MA 38: Ultrafast Magnetization Effects II

Time: Wednesday 15:00–18:45 Location: POT/0361

MA 38.1 Wed 15:00 POT/0361

Ultrafast light-induced spin and orbital moment in nonmagnetic band insulators from RT-TDDFT — •Andri Darmawan, Markus E. Gruner, and Rossitza Pentcheva — Department of Physics, University of Duisburg-Essen

Recently dynamical multiferroicity was predicted in $SrTiO_3$ as well as $KTaO_3$ [1-2] and subsequently observed experimentally in $SrTiO_3$ [3], employing THz circularly polarized pulse. This is particularly intriguing as $SrTiO_3$ and $KTaO_3$ are nonmagnetic band insulators with d^0 occupation at Ti and Ta. Here, using real-time time-dependent density functional theory (RT-TDDFT) as implemented in the Elk code we employ optical circularly polarized laser pulses to investigate laser-induced spin and orbital moment in $SrTiO_3$ and $KTaO_3$. We study systematically the dependence on the laser parameters and find that duration and frequency of the pulse strongly influence the behavior of the light-induced spin and orbital magnetic moment in both $SrTiO_3$ and $KTaO_3$. While in $SrTiO_3$ the induced orbital momentum predominates, at certain frequencies $KTaO_3$ exhibits both substantial light-induced spin moment and orbital moment.

Funding by DFG within CRC1242 (project C02) and computational time at magnitUDE, amplitUDE are gratefully acknowledged.

[1] D. Juraschek et al., Phys. Rev. Mater. **1**, 014401 (2017)
[2] R. M. Geilhufe et al., Phys. Rev. Research **3**, L022011 (2021)
[3] M. Basini et al., Nature **628**, 534 (2024)

MA 38.2 Wed 15:15 POT/0361

Interfacial magnon generation drives ultrafast spin dynamics in Gd — •Corvin Krohn[1], Ekaterina Bobrova[1], Tim Amrhein[1], Dominic Lawrenz[1], Niko Pontius[2], Christian Schüssler-Langeheine[2], Martin Weinelt[1], and Nele Thielemann-Kühn[1,2] — [1]Freie Universität Berlin, Berlin, Germany — [2]Helmholtz-Zentrum Berlin, Berlin, Germany

Previous time-resolved photoemission [1] and x-ray magnetic circular dichroism (XMCD) [2] experiments investigating 4*f* magnetization dynamics in Gadolinium (Gd) showed conflicting results, with demagnetization timescales of 14 ps [1] and 0.7 ps [2], respectively.

Within an XMCD study at the FemtoSlicing facility, we could now show that intrinsic dynamics in Gd is slow. For a thin Gd film, however, where the pump laser directly excites the non-magnetic substrate as well, generation of magnons at the metal-substrate interface drives the ultrafast demagnetization.

In the next step we aim to identify magnons as m_s state excitations within the Gd 4*f* electronic ground level, using time-resolved x-ray absorption spectroscopy.

Revealing signatures of magnetic dynamics in the electronic structure will provide insights into the correlated electronic and magnetic structure of 4*f* metals.

[1] B. Frietsch *et al.*, Nat. Commun. **6**, 8262 (2015).
[2] K. Bobowski *et al.*, J. Phys.: Condens. Matter **29**, 234003 (2017).

MA 38.3 Wed 15:30 POT/0361

Probing ultrafast dynamics of artificial antiferromagnets by soft-x-ray diffraction — •Jasmin Jarecki[1], Martin Borchert[1], Stefan Eisebitt[1,2], and Daniel Schick[1] — [1]Max-Born-Institut für Nichtlineare Optik & Kurzzeitspektroskopie, Berlin, Germany — [2]Institut für Optik & Atomare Physik, TU Berlin, Germany

Ordering phenomena in solids encode key information about microscopic interactions and subsystem coupling. In magnetic materials, magnetic and structural order can be strongly coupled, yet the corresponding periodicities may exhibit different characteristic lengths. This calls for methods capable of simultaneously probing lattice and spin degrees of freedom to disentangle phonon and spin dynamics.

Using on- and off-resonant ultrafast x-ray diffraction (UXRD) in the soft-x-ray regime, we investigate the coupled structural and magnetic dynamics of a Fe/Cr superlattice (SL), an artificial antiferromagnet in which adjacent Fe layers adopt alternating magnetization directions for the chosen Cr spacer thickness. By tracking the structural and magnetic SL Bragg peaks, we study photon-energy- and fluence-dependent dynamics via their transient peak positions and intensities. While the structural peak shift and the magnetic peak intensity follow the expected behavior, the magnetic peak shift deviates markedly from the structural response and, in particular, does not exhibit the anticipated linear fluence dependence. These findings highlight the strong intercoupling between depth-dependent sample dynamics and depth-dependent probing, underscoring the need for careful analysis and modeling to reliably extract microscopic dynamics from UXRD.

MA 38.4 Wed 15:45 POT/0361

Double-pulse all-optical magnetization re-switching of GdFe — Rahil Hosseinifar[1], Felix Steinbach[2], Ivar Kumberg[1], José Miguel Lendínez[3], Sangeeta Thakur[1], Sebastien E. Hadjadj[1], Jendrik Gördes[1], Chowdhury S. Awsaf[1], Mario Fix[4], Manfred Albrecht[4], Florian Kronast[5], Unai Atxitia[3], Clemens von Korff Schmising[2], and •Wolfgang Kuch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Max-Born-Institut, Berlin, Germany — [3]ICMM-CSIC, Madrid, Spain — [4]Universität Augsburg, Augsburg, Germany — [5]Helmholtz-Zentrum Berlin, Berlin, Germany

The reversible helicity-independent switching of the magnetization direction of ferrimagnetic materials like GdFe by individual sub-ps optical laser pulses bears the potential to accelerate magnetic data storage. We present a systematic Kerr-microscopy domain-imaging study of a 10 nm $Gd_{26}Fe_{74}$ film after excitation with two laser pulses with a certain time delay in between. Our results show that when the fluence of the first pulse is adjusted just above the threshold of single-pulse switching, a second pulse with about 60% of the fluence of the first pulse, arriving only 4 ps later, can already switch the magnetization back [1]. Atomistic spin dynamics simulations reproduce the experimental results and show that under these conditions the magnetizations of the Fe and Gd sublattices have already moved sufficiently away from zero when the second pulse hits the sample, a prerequisite for fast re-switching.

[1] R. Hosseinifar *et al.*, Phys. Rev. B **112**, 174406 (2025).

MA 38.5 Wed 16:00 POT/0361

Light-induced ultrafast magnetization dynamics driven by chiral phonons — •Shiqi Hu and Sangeeta Sharma — Max-Born Institute for Nonlinear Optics and Short Pulse Spectroscopy,Berlin,Germany

The pursuit of high-speed, low-power information processing is driving advanced research into ultrafast laser control of magnetic order. Going beyond conventional approaches that rely on heterojunctions for spin-current injection, this work demonstrates direct manipulation of magnetism in bulk materials through intrinsic interactions. Using circularly polarized laser excitation, we generate THz chiral phonons in the non-collinear antiferromagnet Mn3Sn with a Kagome lattice. The angular momentum of these phonons produces an effective magnetic field, inducing coupled in-plane and out-of-plane spin precession that reorients the magnetic octupole. This reorientation, in turn, modulates the topological properties of Weyl points. Spin*orbit coupling and the rotational motion of chiral phonons are shown to be essential to this mechanism. We attribute the observed spin dynamics to a competition between the phonon-induced effective field*favoring ferromagnetic alignment*and the intrinsic antiferromagnetic spin interactions in the Kagome lattice. These findings open a new pathway for controlling magnetic topology.

MA 38.6 Wed 16:15 POT/0361

Exploring the ultrafast change of antiferromagnetic and ferromagnetic order in a Mn_2Au/Py bilayer — •Jendrik Gördes[1], Markus Weissenhofer[1,2], Sangeeta Thakur[1], Chowdhury S. Awsaf[1], Marcel Walter[1], Lorenzo Grilli[1], Deeksha Gupta[3], Niko Pontius[3], Christian Schüssler-Langeheine[3], Peter M. Oppeneer[2], Martin Jourdan[4], and Wolfgang Kuch[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Uppsala University, Uppsala, Sweden — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [4]Johannes Gutenberg-Universität Mainz, Mainz, Germany

Antiferromagnetic (AFM) materials are promising candidates for future data storage devices. One noteworthy material is Mn_2Au, a metallic collinear AFM that can be electrically switched [1]. We report on the time-resolved change of AFM and ferromagnetic (FM) order of a Mn_2Au/permalloy (Py) bilayer after excitation with 800 nm fs laser pulses by X-ray magnetic linear and circular dichroism (XMLD and XMCD) in resonant soft X-ray reflectivity at the Mn and Fe L_3 edges.

We observe an ultrafast loss and an exceptionally fast recovery of the AFM order within a few ps, much faster than the recovery of the adjacent FM order. Local and non-local mechanisms are considered in simulations using an atomistic spin model. The presented research highlights the fast dynamics of AFM layers for spintronic applications.
[1] J. Železný, H. Gao, K. Výborný et al., PRL 113, 157201 (2014)

MA 38.7 Wed 16:30 POT/0361

Intrinsic timescales of ferro- and antiferromagnets in ultrafast demagnetisation — •Tobias Dannegger[1], Stephan Wust[2], Paul Herrgen[2], Martin Aeschlimann[2], Benjamin Stadtmüller[3], and Ulrich Nowak[1] — [1]Fachbereich Physik, Universität Konstanz, Konstanz, Germany — [2]Department of Physics and Research Center OPTIMAS, RPTU University Kaiserslautern-Landau, Kaiserslautern, Germany — [3]Experimentalphysik II, Institute of Physics, University of Augsburg, Germany

For small deviations from the ground state, the spin dynamics of a magnetically ordered material can be described within linear spin-wave theory. There is a well known difference between the intrinsic timescales, given by the eigenfrequencies, of ferro- and antiferromagnets, the latter being approximately two orders of magnitude faster. Here, we present a systematic investigation, based on atomistic spin dynamics simulations, of how ferro- and antiferromagnetic ordering affects the intrinsic timescales of the magnetic order parameter far away from equilibrium, such as in ultrafast light-induced quenching experiments. We find that the speed advantage of antiferromagnets persists in the strongly non-equilibrium regime, but with some striking qualitative differences for very large excitations, where antiferromagnets slow down while the ferromagnetic quenching efficiency increases again.

15 min break

MA 38.8 Wed 17:00 POT/0361

Field-tuning of ultrafast magnetization fluctuations in $Sm_{0.7}Er_{0.3}FeO_3$ — •Julius Schlegel[1], Marvin Alexander Weiss[1], Daniel Anić[1], Emil Steiner[1], Franz Stefan Herbst[1], Makoto Nakajima[2], Takayuki Kurihara[3], Alfred Leitenstorfer[1], Sebastian T.B. Goennenwein[1], and Ulrich Nowak[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Institute of Laser Engineering, Osaka University, Japan — [3]Department of Basic Science, The University of Tokyo, Japan

The missing stray field and the vanishing net magnetization make it challenging to investigate antiferromagnetic dynamics experimentally. Nevertheless, thermal magnetization fluctuations persist in antiferromagnets and can be exploited to gain insights into their dynamics [1].

In this work, we investigate these fluctuations in the canted antiferromagnet $Sm_{0.7}Er_{0.3}FeO_3$ under the influence of an external magnetic field [2]. Using femtosecond noise-correlation spectroscopy combined with atomistic spin-dynamics simulations, we examine the spin noise in the vicinity of the magnetic reorientation transition.

We demonstrate that the external magnetic field suppresses characteristic features of critical fluctuations, such as a diverging noise amplitude. Moreover, it enhances the quasi-ferromagnetic magnon frequency near the reorientation transition. Our results offer a means to tune ultrafast spin fluctuations via experimentally accessible external parameters.

[1] M. A. Weiss et al., Nat. Commun. 14, 7651 (2023).
[2] M. A. Weiss et al., arXiv:2509.26084 (2025)

MA 38.9 Wed 17:15 POT/0361

Large strain contribution to the laser-driven magnetization response of magnetostrictive $TbFe_2$ — •Constantin Walz[1], Fried-C. Weber[1,2], Steffen-P. Zeuschner[1], Karine Dumesnil[3], Alexander von Reppert[1], and Matias Bargheer[1,2] — [1]Institut für Physik und Astronomie, Universität Potsdam, Potsdam, Germany — [2]Helmholtz-Zentrum Berlin, Berlin, Germany — [3]Institut Jean Lamour, Université de Lorraine, Nancy, France

Rare Earth-Iron compounds ($REFe_2$ with $RE = \mathrm{Tb}, \mathrm{Dy}, \mathrm{Tb}_{0.3}\mathrm{Dy}_{0.7}$) are well known for their giant (inverse) magnetostriction, exhibiting lattice-constant changes exceeding 10^{-3} at saturation. While they are widely used as ultrasonic transducers in the MHz regime, their ultrafast magnetization dynamics remain less explored.

We investigate the strain-driven magnetization dynamics in $TbFe_2$ using time-resolved magneto-optical Kerr effect (trMOKE) and optical reflectivity measurements. The delayed strain response in the trMOKE signal indicates a true magnetic origin of these features, ruling out instantaneous changes of the optical constants. In addition, we show that glass-capped sample structures efficiently transduce unipolar strain pulses, which we use to calibrate the contribution of quasi-static-strain-induced magnetization dynamics to the total signal. Modeling with a Landau-Lifshitz-Gilbert equation including a time-dependent magneto-elastic field reproduces the observations and demonstrates that strain can even provide the dominant contribution to the laser-driven magnetization dynamics.

MA 38.10 Wed 17:30 POT/0361

All-optical stochastic switching of magnetisation textures in Fe3Sn2 — •Andras Kovacs[1], Jonathan Weber[2], Michalis Charilaou[3], Rafal Dunin-Borkowski[1], and Sascha Schaefer[2] — [1]Ernst Ruska-Centre, Forschungszentrum Jülich, Germany — [2]Regensburg Center for Ultrafast Nanoscopy, University of Regensburg, Regensburg, Germany — [3]Department of Physics, University of Louisiana at Lafayette, USA

We utilize femtosecond optical pulses to alter the helicity of the magnetic spin configuration in dipolar skyrmions formed in the kagome magnet Fe3Sn2 in the absence of an external magnetic field and at room temperature. In situ Lorentz transmission electron microscopy is used to visualise the light-induced stochastic switching process of chiral Néel caps, while the internal Bloch component of the dipolar skyrmions remains unchanged. To corroborate the spin states and the light-induced magnetisation dynamics, micromagnetic modelling and simulations of the resulting electron phase shift maps are conducted to elucidate the spin rearrangement induced by individual femtosecond optical pulses [1]. We acknowledge the scientific support to D. Kong, L. Prodan, V. Tsurkan, A. Schroder, N. Kiselev, I Kezsmarki, A. Tavabi and the financial support to EU grant No. 856538. [1] A. Kovacs etal, Comm. Mater. 6, 223 (2025)

MA 38.11 Wed 17:45 POT/0361

Nonlinear spin and orbital Rashba–Edelstein effects induced by a femtosecond laser pulse: Simulations for Au(001) — Oliver Busch, •Franziska Ziolkowski, Börge Göbel, Ingrid Mertig, and Jürgen Henk — Martin-Luther-Universität Halle-Wittenberg, 06099 Halle, Germany

Rashba-type spin-orbit coupling gives rise to distinctive surface and interface phenomena, such as spin-momentum locking and spin splitting. In nonequilibrium conditions, it manifests e.g., as the Rashba–Edelstein effect, where an electric current generates a net spin or orbital polarization perpendicular to the current direction. While the steady-state behavior of these effects is well studied, their dynamics on ultrafast timescales remain largely unexplored.

We theoretically investigate the ultrafast spin and orbital Edelstein effects on an Au(001) surface, induced by femtosecond laser excitation [1]. These effects are intrinsic and inherently nonlinear. We simulate the ultrafast electron dynamics in response to the laser pulse by using a real-space tight-binding model combined with unitary time evolution of the density matrix.

Our results reveal pronounced differences between the spin and orbital responses and quantify the resulting charge, spin, and orbital currents, including laser-induced spin and orbital Hall effects. These findings provide insights into ultrafast angular momentum transfer mediated by the light-matter interaction and offer guidance for the design of next-generation spintronic and orbitronic devices.

[1] Busch *et al* PRR **7**, 043023 (2025)

MA 38.12 Wed 18:00 POT/0361

Impact of Structural Imperfections on the Ultrafast Orbital Hall Effect in Metallic Nanoribbons — •Theresa Albrecht, Franziska Ziolkowski, Börge Göbel, Ingrid Mertig, Jürgen Henk, and Samir Lounis — Institut für Physik, Martin-Luther-Universität, D-06099 Halle

The ultrafast orbital Hall effect (UOHE) arises when a femtosecond laser pulse drives a transient orbital current. We investigate how structural defects affect the UOHE in a Cu nanoribbon [1]. Using Evolve, a real-space tight-binding framework for finite systems [2], we simulate the laser-induced electron dynamics and compute the orbital angular momentum (OAM) and its associated currents with atomic resolution. Defects significantly alter the OAM landscape: while defect-free ribbons exhibit pronounced edge accumulation, imperfections redistribute OAM toward defect sites and progressively suppress edge signatures as their number increases. Furthermore, we analyze the phase relation between the p- and d-orbital contributions to the OAM in interface geometries. Our results reveal the pivotal influence of defects on ultrafast

orbital transport and dynamics.

[1] O. Busch *et al.*, Physical Review Research **6**, 013208 (2024)
[2] F. Töpler *et al.*, New Journal of Physics **23**, 033042 (2021)

MA 38.13 Wed 18:15 POT/0361

Pump-induced out-of-equilibrium magnetism in the Mott insulator CuO — •Katja Sophia Moos[1,2], Yun Yen[2], Gian Parusa[1,2], Arnau C. Romaguera[3], Elia Razzoli[3], Hiroki Ueda[3], and Michael Schüler[1,2] — [1]Department of Physics, University of Fribourg, 1700 Fribourg, Switzerland — [2]Center for Scientific Computing, Theory and Data, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland — [3]Center for Photon Science, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

Understanding ultrafast magnetism requires tracking energy flow among coupled electronic, spin, and lattice subsystems. Using time-resolved resonant diffuse scattering combined with complementary X-ray techniques and quantum-kinetic simulations, we reveal microscopic pathways of pump-induced demagnetization in the antiferromagnetic Mott insulator CuO. Above-bandgap photoexcitation creates non-thermal magnons across the Brillouin zone within tens of femtoseconds, followed by magnon-magnon scattering driving quasi-thermalization within picoseconds. Magnetic recovery occurs via magnon-phonon coupling on nanoseconds, constrained by dispersion mismatches imposing intrinsic bottlenecks. Our momentum-resolved quantum Boltzmann simulations establish a hierarchical energy-transfer framework beyond phenomenological multi-temperature models, reproducing key features of the experiments. This approach provides design principles for controlling non-equilibrium magnetic states and highlights time-resolved resonant diffuse scattering as a power tool for ultrafast quantum materials research.

MA 38.14 Wed 18:30 POT/0361

Ultrafast spin and pure spin currents — •Deepika Gill, Sam Shallcross, and Sangeeta Sharma — Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max-Born-Strasse 2A, 12489, Berlin, Germany

Pure spin currents, the flow of spin in the absence of charge flow, represent a promising route toward energy efficient next-generation electronics [1]. Creating such currents often involves designed nanostructures, which can be challenging to create in experiment. Here, relying only on intrinsic material properties, we shift the design to the light pulse via two schemes: (1) via anti-symmetric laser pulses [2] and (2) via composite light pulses that generate pure spin current by tailoring spin density occupation in momentum space [3]. We provide realistic material examples including WSe2 and calculate the ultra-fast spin current response both via state-of-the-art time density function theory as well as Wannier parameterized tight-binding calculations.

[1] S Sharma et al. Nature Communications 15 (1), 7579 (2024)
[2] D Gill et al. Nanoletters 25 (25), 9913-9917 (2025)
[3] D Gill et al. npj 2D Materials and Applications 9 (1), 49 (2025)