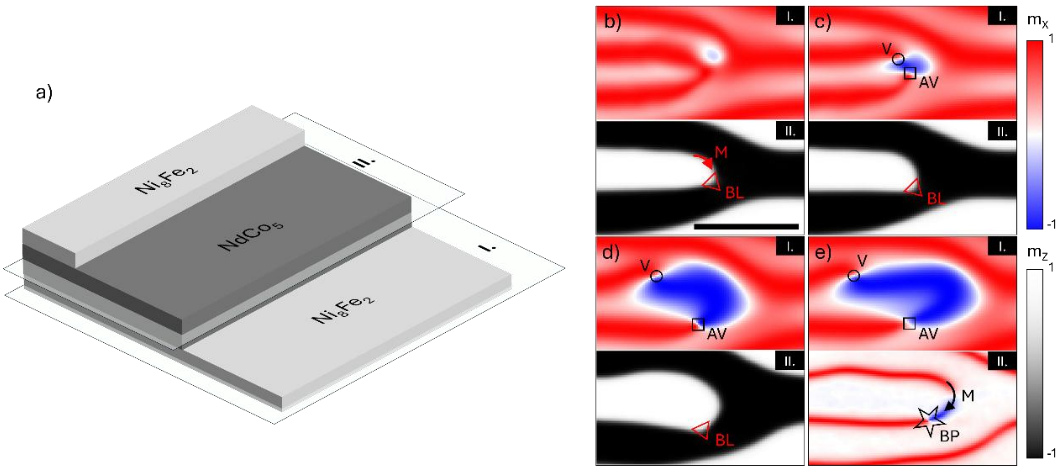


Figure 1 a) $Ni_8Fe_2/NdCo_5/Ni_8Fe_2$ heterostructure scheme. Slices I. (Bottom Ni8Fe2 layer) and II. (central NdCo5 layer) are indicated. Magnetic texture evolution showing bottom Ni_8Fe_2 surface (I.) and $NdCo_5$ central (II.) slices for 0.35 (b), 0.55 (c), 1.95 (d) and 3 (e) ns of simulation time. Vortex (V), antivortex (AV), meron-like (M), Bloch-line (BL) and Bloch point (BP) textures are indicated. Scalebar length 242 nm.

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

[2] R. Blasing et al, Proc. IEEE **108**, 1303-1321 (2020).

[3] A. Hierro-Rodriguez et al, Appl. Phys. Lett. **110**, 262402 (2017).

[4] V.V. Fernández et al, J. Phys. Mater. **9**, 015002 (2026).

Hopfions in screw chiral magnets

Sandra Chulliparambil Shaju[1*], Maria Azhar[1], Karin Everschor-Sitte[1]

[1] Faculty of Physics and Centre for Nanointegration Duisburg-Essen (CENIDE)
University of Duisburg-Essen, Germany
* sandra.shaju@uni-due.de

Three-dimensional (3D) topological spin textures have attracted increasing attention due to their rich physics and potential applications in future information technologies. While chiral magnets naturally stabilize extended twisted spin configurations through Dzyaloshinskii–Moriya interactions (DMI), the realization of isolated 3D solitons in a uniform ferromagnetic background remains challenging and have so far required either finely tuned combinations of higher order interaction terms [1] or a capping with large-PMA interfaces [2,3].

We propose symmetry-transforming magnetic models as a general framework for generating and stabilizing 3D spin textures. Based on this approach, we introduce a screw chiral magnet model [4] with spatially varying DMI, which can stabilize Hopfions and other 3D magnetic textures. The underlying screw symmetry of the model gives rise to unconventional Goldstone modes associated with the Hopfions. In addition, we analyze the evolution of topological indices [5] under continuous transformations using examples of 3D textures.

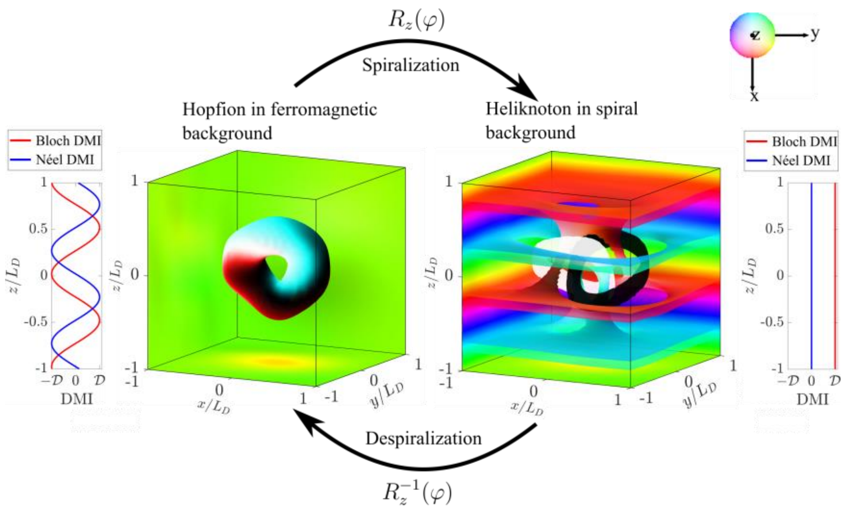


Figure1: Left: a Hopfion stabilized in the ferromagnetic ground state of the screw symmetric model. Right: a heliknoton embedded in the spiral ground state of a conventional chiral-magnet model. These two textures can be transformed into each other via a symmetry transformation. Displayed are the isosurfaces of $m_y = 0$ and the magnetization along the edges of the cubic sample.

[1] P. Sutcliffe, Phys. Rev. Lett. **118**, 247203 (2017).
[2] P. Sutcliffe, J. Phys. A: Math. Theor. **51**, 375401 (2018).
[3] Y. Liu, R. K. Lake, J. Zang, Phys. Rev. B **98**, 174437 (2018).
[4] S. C. Shaju, M. Azhar, K. Everschor-Sitte, arXiv:2601.1053 (2026).
[5] M. Azhar, S. C. Shaju, R. Knapman, et al., arXiv:2411.06929 (2025).

Observation of magnetic skyrmions in permalloy-rich [Pt/Co/NiFe/Ta] multilayers formed on curvilinear surfaces via scanning transmission X-ray microscopy

Takeaki Gokita[1*], Jakub Jurczyk[1], Michal Krupinski[2], Sebastian Wintz[3], Markus Weigand[3], Sabri Koraltan[1], Amalio Fernández-Pacheco[1]

[1] TU Wien, Vienna, Austria
[2]Institute of Nuclear Physics Polish Academy of Sciences, Kraków, Poland
[3] Helmholtz Zentrum Berlin, Berlin, Germany
* takeaki.gokita@tuwien.ac.at

Magnetic skyrmions have attracted considerable attention for future spintronic devices owing to their topological stability [1]. In particular, their dynamics can be utilized in logic gates, reservoir computing, and radio-frequency devices. However, typical skyrmion-hosting multilayers often exhibit relatively high damping, which limits experimental studies of skyrmion dynamics [2]. To overcome this limitation, we employed a NiFe layer to achieve low magnetic damping. Furthermore, inducing curvature is expected to introduce additional magnetic anisotropy and Dzyaloshinskii-Moriya interaction, thereby enabling robust stabilization of skyrmions [3].

Here, we report magnetic skyrmions in permalloy-rich [Pt(2)/Co(0.6)/NiFe(1.5)/Ta(0.5)] multilayers with 13 repetitions deposited on close-packed spherical polystyrene nanoparticles with a diameter of 919 nm via magnetron sputtering. The value inside the parentheses is the layer thickness in nanometers. To observe skyrmions, we performed scanning transmission X-ray microscopy with X-ray magnetic circular dichroism contrast (XMCD), which provides element-specific magnetic contrast with 20 nm spatial resolution under an external magnetic field applied parallel to the X-ray beam. Fig.1 shows XMCD images at the (a) Co (780.2 eV), (b) Fe (709 eV), and (c) Ni (854.6 eV) L_3 edges, where circular objects appear at the same positions, confirming that skyrmions are imprinted across all ferromagnetic layers. In this presentation, we will discuss how the curvilinear surfaces influence stability of the skyrmions. Our results provide a pathway to explore skyrmion dynamics and future skyrmion-based spintronic devices by utilizing NiFe layers to minimize magnetic damping.

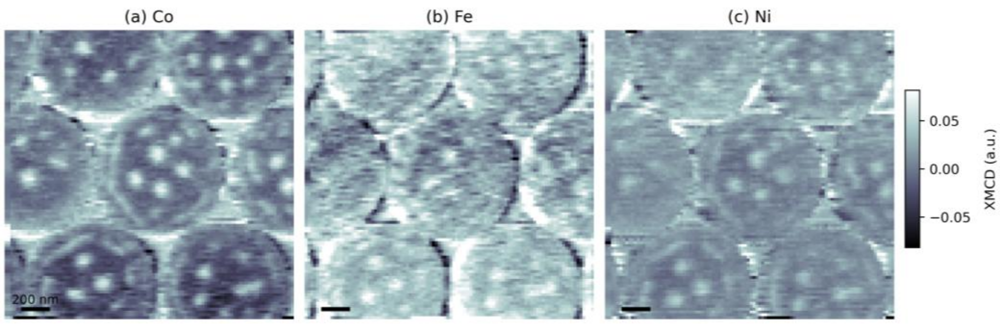


Figure 1. XMCD contrast of the sample measured under an applied magnetic field of 100 mT at the (a) Co (780.2 eV), (b) Fe (709 eV), and (c) Ni (854.6 eV) L_3 edges. Circular objects observed inside the nanoparticles indicate the presence of skyrmions in this system.

[1] S. Koraltan *et. al.,* arXiv:2601.16575 (2026).

[2] L. Flacke *et. al.,* Phys. Rev. B **104**, L100417 (2021).

[3] A. Korniienko *et. al.,* Phys. Rev. B **102**, 014432 (2021).

Structure and dynamics of complex chiral 3D domain walls in cylindrical geometry.

Elias Saugar[1], Roberto Moreno[1], Felipe Tejo[2], Jose Ángel Fernández-Roldán[1] and Oksana Chubykalo-Fesenko[1*]

[1] Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain
[2]Universidad Central de Chile, Santiago de Chile, Chile
* oksana@icmm.csic.es

Cylindrical geometry is inherently three-dimensional and promotes a rich complexity of magnetization configurations and domain wall types that are chiral and topologically non-trivial. Examples of these domain walls are Bloch point (BP) or vortex-antivortex (VAV) domain walls (DWs) in nanowires with longitudinal magnetisation. Much more complex DWs (consisting of two vortices and two anti-vortices on the nanowire surface and a complex trajectory of the core with internal Bloch points) can exist in nanowires with circular magnetisation.

For development of 3D nanotechnologies, it is important to understand the possibility to efficiently manipulate these DWs by external stimuli. Here we discuss from theoretical and modelling perspective their dynamics under external field, current and temperature gradient. The first important characteristic is that only the BP DW is a fast object. However, it is characterized by a complex gyrovector that does not allow its straight motion [1], it goes to the nanowire surface and the known topological transformations from one domain wall to the other may occur [1-4]. Secondly, the shape of this DW is dynamically deformed acquiring the conical shape under the application of the field [3] or butterfly-like shape under the action of current and Oersted field [4]. At the same time, large BP DW velocities, more than 10km/s can be achieved under the action of the field due to the jet-propulsion effect [3]. On the other hand, the VAV DW DWs are stable but very slow objects, rarely exceeding velocities of 10m/s. Their dynamics is quite complex and they experience a rotational and re-coiling effects [5]. 3D domain walls can also be moved by thermal gradients due to entropic torques [6]. However, they are quite stable and large gradients are necessary to initiate the dynamics. The VAV DW requires smaller gradients than the BP DW.

The results are not only applicable to cylindrical geometry, the same DWs will be present in nanowires with other cross-sections but with additional dynamical effects related to different geometrical symmetries [7]

[1]E. Saugar, et al Phys. Rev. Applied **23**, 064028 (2025) .

[2]A. Wartelle et al ,. Phys Rev B **99**, 24433 (2019).

[3] F.Tejo et al., Nanoscale, **16**, 10737 (2024).

[4] J.A.Fernánez-Roldán and O.Chubykalo-Fesenko, APL Mater **10**, 111101 (2022).

[5] GHR Bittencourt et al J. Appl. Phys.**135,** 063906 (2024)

[6] E.Saugar et al, Adv. Funct.Mater. (2026), in press.

[7] D.Altbir et al Sci. Rep. **10**, 21911 (2020).

Thermodynamic stability and magnetoelectric response of emergent magnetic monopoles in topological magnets

Midori Yamada[1*], Kotaro Shimizu[1], Shun Okumura[2,3], Yasuyuki Kato[4], Yukitoshi Motome[1]

[1] Dep. of Appl. Phys, The University of Tokyo, Tokyo, Japan
[2] QPEC, The University of Tokyo, Tokyo, Japan
[3] RIKEN CEMS, Wako, Japan
[4] Dep. of Appl. Phys., University of Fukui, Fukui, Japan

* midori-yamada@g.ecc.u-tokyo.ac.jp

Topological spin textures have raised attention through their emergent electromagnetic properties, including the topological Hall effect and the topological Nernst effect. Among them, magnetic hedgehog lattices (HLs) are three-dimensional topological spin textures that host periodically arranged emergent magnetic monopoles and antimonopoles (Fig. 1). They have been identified in metallic compounds, such as $MnSi_{1-x}Ge_x$ and $SrFeO_3$ [1-3]. While HLs are often modelled using either short-range (localized/insulating) or effectively long-range (itinerant/metallic) interactions [4,5], real materials generically lie in between, with finite and material-dependent exchange ranges. Moreover, experimental probes beyond metallic transport are desirable, especially if HLs can be realized in insulating magnets.

In this work, we investigate thermodynamic stability and magnetoelectric (ME) responses of these HLs using extensive Monte Carlo simulations. First, we map field–temperature phase diagrams, interpolating between the metallic and insulating limits through systematic variation of the range and spatial decay of exchange interactions. We find that HLs are stabilized over a broad interaction range; notably, an intermediate range emerges as optimal, stabilizing multiple and comparatively wide HL phases in parameter space. Next, building on the stabilized phases, we evaluate the ME effect using symmetry arguments and microscopic polarization mechanisms, such as the inverse Dzyaloshinskii-Moriya and the *p*-*d* hybridization mechanism. We show that HLs exhibit field-dependent macroscopic electric polarizations and dielectric constants, which are sensitive to topological and magnetic transitions between different HL phases. Our results enable materials-oriented predictions of HL stability from microscopic interaction models and propose the ME response as a sensitive probe for detecting emergent monopoles, particularly in candidate insulating materials.

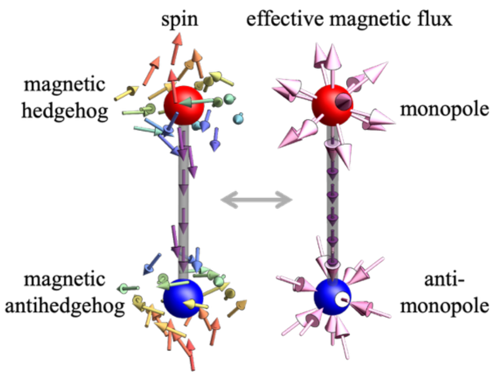


Figure 1. Magnetic hedgehog-antihedgehog pair (left) and corresponding emergent magnetic monopole-antimonopole pair (right).

[1] N. Kanazawa *et al.*, Phys. Rev. B **86**, 134425 (2012).
[2] Y. Fujishiro *et al.*, Nat. Commun. **10**, 1059 (2019).
[3] S. Ishiwata *et al.*, Phys. Rev. B **101**, 134406 (2020).
[4] S. Yang *et al.*, Phys. Rev. B **94**, 054420 (2016).
[5] S. Okumura *et al.*, Phys. Rev. B **101**, 144416 (2020).

Strain control of three-dimensional magnetic nanostructures

José Claudio Corsaletti Filho[1*], Mohammad Sedghi[1], Elina Zhakina[1], Yuchen Zhao[1], Markus König[1], Elena Gati[1,2], Claire Donnelly[1,3]

[1] Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[2] Technical University of Dresden, Dresden, Germany
[3] Hiroshima University, *International Institute for Sustainability with Knotted Meta Matter, Hiroshima, Japan*
* jose.corsaletti@cpfs.mpg.de

Over the past few years, there has been growing interest in the influence of three-dimensional (3D) geometrical effects [1] on the magnetic behavior of suspended 3D nanostructures, where properties such as curvature and torsion [2] have been shown to lead to emergent chirality and anisotropy [3,4]. Recent studies have shown that the magnetic landscape of 3D nanostructures can be controlled by geometrical effects [5]. Consequently, a reversible method to tune 3D nanostructures is highly desirable, with strain offering a promising approach, as it directly influences the geometry. Indeed, extensive research has explored straining of thin-film materials for tuning of global material properties, however, due to the substrates, those methods are typically limited to small strain values (about 0.3–0.7%) [6]. In this work, we directly strained suspended cobalt 3D nanostructures (Fig. 1a) grown by focused electron beam induced deposition (FEBID), and characterize the mechanical properties with in situ electron microscopy. We are able to achieve ultimate strains of up to 22% (Fig. 1b) and also identify regimes associated with the elastic and plastic deformations of 3D nanostructures for different internal angles. The application of strain results in changes to the geometry that directly influence the magnetic properties of the nanostructures, offering a route to reversibly tune the magnetic behavior of a system.

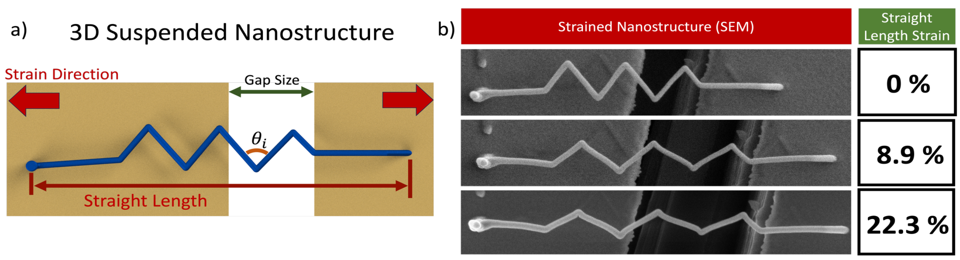


Figure 1. Straining suspended 3D nanostructures. (a) The zigzag cobalt nanostructures growth by FEBID over a gap. (b) Electron microscopy imaging of the nanostructures with uniaxial strain applied.

[1] Fernández-Pacheco, A., et al. (2017). Nature Communications, 8(1).

[2] Streubel, R., et al. (2016). Journal of Physics D: Applied Physics, 49(36).

[3] Raftrey, D., et al. (2025). American Chemical Society Nano, 25(6), 2506279.

[4] Gubbiotti, G., et al. (2025). Journal of Physics: Condensed Matter, 37(14).

[5] Ruiz-Gómez, S., et al. (2025). Nature Communications, 16(1).

[6] Xiang, J., et al. (2025). Acta Mechanica Solida Sinica, 38(2).

A Hall bar on three-dimensional surface fabricated by focused ion beam

Chi Fang[1], Haojie Zhang[1], Stuart S. P. Parkin[1]

[1] Max Planck Institute of Microstructure Physics, Halle (Saale) 06120, Germany
* stuart.parkin@mpi-halle.mpg.de

Hall bar devices are an important class of condensed matter physics devices and have been widely used in carrier transport characterization, magneto-transport studies, and functional device measurements [1]. Owing to their multi-terminal geometry, they enable the simultaneous measurement of longitudinal resistance and transverse Hall voltage, making them a fundamental platform for investigating electronic transport properties.

In this work, based on focused ion beam (FIB) technology, we successfully fabricated continuous metallic thin films on three-dimensional surfaces by optimizing the processing parameters and introducing a buffer layer (Fig.1(a-c)). The optimized fabrication strategy effectively improved film continuity, adhesion, and electrical connectivity across sidewalls, edges, and curved surface regions, thereby enhancing the overall stability of the device. On this basis, electrical transport measurements were carried out, and a clearly distinguishable Hall-effect signal was observed (Fig.1(d)). These results demonstrate that the FIB-based approach provides a feasible route for the fabrication of Hall-bar-like devices on complex three-dimensional geometries, and offers an experimental foundation for future studies of Hall transport, magnetoelectric effects, and three-dimensional micro/nanoelectronic devices in non-planar structures [2,3].

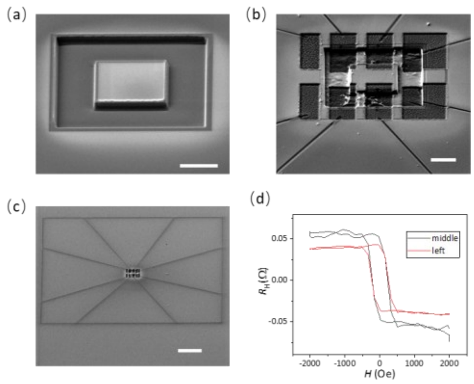


Figure 1. FIB fabrication of 3D hall bar and its Hall response to the magnetic field. Scale bar is 5 µm in (a) and (b) and 50 um in (c).

[1] J. V. Wallbank et al., Sensors (Basel) 24(14), 4610 (2024)

[2] F. Meng et al., ACS Nano 15(4), 6765–6773 (2021)

[3] K. Höflich et al., Appl. Phys. Rev. 10, 041311 (2023)

Engineering of rare-earth microwires for biomedical applications

Oksana Koplak*

University of Milano-Bicocca, Milan, Italy
* oksana.koplak@unimib.it

Magnetic microwires based on rare-earth transition-metal (RE–TM) alloys exhibit exceptionally high permanent magnetization and tunable domain structures, offering potential functionality as sensors for magnetic fields, mechanical stress, and temperature due to their pronounced magnetic anisotropy and domain engineering capabilities [1-2]. Microwires with high magnetocrystalline anisotropy produce strong magnetic fields in microscopic volumes, making them suitable for three-dimensional manipulation of biomaterials, including magnetically labeled cells [3-5]. In particular, the micromagnetic tweezers based on PrDyFeCoB microwires enables the capture, manipulation, analysis, and precise positioning of magnetic micro- and nanoparticles, as well as their labeled biological targets (Fig. 1).

Conical PrDyFeCoB microwires exhibit high saturation magnetization and a concentrated stray field at their tip, enhancing their capture force, which is necessary for manipulating large and heavy biological cells. The magnetic flux gradient at the tip of a single microwire, measured using Kerr microscopy, reaches values up to ~3.7×10^9 Oe/m, sufficient to influence intracellular processes even in the absence of ferromagnetic markers. The high magnetic attraction of the sharpened DyPrFeCoB microwire, up to ~900 pN, enables manipulation of individual DyPrFeCoB ferromagnetic microparticles (1–10 μm) as well as their assemblies. The effective interaction radius of the sharpened microwires is 5–10 μm, adequate for biological and biomedical tasks such as cell capture and precise positioning.

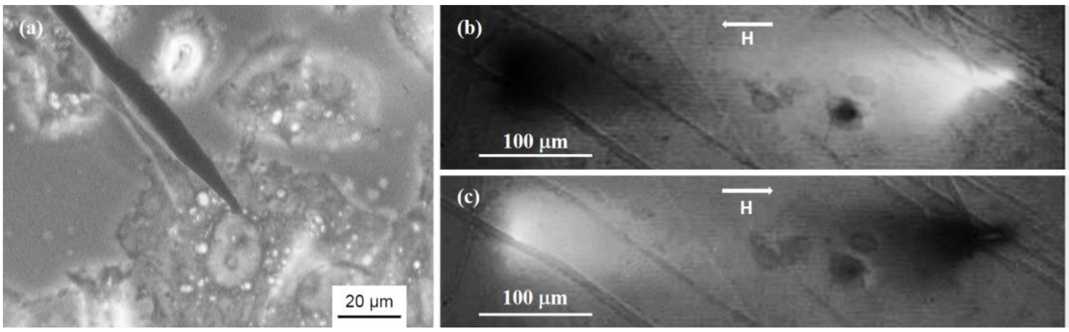


Figure 1. Figure 1. (a) Optical image of a microtweezer manipulating HeLa cells. (b, c) Magneto-optical images of a sharpened microwire in magnetic fields with different orientations.

[1] R. Morgunov, O. Koplak, V. Piskorskii, D. Korolev, R. Valeev, A. Talantsev, JMMM **497**, 166004 (2020).
[2] O. Koplak, R. Morgunov, Mat. Sc. and Eng.: B **263**, 114845 (2021).
[3] O. Koplak, R. Morgunov, I. Khodos, Mat. Lett. **301**, 130375 (2021).
[4] R. Morgunov, O. Koplak, Mat. Lett. **273**, 127954 (2020).

Mapping in-plane stray field components with torsional resonance mode magnetic force microscopy

Jorge Marqués-Marchán[1*], José Claudio Corsaletti Filho[1], Pamela Morales-Fernández[1], Jeffrey Neethirajan[1], Aleš Hrabec[2,3], Praveen Vir[1], Chandra Shekhar[1], Claudia Felser[1,4] and Claire Donnelly[1,5]

[1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[2]Laboratory for Mesoscopic Systems, Department of Materials, ETH Zurich, Zurich, Switzerland
[3]PSI Center for Neutron and Muon Sciences, Villigen PSI, Switzerland
[4]Würzburg-Dresden Cluster of Excellence ct.qmat, TUD University of Technology Dresden, Dresden, Germany
[5]International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM2), Hiroshima University, Hiroshima, Japan

* jorge.marchan@cpfs.mpg.de

In recent years, the emergence of three-dimensional (3D) nanomagnetism and topological configurations has highlighted the importance of mapping the 3D vector field components in these systems [1]. Although established techniques enable such characterization [2], they often require synchrotron facilities or high-cost instrumentation, making rapid and accessible analysis challenging.

A lab-based technique that could provide such contrast is torsional resonance mode magnetic force microscopy (TR-MFM), where the MFM probe oscillates laterally with respect to the sample surface. Despite MFM being a well-established technique to map out-of-plane stray fields, the use of TR-MFM has only been validated on standard samples [3,4]. Here, we use TR-MFM in combination with standard MFM to map both the in-plane and out-of-plane stray field components of different samples, aiding the understanding of different 3D magnetic configurations.

[1] G. Gubbiotti et al., Journal of Physics: Condensed Matter **37**, 143502 (2025).

[2] E. D. V. Christensen et al., JPhys Materials **7**, 032501 (2024).

[3] A. Kaidatzis and J. M. García-Martín, Nanotechnology **24**, 165704 (2013).

[4] J. F. Schmidt et al., Journal of Applied Physics **136**, 113904 (2024).

Magnetic vector tomography of extended chiral magnets

Polly Mitchell[1*], Luke Turnbull[2], Marina Raboni-Ferreira[1], Rikako Yamamoto[1,3], Jeffrey Neethirajan[1], Luke Higgins[2], Benedikt J. Daurer[2], and Claire Donnelly[1,3]

[1] Max Planck Institute for Chemical Physics of Solids, Dresden, Germany
[2] Diamond Light Source, Didcot, United Kingdom
[3]International Institute for Sustainability with Knotted Chiral Meta Matter, Hiroshima, Japan
* Polly.Mitchell@cpfs.mpg.de

Competing Dzyaloshinskii-Moriya and exchange interactions result in chiral magnets hosting a range of complex three-dimensional (3D) textures, such as Bloch points[1], chiral bobbers[2], and hopfions[3]. These textures have technological relevance in advanced spintronics and ultra-efficient memory devices[4]. To unlock this application potential, it is critical to understand the formation, manipulation and annihilation of such configurations.

Here we harness X-ray magnetic vector tomography[1] to image the 3D configuration of patterned chiral magnets. First, we image the configuration of a 300nm thick disc of the chiral magnet $Co_8Zn_9Mn_3$ at Diamond Light Source (I08). We are able to resolve the nanoscale helical winding throughout the material. Intriguingly, skyrmions are observed in the vicinity of curved surfaces at zero field, indicating the influence of the patterned geometry in guiding the formation of complex textures.

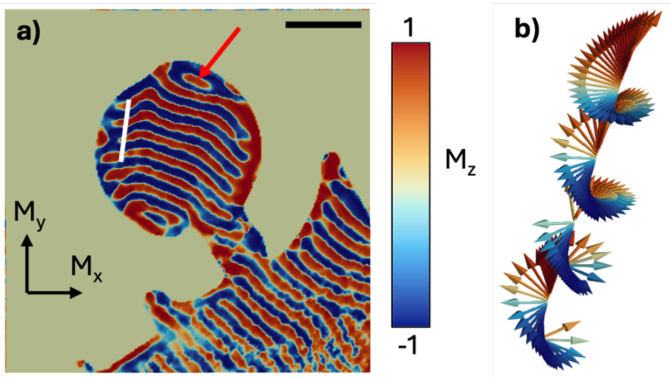


Figure 1. Vector magnetic tomography of $Co_8Zn_9Mn_3$. a) Out-of-plane magnetisation in the central slice of the sample. Arrow indicates a skyrmion that has nucleated near a curved surface. White line indicates the location of the path for which the helical winding is plotted in b). Scale bar is 500nm.

When one moves to larger, thicker samples, such confinement effects are reduced, enabling the formation of more complex 3D magnetic textures. However, imaging thicker samples presents a challenge for vector tomography: the magnetic contrast of opposing magnetic vectors can cancel when projected through the sample bulk, reducing magnetic contrast and possibly hindering the 3D reconstruction. We performed numerical simulations of magnetic vector tomography, determining that increased angular sampling can mitigate vector cancellation and enable the recovery of complex 3D configurations up to 3μm thick. These results establish X-ray magnetic tomography as a powerful tool for the study of chiral systems over micrometre length scales.

[1] Donnelly, C. et al. Nature 547, 328–331 (2017)
[2] Zheng, F. et al. Nat. Nanotech. 13, 451–455 (2018)
[3] Zheng, F. et al. Nature 623, 718-723 (2023)
[4] Gubbiotti, G. et al. J. Phys.: Condens. Matter 37 143502 (2025)

Physics-informed tomographic reconstruction of chiral magnetic textures

Alexander Setescak[1], Anuj Chavan[1], Claire Donnelly[2], Manuel Guizar-Sicairos[3,4], Amalio Fernández-Pacheco[5], Claas Abert[1]

[1] University of Vienna, Vienna, Austria
[2] Max Planck Institute for the Chemical Physics of Solids, Dresden, Germany
[3] Paul Scherrer Institute, Villigen PSI, Switzerland
[4] EPFL, Lausanne, Switzerland
[5] TU Wien, Vienna, Austria
* alexander.setescak@univie.ac.at

The reconstruction of three-dimensional chiral magnetic textures from X-ray Magnetic Circular Dichroism (XMCD) tomography data is typically treated as a purely mathematical inverse problem [1, 2]. To enforce physical consistency, we propose a physics-informed reconstruction framework implemented entirely within a differentiable programming environment using Python and JAX [3]. Our method formulates the reconstruction as a minimization problem that combines standard data fidelity with physics-based regularization. Specifically, we employ a differentiable forward model, based on the Scientific Computational Imaging Code (SCICO) package [4], to map a 3D magnetization vector field to a series of 2D XMCD projections. This model is coupled with the NeuralMag library, which we use to enforce physical validity by minimizing the total micromagnetic energy of the reconstructed state [5, 6, 7]. By constraining the inverse problem in this way, our framework extracts accurate magnetization configurations even when experimental data is sparse or noisy. Furthermore, this fully differentiable simulation pipeline paves the way for the simultaneous reconstruction of the magnetization texture and the identification of intrinsic material parameters, a key objective for our ongoing development.

[1] C. Donnelly et al., “Three-dimensional magnetization structures revealed with X-ray vector nanotomography,” Nature 547, 328–331 (2017).

[2] C. Donnelly et al., “Tomographic reconstruction of a 3D magnetization vector field,” New J. Phys. 20, 083009 (2018).

[3] J. Bradbury et al., “JAX: Autograd and XLA,” Astrophysics Source Code Library, ascl:2111.002 (2021).

[4] T. Balke et al., “SCICO: Scientific Computational Imaging Code,” J. Open Source Softw. 7, 4722 (2022).

[5] C. Abert, “Micromagnetics and spintronics: Models and numerical methods,” Eur. Phys. J. B 92, 120 (2019).

[6] C. Abert et al., “NeuralMag: Open-source nodal finite-difference code for inverse micromagnetics,” npj Comput. Mater. 11, 193 (2025).

[7] A. Setescak et al., “A Fourier-Space Approach to Physics-Informed Magnetization Reconstruction from Nitrogen-Vacancy Measurements,” arXiv:2602.17180 [cond-mat] (2026).

Geometry-modified domain wall dynamics for 3D racetrack memories

Tiange Dong[1*], Jitul Deka[1], Chi Fang[1], André M. A. Farinha[1], Yicheng Guan[1], See-Hun Yang[1], and Stuart S. P. Parkin[1*]
[1] Max Planck Institute of Microstructure Physics, Halle, Germany
* tiange.dong@mpi-halle.mpg.de

Toward a highly compact and information-dense device concept, the transition from traditional two-dimensional architectures to three-dimensional (3D) and the methods of 3D nanofabrication represent one of the most promising advances in spintronics, especially for innovations of next-generation spintronic devices such as racetrack memories. Beyond that, the form of 3D geometries introduces new topology that can fundamentally reshape magnetic energy landscapes and thereby influence spin textures and their dynamics.

Here, we report an experimental investigation of magnetic domain wall motions in 3D racetrack memories with complex 3D geometries. We utilize an advanced nanofabrication approach based on multiphoton lithography and multilayer thin-film deposition. We demonstrate that specific 3D geometrical forms, such as spatial curvature, act as an effective energy/field modification of the magnetic domain walls, leading to an observable influence on the domain wall motion dynamics.

Our results show 3D device geometry as an additional control of current-driven domain wall motions, paving the way for geometry-modified functions of racetrack memories and other 3D spintronic devices.

Domain-wall membranes in 3d nanomagnetism: a geometric effective theory for dynamics and spin waves

J. J. Mankenberg[1*]

[1] Department of Physics and Electrical Engineering, Linnaeus University, SE-39231 Kalmar, Sweden

* jamaab@lnu.se

Three-dimensional magnetic textures are often studied either through full micromagnetic simulation, which can obscure physical mechanisms, or through highly reduced collective-coordinate models, which struggle to capture the local geometry and internal structure of nonuniform configurations [1]. In this talk I present ongoing progress on a geometry-based effective theory for 3D textures that bridges these two limits by treating domain walls as embedded, deformable membranes carrying their own internal degrees of freedom [2].

Within this framework, both static configurations and their excitations can be described on the same footing. Starting from the spin Berry phase and the underlying micromagnetic Hamiltonian, the membrane reduction yields coupled equations for texture motion, internal membrane dynamics, and spin-wave excitations in a controlled gradient expansion. It makes transparent how curvature, frame rotation, and internal wall structure modify magnon propagation and backreaction, providing a direct route to geometry-dependent predictions that are difficult to extract from simulations alone. I will show how this description can be used not only to analyze spin-wave transport on textured backgrounds, but also to engineer domain-wall geometries that act as guiding and focusing elements for magnons.

A key advantage of the approach is that it is systematic and extensible. The same reduction can be applied to broad classes of micromagnetic Hamiltonians, including those with dipolar interactions, and it can be extended to incorporate field gradients and current-driven effects such as spin-transfer and spin-orbit torques in the resulting dynamical equations. Finally, I will demonstrate how the same low-dimensional membrane description provides a natural and physically informed parameterization for constructing image sequences in geodesic nudged elastic band (GNEB) calculations [3]. More broadly, this framework offers an analytical route to magnetization dynamics and excitations in 3D nanomagnetism guided by the geometry of the texture itself.

[1] G. Giubboti et al., 2025 roadmap on 3d nanomagnetism, Journal of Physics: Condensed Matter **37**, 143502 (2025).

[2] J. J. Mankenberg and A. Abanov, Three-dimensional domain-wall membranes, Phys. Rev. B **113**, 014435 (2026).

[3] P. F. Bessarab, V. M. Uzdin, and H. Jónsson, Method for finding mechanism and activation energy of magnetic transitions, applied to skyrmion and antivortex annihilation, Computer Physics Communications **196**, 335 (2015).

Effect of Dimensionality on the Spin Wave Properties on Mix Material Magnonic Crystals

Zhehai Chen, Leon K W Lee, Naga Sai Vishnu Suggula, Vivian Ng*

Information Storage Materials Laboratory, Department of Electrical and Computer Engineering, National University of Singapore
* elengv@nus.edu.sg

Two-dimensional magnonic crystals enable it able tuneable spin-wave propagation. It was shown by stacking different types of structures on a *continuous* film that spin wave channels formed in the underlying film can be manipulated by the pattern above [1]. In this work, we design both connected and disconnected geometries with the intention to modify and enhance spin waves through arrays with mixed material and mixed dimensionality magnetic nano-structures.

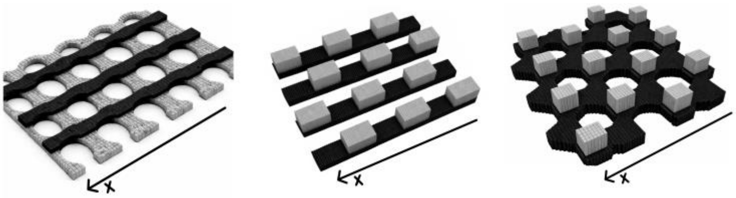


Fig 1: Self Aligned Mix Material Arrays of: (a) nanowire on antidot; (b) dot on nanowire; (c) dot on antidot. Grey represents Co and black represents Py.

Fig 1 shows our simulated structures with similar dimensions. These have been investigated to evaluate how the combination of different dimensional structures fabricated with different materials can be used to effect spin wave propagation. Hysteresis simulations are conducted on MuMax3 [2] with a mixture of Co (grey) and Py (black).

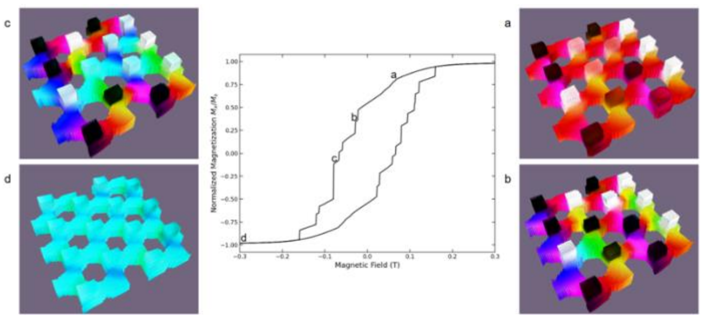


Fig 2: M-H loop with spin configurations for *dot-on-antidot* reversal along x direction

Fig 2 shows that at saturation field in x direction, spins in all layers lie in plane. As the saturation field is gradually reduced, the antidot regions between the dots started to reverse. However, the Co dots positioned on top divided the antidot into various regions which caused a bottleneck in the spin transition, thereby causing the Co dot to rotate out-of-plane (black and white). The understanding of the above behaviour plays an important role in magnonics as the continuous magnetic lattice can also be viewed as a system of domain walls where spin wave propagation is determined by domain wall motion and interactions controlled by overlaying discontinuous structures. Future FMR characterisation is ongoing.

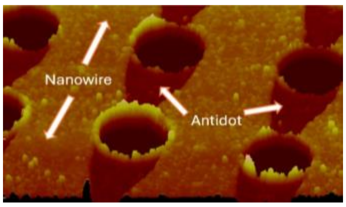


Fig 3: Atomic Force Microscope image of nanowire-on-antidot

Fig 3 shows the fabricated line-on-antidot using a self-aligned technique for fabricating 3D structures previously developed [3]. The other structures will be fabricated and characterized.

References:

[1] E. Iacocca, S. Gliga, O.G. Heinonen, 'Tailoring spin waves channels in a reconfigurable ASI' *Phy Rev Appl* 13 044047 (2020).
[2] Vansteenkiste, A., & Van de Wiele, B. (2011). MuMax: A new high-performance micromagnetic simulation tool. *Journal of Magnetism and Magnetic Materials*, *323*(21), 2585-2591.

[3] Myint, B., & Ng, V. (2021). Magnetization reversal process in 3D permalloy nanomatrix. *Physica Status Solidi–Rapid Research Letters,* 15(8), 2100197.

The Quantum Spin-Polarized Low-Energy Electron Microscope: Pulsed source, low temperature and angle resolved spectroscopy

Alexander Stibor[1*], Usama Choudhry[1], Nicholas Dale[1], Sinéad Griffin[1], Cameron Johnson[1]
[1] Lawrence Berkeley National Laboratory, Molecular Foundry, Berkeley, USA
*astibor@lbl.gov

The Quantum Spin-Polarized Low-Energy Electron Microscope (QSPLEEM) is an advanced Elmitec LEEM III instrument uniquely suited for examining surfaces and structures of state-of-the-art heterogeneous magnetic quantum materials. Here, we present an overview of new capabilities and experimental developments implemented at the Molecular Foundry User Facility at Lawrence Berkeley National Laboratory. Two combined features distinguish the QSPLEEM in addressing fundamental questions in quantum surface science: a femtosecond-laser–excited pulsed spin-polarized electron source and a custom liquid-helium cryogenic sample stage. These advances enable dynamic studies of spin-dependent magnetic structures on their native time scales, the characterization of novel magnetic materials, the mapping of spin-resolved unoccupied band structures, and nanoscale magnetometry with spatial resolutions in the 10-nm regime.
We report recent measurements of unoccupied electronic band structures above the Fermi level using angle-resolved reflection electron spectroscopy (ARRES). In addition, we present first results from the implementation of the ultrafast pulsed spin-polarized electron beam source, achieved by integrating a femtosecond Ti:sapphire laser to generate ultrashort, polarization-controlled electron pulses. This development opens the path toward spin-polarized pump–probe LEEM and photoemission electron microscopy (PEEM) with ultrafast time resolution.
Finally, we highlight several ongoing research efforts, including a project aimed at providing the direct experimental evidence of altermagnetism, a recently predicted unconventional d-wave magnetic state. Our approach leverages spin-resolved ARRES to probe the characteristic spin-dependent unoccupied band structure, and we demonstrate these capabilities using Iridium as a model system, revealing clear signatures of spin–orbit coupling.

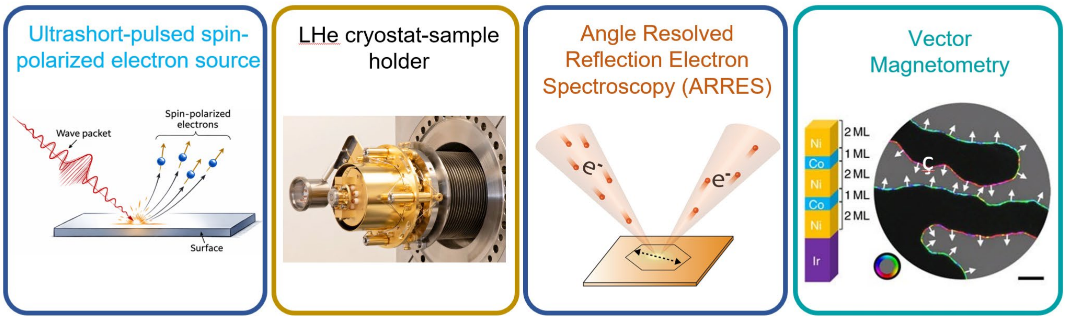


Figure 1. Capabilities of the Quantum Spin-Polarized Low-Energy Electron Microscope (QSPLEEM) user instrument.

Towards 3D magnonics: volumetric magnonic directional coupling in high-aspect-ratio YIG microstructures

Hanadi Mortada[1,2*], Alexandre Hamadeh[2], Philipp Pirro[1]

[1] Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany.
[2] Université Paris-Saclay, Centre de Nanosciences et de Nanotechnologies, CNRS, 91120, Palaiseau, France.
* hanadi.mortada@rptu.de

Expanding magnonics into the third dimension requires low-damping magnetic materials whose thickness is comparable to or exceeds the spin-wave wavelength. Such volumetric microstructures enable all components of the magnon wave vector to participate in information transport and are essential for realizing functional three-dimensional (3D) magnonic architectures [1]. However, directional coupling in high–aspect-ratio waveguides remains largely unexplored. We present a 3D magnonic directional coupler based on micron-thick yttrium iron garnet (YIG) waveguides with thickness-to-width ratio ≥ 1 (see Fig. 1a). In this regime, quantization along thickness and width becomes comparable, producing a dense spectrum of hybridizing volumetric modes. Unlike 2D systems, which support a single dominant mode pair with long coupling lengths [2], simulations predict multiple coupling branches and strongly enhanced coherent interaction (see Fig. 1b), with coupling lengths approaching the spin-wave wavelength (see Fig. 1c), enabling ultra-compact devices. We fabricate isolated and coupled high–aspect-ratio YIG waveguides using focused ion beam patterning while preserving magnetic quality. Micro-focused Brillouin light scattering resolves multiple thickness modes and demonstrates three-dimensional spin-wave intensity distributions formed by interference of width- and thickness-quantized modes, confirming volumetric confinement and validating this platform for compact, tunable 3D magnonic couplers beyond the planar paradigm.

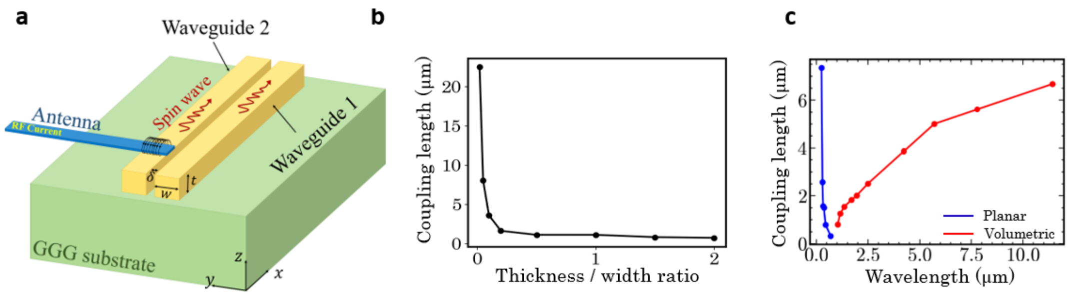


Figure 1. (a) An illustrative depiction of dipolarly coupled SW waveguides with high aspect ratio. (b) The dependence of the coupling length L on the aspect ratio of the waveguides, and (c) the spin-wave wavelength in thick volumetric (red axes) waveguides as compared to those in nanometer scale planar thin waveguides (blue lines).

[1] Popov PA, Sharaevskaya AY, Beginin EN, Sadovnikov AV, Stognij AI, Kalyabin DV, Nikitov SA. Spin wave propagation in three dimensional magnonic crystals and coupled structures. Journal of Magnetism and Magnetic Materials. 2019;476:423-7.
[2] Mortada H, Verba R, Wang Q, Pirro P, Hamadeh AA. Nonreciprocal Spin Waves in Out-of-Plane Magnetized Coupled Waveguides Reconfigured by Domain Wall Displacements. Advanced Electronic Materials. 2025 Dec;11(20):e00575.

Dynamic behaviour of magnetic skyrmions in antidot-based DMI-free multilayer structure

Ganna Kharchenko[1,2*], Sergey Bunyaev[3], Roman Verba[4], Gleb Kakazei[3], Michal Urbanek[1]

[1]CEITEC BUT, Brno University of Technology, Brno, Czech Republic
[2]O.Ya. Usikov Institute for Radiophysics and Electronics NAS of Ukraine, Kharkiv, Ukraine
[3]IFIMUP/Department of Physics and Astronomy, Faculty of Sciences, University of Porto, Porto, Portugal
[4]V.G. Baryakhtar Institute of Magnetism NAS of Ukraine, Kyiv, Ukraine
* kharchenko@vutbr.cz

We present a micromagnetic study of magnetization dynamics and spin-wave excitations in a multilayer nanostructure comprising a hard magnetic layer with perpendicular magnetic anisotropy forming an antidot matrix, a soft ferromagnetic layer, a nonmagnetic spacer, and a spatially separated magnonic waveguide used for dynamic excitation. The micromagnetic simulations are performed using the MuMax3 framework, taking into account materials anisotropy as well as exchange and dipolar and interactions.

The inhomogeneous stray field generated by the antidot matrix of the hard layer produces a strong radial component in the soft layer and enables the stabilization of magnetic skyrmions and vortices in a system without Dzyaloshinskii–Moriya interaction and in the absence of magnetic field. This stabilization mechanism relies solely on dipolar and exchange coupling between the layers and the geometry of the antidot structure [1, 2].

It is demonstrated that GHz-range spin-wave modes of the stabilized skyrmions can be efficiently excited both by the intrinsic precession of the magnetization in the soft layer and by a spatially separated magnonic waveguide. Spectral and modal analysis of the time-dependent magnetization reveals a set of localized dynamical modes with characteristic amplitude and phase distributions corresponding to the internal degrees of freedom of the skyrmion.

These results demonstrate a route toward non-invasive control of skyrmion dynamics in DMI-free materials and open the way to the realization of controllable skyrmion crystals and functional magnon–skyrmion hybrid structures based on dipolarly coupled multilayers with antidot matrices.

G. Kharchenko is thankful to the MSCA4Ukraine for support through the HEUMSCA PF no. 1245611. S. Bunyaev and G. Kakazei acknowledge financial support from FCT – Portuguese Foundation for Science and Technology through the projects LA/P/0095/2020 (LaPMET), UIDB/04968/2025, and from FEDER – European Regional Development Fund through the project 17142|COMPETE2030-FEDER-00854500.

[1] D. Navas, R.V. Verba, A. Hierro-Rodriguez, S.A. Bunyaev, X. Zhou, A.O. Adeyeye. O.V. Dobrovolskiy, B.A. Ivanov, K.Y. Guslienko, and G.N. Kakazei, APL Mater. 7, 081114 (2019).

[2] S.A. Bunyaev, G.O. Kharchenko, R. V. Verba, M. Moalic, M. Krawczyk, M. Urbánek, K.Y. Guslienko, and G.N. Kakazei, Low Temp. Phys. 51, 1017 (2025).

Impact of Spin-Diffusion Mechanisms on Magnetization Switching in 3D Perpendicular Shape-Anisotropy Pillars

Mouad Fattouhi[1], Natalia Boscolo-Meneguolo[1], Ioan-Lucian Prejbeanu[1], Olivier Fruchart[1] and Daria Gusakova[1*]

[1] Université Grenoble Alpes, CEA, CNRS, Grenoble INP, SPINTEC, 38000 Grenoble, France
* daria.gusakova@cea.fr

Current-induced spin-transfer torque enables electrical control of magnetization and forms the basis of modern spintronic memory technologies. While phenomenological models such as Slonczewski's description capture switching in nearly uniform thin layers, they do not fully account for the interplay between spin transport and spatially non-uniform magnetization. A self-consistent coupling between magnetization dynamics and spin diffusion is therefore required to describe realistic devices, particularly three-dimensional perpendicular shape-anisotropy (PSA) pillars. Understanding how spin-diffusion processes influence switching in these structures is essential to accurately model and optimize current-driven magnetic nanodevices.

We first develop an analytical macrospin framework to elucidate the thickness dependence of the spin-transfer torque structure. In ultrathin ferromagnets, the transverse spin accumulation is dominated by S_y, resulting in a predominantly damping-like torque. In contrast, for thick layers, the transverse components S_x and S_y acquire comparable magnitudes, leading to similar damping-like and field-like torque contributions. Fully coupled micromagnetic simulations are then performed to assess the impact of spin transport on switching dynamics. For thin films, both macrospin and micromagnetic approaches predict negligible sensitivity of the switching behavior to the spin-flip diffusion length l_{sf}, since torque-generating transverse spins are absorbed over the much shorter s-d exchange length l_{sd}. However, in thick films, the two models diverge. While macrospin predicts no dependence on l_{sf}, micromagnetic simulations reveal a strong sensitivity of the switching time and magnetization dynamics. This discrepancy arises from the emergence of spatially non-uniform reversal modes in thick layers, which reshape the spin-accumulation profile and modify the effective torque distribution [2]. We further analyze the role of the s-d exchange length l_{sd} and find that increasing l_{sd} systematically increases the switching time in both thin and thick films. A larger l_{sd} reduces the efficiency of transverse spin absorption, leading to weaker torque amplitudes and slower reversal dynamics.

Finally, we compare the fully coupled spin-diffusion framework with micromagnetic simulations employing effective Slonczewski torques characterized by exponentially decaying damping-like and field-like components, a common strategy used to extend interfacial torque models to bulk ferromagnetic systems. This comparison highlights the importance of self-consistent spin transport in capturing the torque contribution to the domain-wall nucleation at the interface of PSA pillars and reveals significant differences in switching times and critical currents between the two approaches.

[1] N. Boscolo-Meneguolo, O. Fruchart, J.-C. Toussaint, M. Fattouhi, L. D. Buda-Prejbeanu, I.-L.Prejbeanu, and D.Gusakova, Physical Review B, **112**, 1 (2025).

[2] S. Zhang and Z. Li, Physical Review Letters, **93**, 127204 (2004).

Magnetisation reversal in FeGa 3D nanostructures

Irdi Murataj[1*], Federica Celegato[1], Gabriele Barrera[1], Marco Coisson[1], Alessandro Magni[1], Adriano Di Pietro[1], Gajanan Pradhan[1], Luca Boarino[1], Natascia De Leo[1], Paola Tiberto[1]

[1] Istituto Nazionale di Ricerca Metrologica, Torino, Italy
* i.murataj@inrim.it

The manipulation of size and shape in nanostructures has been crucial to discover novel functionalities and applications across various scientific domains. In recent years, nanolithographic techniques have been extensively employed in the fabrication of three-dimensional magnetic material [1,2], and the investigation of their magnetization processes with respect to applied magnetic fields or electrical voltages, is crucial for understanding and optimizing their performance [3]. In this work, a bottom-up process is used to design complex 3D magnetic structures, specifically nanowires with nanodots on one edge has been exploited as shown in Fig 1a. The fabrication process relies on the patterning of a silicon substrate by nanosphere self-assembly lithography combined with selective etching by reactive ion etching (RIE) and followed by sputter deposition of a thin film of FeGa. By carefully tuning the parameters of the RIE process, such as gas composition, pressure, and power, the length of the nanowires can be precisely controlled. The selective etching results in the formation of nanodots on one edge of the nanowires, with a typical diameter of around 250 nm. The magnetic properties of the structures have been investigated by high-sensitive magnetometry at room-temperature are shown in Fig 1(b) and Moke measurements. All the samples display the typical loop shape of vortex state configuration and the nucleation field is tuned by different etching times. In addition to room-temperature magnetization curves, First-Order Reversal Curve (FORC) analysis has been employed to disentangle the contributions of the nanodisks and the nanowires to the overall magnetic behaviour. This analysis will support the refinement of the nanostructure designs to achieve desired magnetic functionalities.

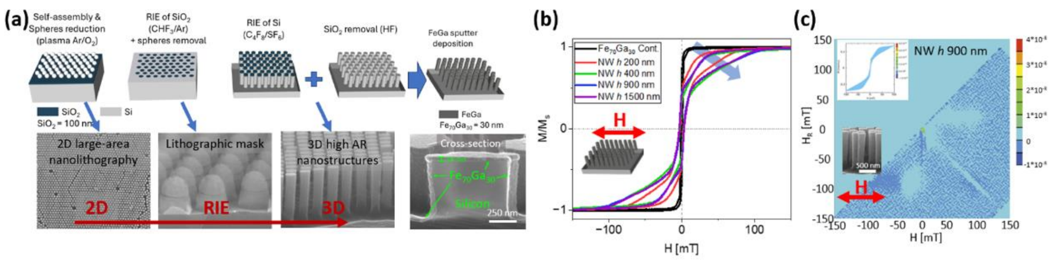


Figure 1. (a) Schematic of the fabrication process of nanowires covered with $Fe_{70}Ga_{30}$ by self-assembly of polystyrene nanosphere and relative SEM micrographs; (b) Room-temperature hysteresis loops as a function of etching time and (c) First-order reversal-curve (FORC).

[1] O. Bezsmertna, Nano Lett. **24** (49), 15774–15780 (2024).

[2] S. A. Sam et al. Nanotechnology **35**, 225701 (2024).

[3] A. Fernández-Pacheco et al. Nature Communications **8**, 15756 (2017).

AUTHOR INDEX

SOCIAL PROGRAMME HIGHLIGHTS

- Monday 13 July, 13:00: conference inauguration with TU Wien Orchestra string quartet.
- Monday 13 and Tuesday 14 July, 17:10-18:00: optional visits to the host laboratories at TU Wien.
- Wednesday 15 July, 17:00-17:20: conference photo at Karlsplatz.
- Thursday 16 July, 17:00-18:30. Guided tour of Vienna aboard a historic tram. The tour concludes near the dinner venue.
- Thursday 16 July, 18:30: conference dinner at Feuerwehr Wagner Heuriger.

Social programme page: https://www.tuwien.at/en/phy/iap/conferences/3dmag-2026/social-events

Conference Dinner Venue

Weingut Feuerwehr-Wagner

Thursday 16 July, 18:30

Address: Grinzinger Strasse 53, 1190 Wien
Phone: +43-1-320 2442
https://www.feuerwehrwagner.at/

The dinner venue is located in Grinzing. For participants joining the tram tour, the venue is approximately a 10-minute walk from the final tram stop. Participants who are not joining the tram tour but plan to attend the dinner can reach the venue by several public transport options, which are outlined on the following pages.

For those not joining the tram tour, the venue can be reached easily by public transport. In that case, the venue is a short walk from the Neugebauerweg bus stop.

Important travel note
Due to renovation works, the U4 does not operate between Schwedenplatz and Landstrasse-Wien Mitte. Please do not take the U4 directly at Karlsplatz.

Option 1 **U1, U4 and bus 38A via Schwedenplatz and Heiligenstadt** about 51 minutes
Best public-transport option from TU Wien Freihaus.

1. Leave Freihaus through the main entrance and turn left to Karlsplatz station.
2. Take U1 direction Leopoldau to Schwedenplatz, 3 stops.
3. Change to U4 direction Heiligenstadt and travel to Heiligenstadt, 5 stops.
4. Walk about 2 minutes to the Heiligenstadt bus stop.
5. Take bus 38A direction Kahlenberg to Neugebauerweg, 6 stops.
6. Walk 1-2 minutes along Grinzinger Strasse; the venue is on the right.

Option 2 **U2 and tram 37 via Schottentor and Hohe Warte** about 46 minutes
Alternative route using U2 and tram 37.

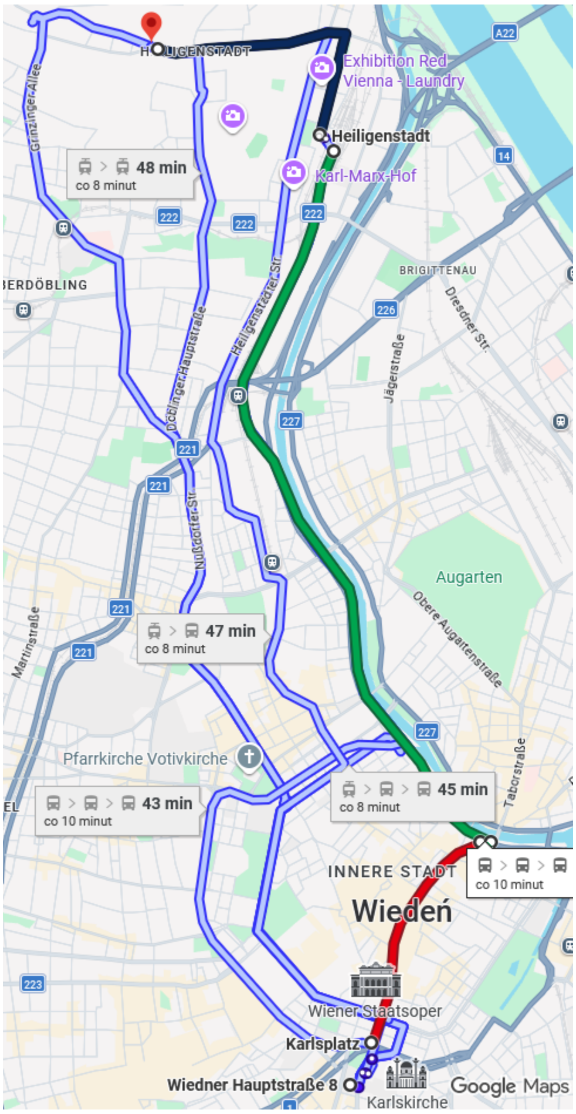
1. Leave Freihaus through the main entrance and turn left to Karlsplatz station.
2. Take U2 to Schottentor U, 4 stops.
3. Change to tram 37 direction Hohe Warte and travel to Hohe Warte, 12 stops.
4. Walk along Wollergasse, turn right into Hohe Warte, then left into Grinzinger Strasse.
5. Continue along Grinzinger Strasse until the venue appears on the right.

Option 3 **Tram D and bus 38A via Grinzinger Strasse** about 46 minutes
Surface route via tram D and bus 38A.

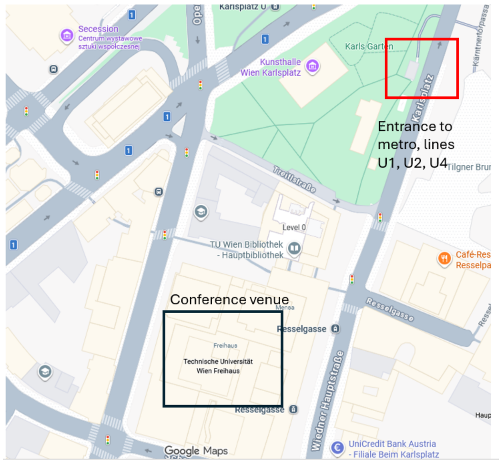
1. Walk to the tram stop Oper, Karlsplatz U.
2. Take tram D direction Nussdorf, Beethovengang to Grinzinger Strasse, 19 stops.
3. Change to bus 38A direction Kahlenberg and travel to Neugebauerweg, 3 stops.
4. Walk 1-2 minutes along Grinzinger Strasse; the venue is on the right.

Route Maps: Option 1

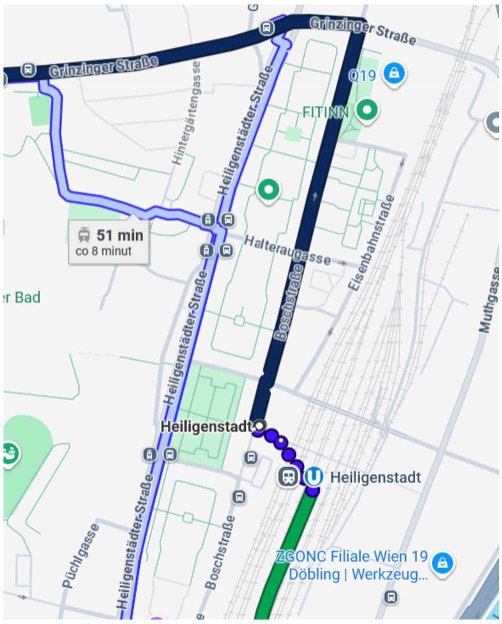
U1, U4 and bus 38A via Schwedenplatz and Heiligenstadt about 51 minutes



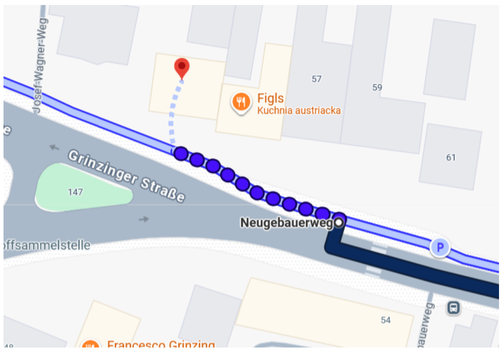
Overview from TU Wien Freihaus to the dinner venue.



Close-up for Karlsplatz access and the Heiligenstadt transfer.



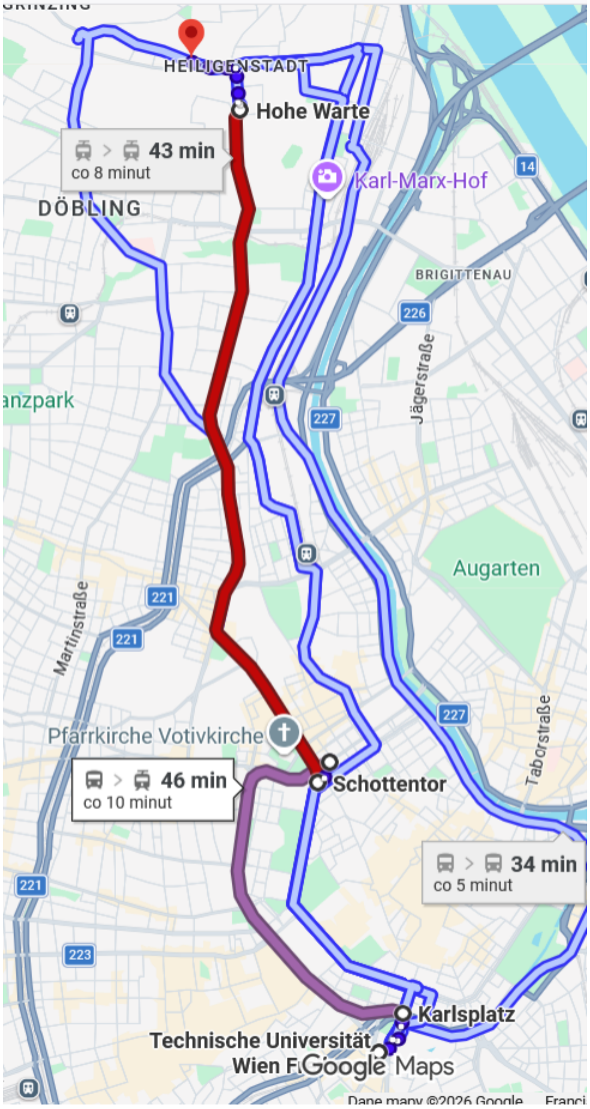
Heiligenstadt bus stop area and the connection to bus 38A.



Final walk from Neugebauerweg to Feuerwehr-Wagner.

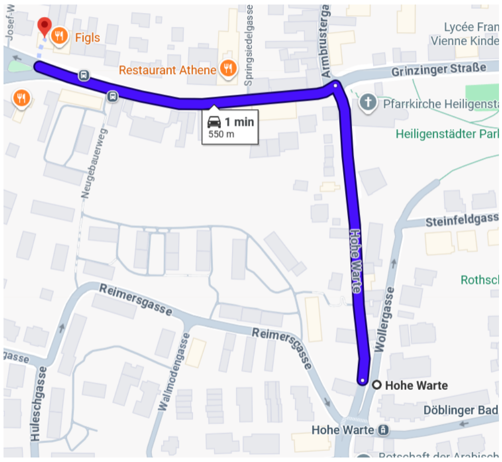
Route Maps: Option 2

U2 and tram 37 via Schottentor and Hohe Warte about 46 minutes



Overview via U2, Schottentor, tram 37 and Hohe Warte.

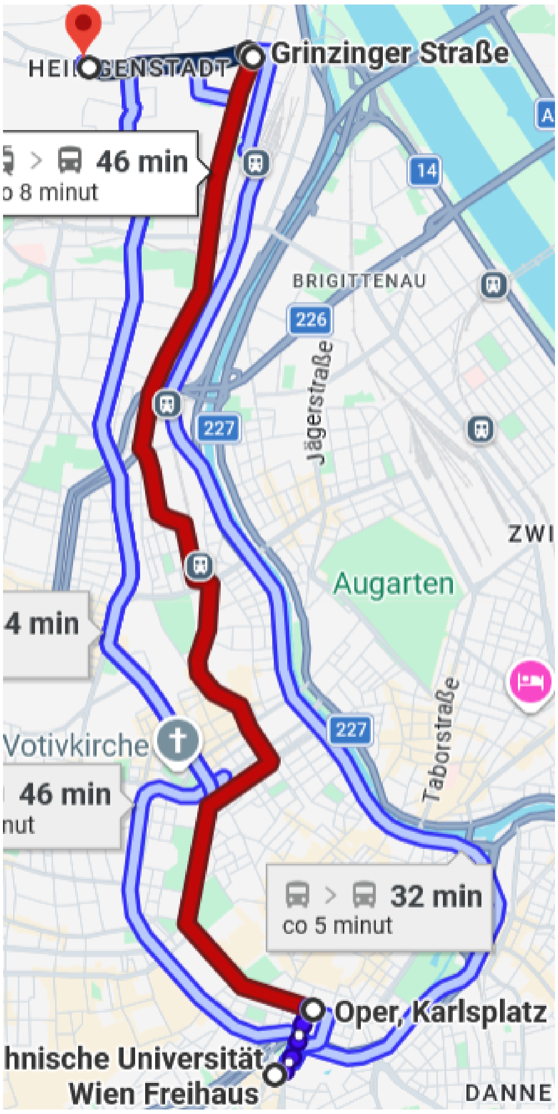
Transfer at Schottentor from U2 to tram 37.



Walk from Hohe Warte to Feuerwehr-Wagner.

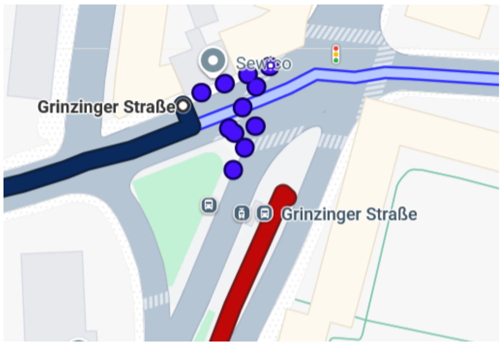
Route Maps: Option 3

Tram D and bus 38A via Grinzinger Strasse about 46 minutes

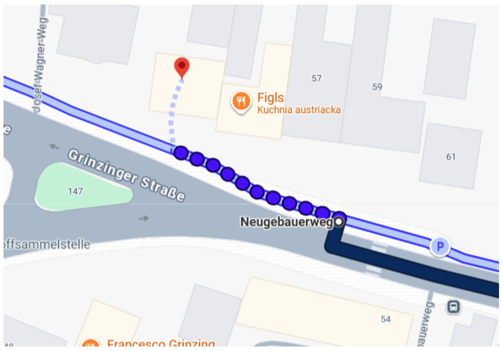


Overview via Oper, Karlsplatz U, tram D and bus 38A.

Walk from TU Wien Freihaus to Oper, Karlsplatz U.



Transfer from tram D to bus 38A at Grinzinger Strasse.



Final walk from Neugebauerweg to Feuerwehr-Wagner.