SYAS 1: Attosecond and Coherent Spins: New Frontiers

Ultrafast magnetism, attosecond lasers and methods using x-ray pulses to explore structural dynamics are reaching new limits. This session is dedicated to new developments and recent major recent milestones, from hard x-ray bunches to attosecond pulses, breaking new frontiers and time records, towards the observation to study coherent spin processes. This phenomena is originating from coherent charge transfer, driven by a few cycle laser pulse, and is relevant for all materials and interfaces, from semiconductors, metals to molecules. Examples for these systems will be demonstrated.

Time: Thursday 10:00–12:45 Location: Audimax 2

Invited Talk SYAS 1.1 Thu 10:00 Audimax 2
Ultrafast Coherent Spin-Lattice Interactions in Iron Films — •Steven Johnson — Institute for Quantum Electronic, Eidgenossische Technische Hochschule, Zürich, Swiitzerland — SwissFEL, Paul Scherrer Institut, Villigen, Switzerland

The interaction of spins in a ferromagnet with the underlying lattice during the process of ultrafast demagentization has for some time been shrouded in mystery, and is intimately connected to the fundamental question of exactly how angular momentum is conserved in such processes. The original Einstein de Haas experiment of the early 20th century showed dramatically that the angular momentum of the electron spins responsible for ferromagnetism is the same angular momentum that we know well from classical mechanics. In this talk I explore how the Einstein de Haas effect can manifest in the time domain on ultrafast time scales in response to ultrafast demagnetization of a 3d ferromagnet. In a thin film geometry, the transfer of angular momentum to the lattice is accomplished by a transient mechanical torque that launches a small but measurable transverse displacement wave into the film. I also describe an experiment using ultrafast x-ray diffraction performed at the LCLS free electron laser that observed these dynamics. Based on this we make a first estimate of the magnitude and time scale of angular momentum transfer to the lattice in the first few hundred femtoseconds after ultrafast demagnetization. I also discuss future directions in this research to further investigate the underlying mechanisms.

Invited Talk SYAS 1.2 Thu 10:30 Audimax 2
Ultrafast spin, charge and nuclear dynamics: ab-initio description — •Sangeeta Sharma[1] and John Kay Dewhurst[2] — [1]Max Born Institute Berlin — [2]Max planck Institute Halle

Laser induced ultrafast dynamics is a burgeoning field of condensed matter physics promising the ultimate short time control of light over matter. 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 degrees of freedom during this interaction? What causes the ultrafast optical switching of magnetic structures from anti-ferromagnetic to ferromagnetic and back again? 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. In particular I will demonstrate OISTR (optical inter-site spin transfer)[1,2] to be one of the fastest means of spin manipulation via light with changes in magnetic structure occurring on attosecond time scales. I will also discuss the impact of nuclear dynamics on laser induced spin dynamics and demonstrate how selective phonon modes can be used to enhance the OISTR effect.

15 min. break

Invited Talk SYAS 1.3 Thu 11:15 Audimax 2
Light-wave driven Spin Dynamics — •Martin Schultze[1], Markus Münzenberg[2], and Sangeeta Sharma[3] — [1]Institut für Experimentalphysik, TU Graz, Austria — [2]Ernst-Moritz-Arndt-Universität, Greifswald — [3]Max-Born-Institut, Berlin

In electronics, functionality is achieved by switching between electronic states of matter by applying external electric or magnetic fields. Strong couplings in-between charge carriers and to the crystal lattice conspire to randomize energies and momenta extremely fast and efficiently, leaving no room for any sort of coherence.

However, the prospects of coherent control protocols as demonstrated in isolated atomic systems are alluring and contemporary ultrafast laser sources might be a new ingredient to overcome this entrapment. This talk will discuss two experiments demonstrating that single cycle optical fields at optical frequencies allow manipulating electronic and spin degrees of freedom in solid state systems at optical clock rates faster than de-coherence. Ultrafast bidirectional energy transfer between a light-field and the band-structure of silica proves the early times reversibility of electronic excitations and holds promise of novel ultrafast, coherent optoelectronic applications.

As a corollary of this ultrafast coherent modification of the electronic system, in suitably chosen herterostructures also the spin system can be manipulated coherently. Optically induced spin transfer is demonstrated as a route to the direct, all-optical manipulation of macroscopic magnetic moments on previously inaccessible attosecond timescales.

Invited Talk SYAS 1.4 Thu 11:45 Audimax 2
All-coherent subcycle switching of spins by THz near fields — •Christoph Lange[1], Stefan Schlauderer[2], Sebastian Baierl[2], Thomas Ebnet[2], Christoph Schmid[2], Darren Valovcin[3], Anatoly Zvezdin[4], Alexey Kimel[5], Rostislav Mikhaylovskiy[6], and Rupert Huber[2] — [1]Department of Physics, TU Dortmund University, 44227 Dortmund, Germany — [2]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [3]Department of Physics, University of California at Santa Barbara, Santa Barbara, California 93106, USA — [4]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow 119991, Russia. — [5]Radboud University, Institute for Molecules and Materials, Nijmegen 6525 AJ, The Netherlands. — [6]Department of Physics, Lancaster University, Bailrigg, Lancaster LA1 1YW, UK.

As state-of-the-art electronics encounters ultimate limits, novel concepts for harnessing coherent charge and spin dynamics are being sought after. Here, we perform subcycle control of solid-state spins by exploiting a novel electric-dipole mediated mechanism to induce unprecedentedly large spin oscillations in the antiferromagnet TmFeO3. Strong, single-cycle THz pulses are enhanced by a custom metallic antenna fabricated on top of a bulk TmFeO3 sample, where the antenna's atomically strong near fields change the magnetic anisotropy on a subcycle scale. The resulting spin dynamics include a characteristic phase flip, an asymmetric splitting of the magnon resonance, and a long-lived offset of the polarization rotation, representing a novel fingerprint of all-coherent spin switching with minimal energy dissipation.

Invited Talk SYAS 1.5 Thu 12:15 Audimax 2
Ultrafast optically-induced spin transfer in ferromagnetic alloys — •Stefan Mathias — I. Physikalisches Institut, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

The idea of using light to manipulate electronic and spin excitations in materials on their fundamental time and length scales requires new approaches in experiment and theory, to observe and understand these excitations. The ultimate speed limit for all-optical manipulation requires control schemes for which the electronic or magnetic sub-systems of the materials are directly manipulated on the timescale of the laser excitation pulse. In our work, we provide experimental evidence of such a direct, ultrafast optically-induced spin transfer between two magnetic subsystems in an alloy of Fe and Ni [1] and various Heusler compounds [2].

[1] Hofherr et al., Ultrafast optically induced spin transfer in ferromagnetic alloys, Science Adv. 6, eaay8717 (2020) [2] Steil et al., Efficiency of ultrafast optically induced spin transfer in Heusler compounds, Physical Review Research 2, 023199 (2020)