MA 46: Ultrafast Magnetization Effects II

Time: Friday 9:30–12:45 Location: HSZ 02

MA 46.1 Fri 9:30 HSZ 02

Spin noise in magnetically ordered models — •Julius Schlegel, Martin Evers, and Ulrich Nowak — Department of Physics, University of Konstanz

Spin noise spectroscopy has emerged in the last years as a new tool to investigate magnetic material properties [1].

On the basis of a classical Heisenberg model and the stochastic Landau-Lifshitz-Gilbert equation of motion we numerically compute the time evolution of magnetically ordered structures on a time scale of several hundreds of picoseconds. By analyzing the spectral noise power density and the autocovariance of the magnetization in both ferro- and antiferromagnetic models, we find that the magnetic noise in thermal equilibrium comprises several features of the system. Resonances in the noise spectra are observed, which can be assigned to the eigenmodes of the magnetic structure. Moreover, the noise can mark phase transitions like the transition to the paramagnetic state or a spin-flop transition.

We thus conclude that by means of investigating the noise of the magnetization, the magnetic order of a system can be extracted even in cases where the mean equilibrium magnetization does not reflect the transition at all.

[1] Valerii S. Zapasskii, "Spin-noise spectroscopy: from proof of principle to applications", Adv. Opt. Photon. 5, 131-168 (2013)

MA 46.2 Fri 9:45 HSZ 02

Spin and momentum resolved ultrafast carrier dynamics in antiferromagnetic Dirac semimetal models — •Marius Weber[1], Kai Leckron[1], Baerbel Rethfeld[1], Libor Šmejkal[2], Jairo Sinova[2], and Hans Christian Schneider[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, Germany

Systems with antiferromagnetic ordering in real space often exhibit topological features in momentum space that only recently have been investigated in a comprehensive fashion [1]. For instance, depending on the magnetic ordering, they may have band structures with a pronounced anisotropy in band energies and in the spin structure of their single-particle states due to Dirac fermions. We present numerical calculations of the electron dynamics due to electron-phonon interactions [2,3] in model systems with two-dimensional k-space that capture key properties of antiferromagnetic Dirac materials in momentum space. After an instantaneous heating of the electronic system we obtain a transient carrier distributions, which reflect the momentum-space features. Surprisingly, completely anisotropic carrier distribution may evolve, even from excited carrier distributions that are isotropic in energy, i.e., f(E(k)) = f(E).

[1] L. Šmejkal et al.; Phys. Rev. Let 118, 106402 (2017).
[2] K. Leckron et al.; Phys. Rev. B 96, 140408 (2017).
[3] S. Essert et al., Phys. Rev. B 84, 224405 (2011).

MA 46.3 Fri 10:00 HSZ 02

Inertial spin dynamics in ferromagnets and antiferromagnets — Ritwik Mondal[1], Lucas Winter[2], Sebastian Grossenbach[2], Ulrich Nowak[2], and •Levente Rózsa[2,3] — [1]Indian Institute of Technology (ISM) Dhanbad, Dhanbad, India — [2]University of Konstanz, Konstanz, Germany — [3]Wigner Research Centre for Physics, Budapest, Hungary

Inertial spin dynamics emerges in magnetic materials at very short time scales where the directions of the atomic magnetic moment and angular momentum become separated, and nutation can be observed. The inertia gives rise to additional high-frequency or nutational excitations recently detected in ferromagnetic resonance experiments [1].

Here the signatures of inertial spin dynamics are discussed theoretically in ferromagnets (FMs) and antiferromagnets (AFMs). The nutational spin-wave bands are shifted by a constant frequency compared to the low-frequency bands in FMs, while in AFMs the nutational bands have a maximum in the center of the Brillouin zone [2]. It is demonstrated that a resonant excitation of the nutation may be utilised for switching the order parameter [3]. The switching is found to proceed faster in AFMs than in FMs, and in AFMs tuning the excitation frequency can be used to control the direction of the switching.

[1] K. Neeraj et al., Nat. Phys. 17, 245 (2021).
[2] R. Mondal et al., Phys. Rev. B 106, 134422 (2022).
[3] L. Winter et al., arXiv:2207.08566.

MA 46.4 Fri 10:15 HSZ 02

Magnetic field-dependent ultrafast control of an antiferromagnet — •Abeer Arora[1,6], Yoav Will Windsor[2], Sang-Eun Lee[1], Jit Sarkar[1], Kristin kliemt[3], Ch. Schüssler-Langeheine[4], Niko Pontius[4], Cornelius Krellner[3], Denis V. Vyalikh[5], and Laurenz Rettig[1] — [1]FHI der MPG, Berlin — [2]IOAP, TU Berlin — [3]Phy. Inst., Goethe-Uni., Frankfurt am Main — [4]HZB für Materialien und Energie GmbH, Berlin — [5]DIPC, Basque, Spain — [6]Fachbereich Physik, FU Berlin

Antiferromagnetic (AF) materials offer faster manipulation of spins, while making control of magnetic order challenging. A promising approach is utilizing the magnetic anisotropy (MA) to manipulate the spin arrangement on femtosecond timescales [1]. In addition, external magnetic fields can induce a spin flop (SF), providing an additional control knob for AF order. Understanding the interplay of these effects is of strong interest. Here, we present time-resolved resonant soft X-ray diffraction (RSXRD) experiments on the prototypical A-type antiferromagnet $GdRh_2Si_2$. We observe a coherent rotation of the AF arrangement followed by oscillations of the AF order due to light-induced change in the MA potential. Remarkably, upon increasing magnetic field, the frequency of the oscillations increases while the amplitude of reorientation upon photoexcitation decreases. These observations demonstrate the interplay of the MA potential and the SF field, and offer new ways towards deterministic control of AF spin order. [1]Windsor et al. Commun Phys 3, 139 (2020)

MA 46.5 Fri 10:30 HSZ 02

Dynamics of the Morin transition in hematite — •Maik Kerstingskötter[1], Tobias Dannegger[1], András Deák[2], László Szunyogh[2,3], and Ulrich Nowak[1] — [1]Department of Physics, University of Konstanz — [2]Department of Theoretical Physics, Budapest University of Technology and Economics — [3]ELKH-BME Condensed Matter Research Group, Budapest University of Technology and Economics

Below a critical temperature T_M of about 264 K, hematite is a perfect antiferromagnet with zero net magnetization due to the fact that the spins of the four sublattices are antiparallel and aligned with the c-axis. If the temperature exceeds this critical point, the spins reorient into the basal plane and assume a small canting angle that results in a finite net magnetization. This first-order phase transition from the antiferromagnet to the weak ferromagnetic phase is the Morin transition. While the equilibrium properties are well known, we want to investigate the nonequilibrium dynamics of the transition. Here we use atomistic spin dynamics simulations on the basis of an ab initio model to study the system's response to an instantaneous temperature increase from $T < T_M$ to $T > T_M$. In the model used, we indeed observe this Morin transition, which takes place in the range of five to a few hundred picoseconds, depending on the size of the Gilbert damping used.

MA 46.6 Fri 10:45 HSZ 02

Non-collinear spin reorientation in FeRh from first principles: Ultrafast laser quenching vs. coherent rotation of Fe moments — •Mike Jos Bruckhoff, Markus Ernst Gruner, and Rossitza Pentcheva — Faculty of Physics and Center for Nanointegration (CENIDE), University of Duisburg - Essen

The binary alloy FeRh exhibits a metamagnetic first-order phase transition from antiferromagnetic (AFM) to ferromagnetic (FM) order, which can be driven by an external magnetic field or laser excitation. Here, we present a comprehensive non-collinear density functional theory study, where we investigate the multidimensional energy landscape $E(M, V)$, by constraining the total spin moment in order to compare different kinds of spin reorientation pathways. The absence of significant energy barriers suggests that the coherent in-plane rotation of the Fe moments is a likely scenario for the magnetic phase transition in an external magnetic field. In contrast to this, FeRh exhibits an laser-induced ultrafast demagnetization, which is initiated by optical inter-site spin transfer (OISTR) and a net Rh-to-Fe charge transfer at early times after excitation. We study extensively the response of FeRh to laser pulses with different laser parameters in both magnetic phases, simulated by means of real-time time-dependent DFT (RT-TDDFT). We find that the magnitude of the response strongly depends on the incident laser pulse, as well as the magnetic state of FeRh. We conclude that laser excitations and applied magnetic fields initiate distinct transition pathways, which may be exploited to control the phase transition by the external stimuli.

MA 46.7 Fri 11:00 HSZ 02

Signature of spatial gradients in ultrafast demagnetization observed with angle-resolved complex magneto-optical Kerr-effect (CMOKE) — •Sanjay Ashok[1], Jonas Hoefer[1], Martin Stiehl[1], Martin Aeschlimann[1], Hans Christian Schneider[1], Bärbel Rethfeld[1], and Benjamin Stadtmüller[1,2] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]Institute of Physics, Johannes Gutenberg-University Mainz, Germany

Understanding the laser-induced ultrafast magnetization dynamics of thick metallic films is even in simple materials still challenging due to different transport mechanisms contributing to the magnetization dynamics. While heat- and particle diffusion are slow processes, ballistic and superdiffusive transport lead to an ultrafast equilibration of spatial inhomogeneities. However, quantifying experimentally their impact on ultrafast demagnetization of bulk material is difficult, since surface-sensitive experimental techniques integrate the response of the material over a certain depth.

Our theoretical calculations reveal that the Kerr-rotation dynamics is nearly insensitive to gradients in magnetization. In contrast, we find a strong influence for the angle-resolved ellipticity dynamics. These findings are confirmed by CMOKE experiments on Nickel films of varying thicknesses. The probe-angle resolved CMOKE technique thus provides a method to study the presence of transient gradients in magnetization at ultrafast timescales.

MA 46.8 Fri 11:15 HSZ 02

Dynamic versus Static Spectral Weight Transfer in LPCMO Thin Films — •Karen P. Stroh, Tim Titze, Pia Henning, Daniel Steil, Stefan Mathias, and Vasily Moshnyaga — I. Physikalisches Institut, Georg-August-Universität Göttingen, DE

$(La_{1-y}Pr_y)_{1-x}Ca_xMnO_3$ (LPCMO) is a prototypical bandwidth-controlled manganite with strong electron-phonon coupling and colossal magnetoresistance (CMR), originating from a nm-scale phase separation with ferromagnetic nanodomains antiferromagnetically coupled by correlated Jahn-Teller polarons (CPs).

The present study made use of strain-engineered LPCMO thin films prepared by a metalorganic aerosol deposition technique on LAO-buffered STO(100) substrates. Temperature-dependent static reflectivity spectra, showing the phase-transition-mediated spectral weight transfer (SWT), served as reference for identifying thermally driven behaviour. Further, pump-probe reflectivity (PPR) and time-resolved magneto-optical-Kerr effect (MOKE) data at different temperatures and probe wavelengths provided insights into the role of CPs in ultrafast electron and magnetization dynamics on femto- to nanosecond timescales.

As a main result, we observed a long-lived non-thermal state with increased optical conductivity in the polaron hopping regime at a probe energy of 0.7eV, indicating the destruction of polarons or a loss of their correlation upon laser excitation.

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MA 46.9 Fri 11:30 HSZ 02

Experimental exploration of criticality in dynamic magnetic phase transitions — •Mikel Quintana and Andreas Berger — CIC nanoGUNE BRTA, E-20018 Donostia-San Sebastián, Spain.

The dynamic phase transition (DPT) of ferromagnets is a well-known phenomenon describing an abrupt change in the time-evolution behavior of magnetization in the presence of a time-dependent magnetic field. Its similarities with the conventional thermodynamic phase transition (TPT), particularly in terms of scaling behavior close to their respective critical points, are of utmost importance to understand collective behaviors in systems out-of-equilibrium [1]. However, a lack of experimental verification of these theoretical predictions has impeded further progress in the field up to now. Here, we experimentally explore for the first time the scaling behavior and critical exponents of the DPT in ultrathin Co films by means of real-time magneto-optical Kerr effect measurements in the relevant dynamic phase space. Surprisingly, we observe that the DPT and TPT critical exponents correspond to different dimensionalities for the same film. Our results seem to indicate different dimensional crossover length-scales for the TPT and DPT, a fact that has not been explored to date. [1] P. Riego et. al., Physica B 549, 13-23 (2018).

MA 46.10 Fri 11:45 HSZ 02

Slow dynamics from ultrafast phononic driving in $CuGeO_3$ — •Leonie Spitz[1], Eugenio Paris[1], Flavio Giorgianni[1], Bruce Normand[1], Thorsten Schmitt[1], and Christian Rüegg[1,2,3,4] — [1]Paul Scherrer Institute, CH-5232 Villigen-PSI, Switzerland — [2]Department of Quantum Matter Physics, University of Geneva, CH-1211 Geneva, Switzerland — [3]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [4]Institute of Quantum Electronics, ETH Zürich, CH-8093 Hönggerberg, Switzerland

The coherent manipulation of magnetism by optically driven phonons is a rapidly growing field [1-4]. However, experimental studies of quantum spin systems by ultrafast pump-probe schemes remain rare, because the most common optical techniques to probe magnetic phenomena fail in the absence of magnetic order. We present a multi-method study of the spin-chain material $CuGeO_3$, in which the magnetic correlations are associated with a lattice instability, also called the spin-Peierls (SP) transition, that drives the system into a collective singlet ground state of spin dimers [5]. By the coherent driving of phonons we observe low-frequency dynamics of the optical response which may offer new insight into the mechanism driving the SP transition in $CuGeO_3$, a problem that has remained unsolved for almost 3 decades.

[1] T. F. Nova et al., Nat. Phys. 13, 132-136 (2017). [2] A. S. Disa et al., Nat. Phys. 16, 937-941 (2020). [3] D. Afansiev et al., Nat. Mater. 20, 607-611 (2021). [4] F. Giorgianni et al., arXiv:2101.01189 (2021). [5] M. Hase et al., Phys. Rev. Lett. 70, 3651 (1993).

MA 46.11 Fri 12:00 HSZ 02

Spin-lattice coupling in a Van der Waals ferromagnet on ultrafast time scales — •Hyein Jung[1,2], Victoria C. A. Taylor[2], Yoav William Windsor[1,2], and Ralph Ernstorfer[1,2] — [1]Technische Universität Berlin, Berlin, Germany — [2]Fritz Haber Institute der MPG, Berlin, Germany

Two-dimensional (2D) van der Waals (vdW) magnetic materials hold great potential for spintronic applications. Cr2Ge2Te6 (CGT) is one such material which exhibits ferromagnetism even at the monolayer limit. With functionality in mind, investigation of dynamic processes on their fundamental time scales is of great importance, in particular energy flow and coupling between subsystems (carriers, spins, lattice). Furthermore, we have recently shown that understanding lattice dynamics in ferromagnets is essential for a complete understanding ultrafast spin dynamics. Here we use femtosecond electron diffraction (FED) to study lattice dynamics in CGT and other 2D magnets. We discuss the interaction between magnetic order and the lattice, and the influence of studying such effects at the monolayer limit.

MA 46.12 Fri 12:15 HSZ 02

Modelling spin-lattice coupling in computer simulation — •Michael Saur[1], Markus Weissenhofer[1], Hannah Lange[2], Akashdeep Kamra[3], Sergiy Mankovsky[2], Svitlana Polesya[2], Hubert Hubert[2], and Ulrich Nowak[1] — [1]University of Konstanz, Germany — [2]LMU Munich, Germany — [3]Universidad Autónoma de Madrid, Spain

We develop a multiscale framework for the description of spin-lattice coupling in computer simulations [1]. The derived Hamiltonian describes a closed system of spin and lattice degrees of freedom and explicitly conserves the total momentum, angular momentum and energy. Using a new numerical implementation that corrects earlier Suzuki-Trotter decompositions we perform simulations on the basis of the resulting equations of motion to investigate the combined magnetic and mechanical motion of a ferromagnetic nanoparticle. The framework developed herein will enable the use of multi-scale modeling for investigating and understanding a broad range of spin-phonon-mediated phenomena from slow to ultrafast time scales.

[1] M. Weißenhofer, H. Lange, A. Kamra, S. Mankovsky, S. Polesya, H. Ebert, U. Nowak, doi 10.48550/ARXIV.2211.02382

MA 46.13 Fri 12:30 HSZ 02

Ultrafast energy flow in the van der Waals ferromagnet Fe3GeTe2 (FGT) — •Yoav William Windsor[1,2], Daniela

Zahn[2], Victoria C. A. Taylor[2], Theodor Griepe[4], Tommaso Pincelli[2], Hyein Jung[2], Sang-Eun Lee[2], Christian Schüssler-Langeheine[3], Niko Pontius[3], Unai Atxitia[4], Ralph Ernstorfer[1,2], and Laurenz Rettig[2] — [1]TU Berlin — [2]Fritz Haber Inst. — [3]Helmholz Zentrum Berlin — [4]CSIC Madrid

Van der Waals bonded magnetic materials expand the technological promise of 2D materials (TMDCs, Graphene) into the field of spintronics. To this end, understanding their nonequilibrium behavior is essential. Here we experimentally probed the response of FGT to photoexcitation using three probes: time-resolved ARPES (probes the carriers), time-resolved XMCD (probes the spins), and femtosecond electron diffraction (FED; probes the lattice). We resolve sub-picosecond responses in all three sub-systems, and find that the conventional M3TM model must be modified to reliably reproduce the combined response of all three sub-systems together.