MA 14: PhD Focus Session: What about the lattice? Lessons from (ultrafast) magnetism

This focus session brings together experimental, theoretical and numerical perspectives to highlight recent discoveries and unresolved questions on ultrafast magnetization effects facilitated by spin-lattice interactions. In recent years, the transfer of magnetic angular momentum during ultrafast demagnetization processes has been observed experimentally. Studies have revealed both the microscopic mechanism through circularly polarized phonons and the macroscopic mechanical response in the form of the ultrafast Einstein-de Haas effect. Further, the complementary ultrafast Barnett effect has been demonstrated, where angular momentum is transferred into the spin system from non-equilibrium angular momentum sources (e.g. lattice vibrations or optical fields) Furthermore, inertial effects in spin dynamics were measured by observing additional nutation frequencies on top of the precessional motion Theoretical work suggests that these frequencies arise due to the spin-lattice coupling, however, the underlying mechanisms are not yet fully understood. In order to predict and explain these different types of phenomena, spin-lattice dynamics simulations have been developed in recent years. These allow energy and angular momentum to be exchanged between the magnetic spin system and the lattice.

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Time: Tuesday 9:30–12:40 Location: HSZ/0002

Introduction and Welcome

Invited Talk MA 14.1 Tue 9:35 HSZ/0002

Femtophonomagnetism — •Sangeeta Sharma[1] and John Dewhurst[1,2] — [1]Max Born Institute, Berlin, Germany — [2]Max Planck Inst. Halle, Germany

From the outset of research into femtomagnetism, the field in which spins are manipulated by light on femtosecond or faster time scales, several questions have arisen and remain highly debated: How does the light interact with spin moments? How is the angular momentum conserved between the nuclei, spin, and angular momentum during this interaction? What causes the ultrafast optical switching of magnetic structures? What is the ultimate time limit on the speed of spin manipulation? What is the impact of nuclear dynamics on the light-spin interaction?

In my talk I will advocate a parameter free ab-initio approach to treating ultrafast light-matter interactions, and discuss how this approach has led both to new answers to these old questions but also to the uncovering of novel and hitherto unsuspected early time spin dynamics phenomena [1, 2]. In particular I will show that phonons strongly influence the spin dynamics[3], demonstrating nuclear system can play a profound role in controlling femtosecond magnetization of materials.

[1] Dewhust et al., Nano Lett. 18, 1842 (2018).
[2] Siegrist et al. Nature 571, 240 (2019)
[3] Sharma et al. Sci. Advs. 8, eabq2021 (2022)

Invited Talk MA 14.2 Tue 10:20 HSZ/0002

THz-driven dynamical ferroicity in paraelectric and diamagnetic perovskites — •Martina Basini — ETH Zürich, Department of Phyisics, August-Piccard-Hoff,1, 8049, Zürich, Switzerland

The emergence of collective order in matter is among the most fundamental and intriguing phenomena in physics. In recent years, the dynamical control and creation of novel ordered states of matter not accessible in thermodynamic equilibrium have received much attention. The theoretical concept of dynamical multiferroicity has been introduced to describe the emergence of magnetization due to time-dependent electric polarization in non-ferromagnetic materials. Here, we provide experimental evidence of magnetization in the archetypal paraelectric and diamagnetic perovskites SrTiO3 and KTaO3 due to this mechanism. To induce such a magnetic response, we resonantly drive the infrared-active soft phonon mode with an intense circularly polarized terahertz electric field and detect the time-resolved magneto-optical Kerr effect. Our findings show a new path for the control of magnetism, for example, for ultrafast magnetic switches, by coherently controlling the lattice vibrations with light.

Invited Talk MA 14.3 Tue 10:50 HSZ/0002

Angular momentum transfer and chiral phonons from first principles — •Markus Weissenhofer[1], Philipp Rieger[1], MS Mrudul[1], Luca Mikadze[1], Sergiy Mankovsky[2], Svitlana Polesya[2], Hubert Ebert[2], Ulrich Nowak[3], and Peter M. Oppeneer[1] — [1]Uppsala University, Uppsala, Sweden — [2]Ludwig Maximilian Universität, München, Germany — [3]Universität Konstanz, Konstanz, Germany

Transfer and manipulation of angular momentum is a key aspect in spintronics. Recently, it has been shown that angular momentum transfer between spins and lattice is possible on ultrashort timescales [1]. To contribute to the understanding of this transfer, we have developed a theoretical multiscale framework for spin-lattice coupling, which is linked to ab-initio calculations on the one hand and magnetoelastic continuum theory on the other [2], allowing for the study of a wide range of magnetomechanical phenomena. Here I will demonstrate how this framework can be used to calculate magnon-phonon coupling parameters, emphasizing the importance of a Dzyaloshiskii-Moriya type interaction for angular momentum transfer [2] and revealing the existence of chiral phonons in iron arising from a chirality-selective coupling [3].

[1] Tauchert al., Nature 602, 73 (2022); Luo et al., Science 382, 698 (2023). [2] Mankovsky et al., PRL 129, 067202 (2022); Weißenhofer et al., PRB 108, L060404 (2023). [3] Weißenhofer et al., PRL 135, 216701(2025).

15 min break

Invited Talk MA 14.4 Tue 11:35 HSZ/0002

Inertial Spin Dynamics: A Signature of Non-Markovian Interactions in Ferromagnets — •Vivek Unikandanunni[1,5], Felix Hartmann[2], Matias Bargheer[2], Eric Fullerton[3], Stefano Bonetti[4,5], and Janet Anders[2] — [1]Institute of Applied Physics, University of Bern,Switzerland — [2]Institute of Physics and Astronomy, University of Potsdam, Germany — [3]Center for Memory and Recording Research, University of California San Diego, USA — [4]Department of Molecular Sciences and Nanosystems, Ca Foscari University of Venice, Italy — [5]Department of Physics, Stockholm University, Stockholm, Sweden

We report direct experimental observation of intrinsic inertial spin dynamics in ferromagnetic thin films, manifested as a damped THz frequency oscillation of the magnetization. Using a broadband tabletop THz source, we resonantly drive epitaxial cobalt and directly measure the frequency and relaxation time of the inertial response, which is well described by the inertial Landau-Lifshitz-Gilbert (LLG) equation. We find that the frequency and relaxation time of the inertial dynamics are dependent on the structural symmetry of the sample.

Broadband measurements further reveal a multi-peaked magnetic spectrum that cannot be captured by the inertial LLG alone. An open-quantum-system approach incorporating spin-phonon coupling through a memory kernel yields a non-Markovian LLG equation that reproduces the full experimental spectra demonstrating the fundamental role of non-Markovian memory effects in ultrafast spin dynamics.

Invited Talk MA 14.5 Tue 12:05 HSZ/0002

Atomistic simulations of ultrafast spin-lattice dynamics —
•Richard Evans[1] and Mara Strungaru[2] — [1]University of York, York, United Kingdom — [2]University of Manchester, Manchester, United Kingdom

Atomistic spin dynamics (ASD) has become a standard method for studying finite temperature processes in magnetic materials and devices. In some systems, such as magnetic insulators, coupled spin-lattice dynamics can play a dominant role in the thermal and dynamic properties that have so far been neglected in spin-only models. Recent exciting results in ultrafast dynamics have shown that the spin-lattice interaction is a critically important component to the physical properties of a magnetic material. Spin-Lattice Dynamics (SLD) is a relatively recent theoretical development aiming to directly couple an atomistic spin model with a molecular dynamics solver to incorporate the fascinating and complicated dynamics of these coupled systems into a practical numerical framework. In this talk I will introduce the theoretical background and numerical methods for SLD as recently implemented in the VAMPIRE software package, including its parallelisation and scalability on the UK National Supercomputer ARCHER2. I will present recent results on coherent ultrafast THz switching where we found that it is possible to induce magnetic switching through a coherent phonon excitation. I will conclude with a brief perspective on open problems in spin-lattice dynamics, including numerical challenges, quantum thermostats and correlated noise, and how to model electron processes in metallic magnetic systems.

Closing Remarks