REXS 2025 Almadraba

Monday, 6 October 2025 - Friday, 10 October 2025

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Book of Abstracts

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Welcome and Introduction to the Tutorials

Tutorials + coffee break

X-ray Photon Correlation Spectroscopy (XPCS) - I

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Many of the world's synchrotrons are completing upgrades to fourth generation light sources this decade which provides the source with a huge boost in brightness and coherence. X-ray photon correlation spectroscopy (XPCS) is a powerful technique which relies on the coherence of x-rays and is used to study dynamics in materials at the micro to atomic scale. When coherent light is used to illuminate a sample, it scatters and forms an interference pattern on the two-dimensional detector known as speckle. Measuring speckle patterns as a function of time is the basis of XPCS. Using the speckle pattern movies, you can compute characteristic fluctuation times of your sample and further connect them to specific spatial features such as defect motion using theory and modelling1. In this way XPCS provides insight into the temporal and spatial evolution of material properties, from diffusion and relaxation processes to phase transitions and non-equilibrium phenomena2,3.

This tutorial will provide a comprehensive introduction to the principles and applications of XPCS, combining short lectures with hands-on analysis examples and exercises. The lecture portion will cover the fundamental concepts of XPCS, including the theory of x-ray coherence, speckle and photon correlation spectroscopy, experimental implementation, and data analysis techniques. Topics will include the advantages and limitations of XPCS compared to other techniques, instrument design and optimization, data interpretation and some of the possible pitfalls.

The hands-on component will allow participants to gain practical experience with XPCS data analysis using Python, as well as explore case studies of XPCS applications in magnetic materials. By the end of this tutorial, participants will have a solid understanding of the principles and practices of XPCS, as well as the skills to design XPCS experiments and analyze data. This tutorial is intended for researchers and students interested in using XPCS to study dynamics in materials and will provide a valuable opportunity for hands-on learning and discussion.

Tutorials + coffee break

Practical Coherent Diffractive Imaging (CDI) - I

Authors: Daniel Pérez Salinas[1]; Riccardo Battistelli[2]

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This tutorial provides a hands-on introduction to Fourier Transform Holography (FTH) and Coherent Diffractive Imaging (CDI), with a focus on practical implementation at synchrotron facilities. Aimed at both new and experienced users, the session will cover the fundamentals of lensless imaging, including experimental setup considerations, data acquisition strategies, and reconstruction workflows. Participants will gain insight into the comparative strengths of FTH and CDI, when and how to use each technique, and how to troubleshoot common challenges encountered during

beamtime—such as coherence constraints, reference design, and detection limitations. Real and simulated datasets will be used to demonstrate key steps in phase retrieval and image analysis. By the end of the session, attendees will be equipped with the knowledge to plan and analyze FTH/CDI experiments, and to critically assess the quality and limitations of their reconstructions. No prior experience with CDI is required, though familiarity with basic diffraction and synchrotron instrumentation is assumed.

Tutorials + coffee break

Simulation O REXS With FDMNES -I

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The tutorial is devoted to the ab initio simulations of resonant X-ray diffraction spectra using the FDMNES code1.
First a little lecture will be given. It will include a brief historical overview, the basics in theory necessary to understand the sensitivity of the technique, and some typical examples. To introduce the practical, an introduction to the FDMNES code and its specificities will also be given.
Then, the participants will start simulations on different examples. They will learn at the same time the use of the FDMNES code and the way to check specific properties as the polarization in and out dependence, the effect of dipole and quadrupole transitions, what can be seen in azimuthal scans, etc⋯
We will also show how the extraction of the spherical components of the scattering tensors can give information on specific projections of the density of states on the absorbing atoms. Relation to the magnetic and spatial symmetries will be evocated. Effects of self-absorption and birefringence will also be simulated.

Examples at K edges in magnetite, V2O3 and L23 in CuO will illustrate all this for non-magnetic and magnetic studies. Eventually on demand, examples from the participants could be addressed.

Participants must have their own laptop. A specific package with documentation, in-data files and the FDMNES executables for Mac OS, Windows 64 and Linux are provided. They must nevertheless have their own software to plot spectra (Origin, Kaleidagraph, ⋯).

Tutorials + coffee break

Circular Dichroism in Resonant Elastic X-ray Scattering-I

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Circular dichroism in resonant elastic X-ray scattering (CD-REXS) has emerged as a uniquely probe for chiral and topological magnetic orders in condensed matter systems. In this extended tutorial, we provide a comprehensive introduction to the fundamental principles, experimental implementations, and practical applications of CD-REXS, with a focus on its ability to extract symmetry, chirality, and topological invariants from spin textures.
We begin with the theoretical foundation of resonant scattering processes, highlighting the role of x-ray polarization in magnetic scattering cross-sections. Particular emphasis is placed on the geometric and symmetry constraints that govern dichroic signal formation, and how they relate to the vectorial structure of magnetization. We will then introduce the Dichroism Extinction Rule

(DER), a recently developed principle that allows a one-to-one correspondence between spin motif and circular dichroic intensity, enabling direct determination of spin helicity and winding number. The tutorial will feature case studies from chiral magnets, magnetic multilayers and heterostructures, demonstrating how CD-REXS can resolve complex spin structures, and even with a 3D depth profile. By the end of the session, participants will gain the conceptual and practical tools necessary to design, perform, and interpret CD-REXS experiments, as well as appreciate its unique role in modern spin and topological materials research.

Opening session

Welcome REXS2025

Authors: Gloria Subias-Peruga[1]; Javier Herrero Martin[None]; Klaus Attenkofer[None]; Manuel Valvidares[None]; Nicolas Jaouen[2]

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REXS 2025 local chairs and int.comm. chair
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Opening session

REXS Opening Keynote talk : REXS: a Journey Across Space and Time

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In this introductive talk, an overview of Resonant Elastic X-ray Scattering will be presented, with the intent of introducing the audience to the following talks.

After a short historical perspective, a reminder on the complementarity to other technique (mainly neutrons) for the determination of magnetic structures, and on the relevance of the character of resonances and higher-rank orders, an introduction to more modern contributions across electronic orderings as realized in intriguing states of correlated materials will be proposed. Spanning across multiferroics and magnetoelectrics, high temperature superconductors and charge density waves, Skyrmions and AlterMagnets, examples of relevant microscopic information on structures and interactions, on phases and transitions across a broad spectrum of materials, resonances and approaches, will be provided.

Then, the discussion will naturally progress on the opportunities and challenges offered by coherent beams available at the new generation machines. Together with the development of various imaging techniques, the extraction of time scales characteristic of collective dynamics will be introduced. Few ideas on possible approaches to the investigation of space- and-time (either extrinsically –by informed average, or intrinsically –by Orbital Angular Momentum) will be considered.
Finally, current scientific questions and technical requirements will be surfed upon.

Talks Tuesday Morning

Beyond the Surface: 3D Probing of Antiferromagnets —A Journey Through Failures and Breakthroughs

Author: Valerio Scagnoli[1]

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Three dimensional magnetic systems hold the promise to provide new functionality associated with greater degrees of freedom. Over the last years we have worked towards developing methods to fabricate and characterize three dimensional magnetic structures. Specifically, we have combined X-ray magnetic imaging via circular dichroism (XMCD) with new iterative reconstruction algorithms to achieve X-ray (ferro)magnetic tomography and laminography in 3D volumes with sub 100 nm spatial resolution [1-4]. Recent revival of interest on antiferromagnets have driven our recent efforts in developing an approach to image the antiferromagneticorder parameter in micron-size sample with nm spatial resolution.

To this end, we have attempted to use coherent magnetic diffraction and antiferromagnetic tomographic imaging via X-ray linear dichroism. Over the course of several experimental campaigns, we have advanced these approaches and ultimately developed X-ray Linear Dichroic Orientation Tomography (XL-DOT) —a novel, quantitative, and non-invasive technique for three-dimensional characterization of extended polycrystalline and non-crystalline materials at the intra- and intergranular levels [5-6].

The figure included here shows a reconstructed grain structure along with the local crystallographic c-axis alignment. The spectroscopic and non-destructive nature of XL-DOT makes it ideally suited for operando investigations, enabling simultaneous chemical and microstructural analysis of functional materials, including antiferromagnets.

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5. A. Apseros et al., Nature 636, 354 (2024), https://doi.org/10.1038/s41586-024-08233-y.
6. A. Apseros et al., submitted to New J. Phys., https://arxiv.org/abs/2504.12978.

Talks Tuesday Morning

SoftiMAX-CXI: A new soft x-ray branch or scattering and diffraction methods at MAX IV

Authors: Jörg Schwenke[1]; Erik Malm[2]; Niklas Johansson[2]; Joaquin Gonzalez[3]

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SoftiMAX is a soft X-ray spectro-microscopy beamline at MAX IV Laboratory, the Swedish national synchrotron center in Lund, Sweden. It is situated at the 3 GeV ring at MAX IV and provides a very high average coherent flux owing to the low emittance properties of the ring1,2.
SoftiMAX consists of two branch lines utilizing different focusing solutions and catering to various imaging methods. The main branch, in user operation since 2021, hosts an end-station optimized

for scanning techniques such as Scanning Transmission X-ray Microscopy (STXM) and diffraction imaging such as ptychography3.

Here we report on the design and commissioning of the second branch of the beamline SoftiMAX-CXI, which hosts a dedicated end-station for X-ray Photon Correlation Spectroscopy (XPCS), and diffraction and scattering experiments with a flexible detector geometry.
SoftiMAX-CXI, which started commissioning in 2024 and has since been part of our user program as an open port, operates over an X-ray photon energy range of 275 eV to 2200 eV with full polarization control above 400 eV. This branch line has a Kirkpatrick-Baez mirror pair to focus the beam to a size down to about 20 μm. External end-stations have been used for XPCS measurements and Fourier Transform Holography of magnetic thin films, and for developing a TIMEPIX imaging detector for the soft X-ray regime.

The commissioning of the main CXI end-station has started. It is built around a rotatable detector arm that can accommodate sample-detector distances of at least 2m over 120-degree scattering angles. This makes the CXI end-station suitable for XPCS, scattering, diffraction experiments, and measurements in reflection.

Talks Tuesday Morning

Imprinted emergent textures in amorphous rare-earth transition-metal errimagnets

Authors: Felix Buettner[1]; Tamer Karaman[2]

Co-authors: Aladin Ullrich [2]; Andrada-Oana Mandru [3]; Bastian Pfau [4]; Christopher Klose [4]; Daniel Metternich [1]; Daniel Pérez Salinas [5]; Hans J. Hug [3]; Jordi Llobet [5]; Kai Litzius [2]; Konrad Samwer [6]; Manas Patra [1]; Manfred Albrecht [2]; Manuel Valvidares [5]; Michael Schneider [4]; Reshma Peremadathil Pradeep [3]; Riccardo Battistelli [1]; Timo Schmidt [2]

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Amorphous rare-earth transition-metal (RE-TM) ferrimagnets are workhorse materials in the field of spintronics. Developed chiefly for magneto-optical recording and bubble memories in the second half of the 20th century, they have remained at the forefront of the field, for example because they allow for ultrafast all-optical switching1, ultrafast current-driven domain wall motion2, and easy, gradual tuning from ferromagnetic to antiferromagnetic behavior. However, these materials are also known to exhibit chemical heterogeneity, both laterally3 and in thickness direction4, as well as sperimagnetism5, i.e., intrinsically non-collinear alignment of spins. So far, these effects were largely ignored in spintronics research.
Here, we report on the discovery of emergent textures in the structure of amorphous RE-TM ferrimagnets (Fig. 1), which are imprints the magnetic domains walls of the as-grown state and can be traced back to long-range-ordered patterns of chemical heterogeneity and sperimagnetism. The nature and implications of these imprinted emergent textures are revealed by resonant x-ray scattering and imaging experiments, in concert with advanced transmission electron microscopy and scanning probe microscopy, as discussed in this talk.

Talks Tuesday Morning

Coherent x-ray studies of spontaneous fluctuations in rare earth nickelates

Rare-earth nickelates ($RNiO_3$) exhibit a rich interplay of electronic, magnetic, and structural phase transitions, including a metal-to-insulator transition (MIT), charge ordering, and a symmetry change from orthorhombic to monoclinic structure [1]. While these transitions have been widely studied, the spatio-temporal nature of spontaneous fluctuations across the phase boundary remains largely unexplored. Such fluctuations are increasingly recognized as crucial for stabilizing emergent magnetic textures and for enabling stochastic functionality in neuromorphic computing. Here, we employ X-ray photon correlation spectroscopy (XPCS) [2-3] to directly probe the dynamics of structural and magnetic fluctuations in epitaxial thin films of $NdNiO_3$ and $SmNiO_3$. For $NdNiO_3$, we observe a pronounced slowdown in fluctuation timescales—by an order of magnitude—near the Néel temperature, highlighting strong coupling between structural and magnetic order parameters, independent of epitaxial strain. In contrast, $SmNiO_3$ shows no such slowdown, emphasizing the distinct dynamics. Unexpectedly, wavevector-dependent measurements reveal that short-range structural fluctuations are significantly slower (by a factor of 3–5) than long-range fluctuations [4]. Our results demonstrate the power of coherent X-ray techniques in capturing nanoscale fluctuation dynamics in quantum materials and provide new insight into the role of fluctuations near phase transitions in complex oxides.

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Talks Tuesday Morning

Controlling Skyrmion Lattice Dynamics with Thermal and Magnetic Field Gradients

Author: Thorsten Hesjedal[1]

Co-authors: Gerrit van der Laan [2]; Jingyi Chen [3]; Shilei Zhang [3]; haonan jin [3]

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Magnetic skyrmions exhibit a rich landscape of dynamical behavior shaped by their topological character and collective organization. In this work, we explore the motion of skyrmion lattices in chiral magnets under two orthogonal driving mechanisms: magnetic field gradients [1] and thermal gradients [2,3]. Using resonant elastic x-ray scattering (REXS) on Cu_2OSeO_3, we demonstrate how finite-sized skyrmion lattices respond to these drives not only by translation, but also by rotation, undergoing a coherent rolling motion driven either by magnon flow (in thermal gradients) [2] or by field-induced torques [1]. The rotational sense and velocity scale predictably with gradient strength and crystallite size, revealing the emergence of a chiral lattice torque, also allowing for the direct

measurement of the skyrmion Hall angle in the lattice state [4]. To access the three-dimensional nature of skyrmion textures, we complement these surface-sensitive studies with small-angle neutron scattering (SANS) experiments on MnSi [3]. There, we uncover depth-resolved bending of skyrmion strings under two-dimensional thermal gradients, driven by a temperature-dependent skyrmion Hall effect and governed by a modified Thiele equation incorporating magnon friction. This dual approach, combining high-resolution REXS at the surface and SANS through the bulk, offers a unified view of skyrmion lattice dynamics and demonstrates new modalities for manipulating topological spin textures in three dimensions.

Talks Tuesday Morning

Fluctuation and phase transition in amorphous FeGe thin film

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The question of fluctuation and population growth at the local level and how that influences global properties has been studied extensively in physical, biological and social sciences. In quantum material interplay of fluctuation and phase transitions provide deep insight into the phase transition pathways. Using coherent x-ray scattering we have shown that phase transition in amorphous FeGe (a-FeGe) involve existence of nanoscale fluctuation "hot-spots"whose origin lies in local non-equilibrium states. The fluctuating hot spots start over a small fraction of the domains at random length scales, and the fluctuating population gradually grows non-linearly into collective fluctuations. The growth of the fluctuation population resembles dynamic coherence length which forms the basis of phase transition. We further showed that are exists a highly non-trivial fluctuating phase that can be described as a helical nematic phase. We also studied the distribution of the fluctuation amplitude and it followed a gaussian distribution implying ergodic dynamics whereas few kelvins below this transition temperature the distribution becomes skewed or asymmetric due to non-ergodic behavior. We also showed that our approach provides a new way to evaluate the statistics of the fluctuations in many classes of heterogeneous materials. Work is funded by U.S. DOE.

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Talks Tuesday Afternoon

Advancing the Sample Space to Elevate the Power o Resonant X-ray Scattering.

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Deploying in-situ strain with electrical multi-modal x-ray scattering measurements has allowed for powerful experimental configurations deepening our understanding of complex quantum phenomena. Touching upon a few recent topics e.g., nematic behavior in Fe superconductors (1-4) and quantum paraelectric behavior in SrTO3 membranes (5) I'll demonstrate the value-added power of investing in the sample space and overview our plans to explore dopant-vacancy color center qubit behavior with symmetry and strain combining photoluminescent spectroscopy and x-ray scattering.

The ability to measure and control structure, symmetry or domain population of a twinned system, like an orthorhombic crystal or magnetic orientated domains can be a critical sample control parameter to study intricate quantum behaviors. In the iron based superconductor, electronic nematicity is coupled to both the lattice and the conducting electrons leading to both structural and transport measurements sensitive to nematic fluctuations. While spin driven nematicity is prevalent in Fe pnictides, the role of spin versus orbit in the chalcogenide nematic behavior has been under investigation. The consortium of electrical and x-ray scattering measurements keenly addresses the relationship of lattice, spin and orbital order in the nematic phase space. SrTO3 is a ubiquitous prototype material but is itself an intriguing enigmatic host of quantum behaviors, using strain as a tuning parameter we investigate the transition from classical to quantum behaviors and consider the unbounded potential studies deploying this combination of strained single crystal membranes with resonant x-ray scattering.

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Talks Tuesday Afternoon

Structural and Magnetic Chirality In NiCo2TeO6

Authors: Alessandro Bombardi[1]; Anuradha Vibhakar[1]; C.J. Won[2]; Fellipe Carneiro[1]; Ketty B eauvois[None]; Navid qureshi[3]; Rebecca Scatena[1]; Sang-Wook Cheong[4]

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ABSTRACT

The chiral nature of our immediate environment is obvious to us structurally and functionally, and it seems to be a key ingredient of life, yet it remains one of the most elusive properties to understand and investigate at the atomic length scale.
X-rays measure structural chirality via the interference of the anomalous scattering factor. This provides a tiny variation in the measured intensity, usually sufficient to distinguish between different enantiomers, whereas both non-resonant and resonant magnetic scattering can be used to assess inversion domains in non collinear magnetic structure via the helicity of the probe, see [1] and references therein. The case of neutrons is similar, with polarized neutrons able to assess magnetic chirality and inversion domains [1], whereas the tiny relativistic Schwinger term is the only cross section term to measure the structural chirality [1].
Here, we present a combined X-ray and polarized neutron scattering study on chiral, polar and magnetoelectric compound NiCo2TeO6[2,3]. This system adopts a structural arrangement derived from the corundum R3c of Al2O3, but the introduction of Co and Te at the Al site breaks the inversion and the c-glide symmetry, generating a ferri-chiral structural arrangements, with often both chirality present in the same crystal.
Using a similar methodology to the one adopted in the case of Ba3NbFe3Si2O14 [1], we determine the relation between the magnetic and structural chirality in this system.
A clear theoretical framework of the microscopic interactions driving the chirality of NiCo2TeO6 is still missing, but our experimental results provide a sound foundation to understand the origin of this phenomenon and to future application of the magnetoelectric properties of this system.
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Talks Tuesday Afternoon

Dispersion-Induced Pseudo-Extinction o the Bragg Reflection and the Magnetic Asymmetry in REXS rom Ferromagnets

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The signal of the x-ray magnetic scattering is usually much weaker than that of the electric one. One of the well-known methods of making up for this disadvantage is to tune the x-ray energy to an absorption edge of the magnetic element. Since the theoretical prediction and the pioneering experiments in 1980's [1-3], an enhancement of the magnetic signal at, for example, the rare-earth L2,3 edges, has been observed for many systems.
Another method of improving the detectability for the magnetic signal is to utilize the polarization dependence of the x-ray scattering. When the incident x rays are linearly polarized within the scattering plane, for example, the electric Thomson scattering is largely suppressed at the scattering angle of around 90 degrees. With such a scattering geometry, therefore, the magnetic scattering having different polarization properties can be relatively magnified [4,5].
In the resonant diffraction from ferromagnetic compounds, there can be an additional method of clarifying the originally weak magnetic signal. That is to aim at the reflection indexes where the electric diffraction signal almost disappears in the vicinity of an absorption edge by the destructive interference among the scattered waves from plural types of constituent elements and the modification of the scattering power of the resonating element due to the so-called dispersion effects. The 444 reflection of the ferromagnetic intermetallic compound GdAl2 meets such a fortuitous pseudo-extinction condition at the Gd L3 edge [6]. In the presentation, the experimental results for this reflection at the L3 edge together with those at the L2 one will be shown, and the large magnetic asymmetry will be discussed [7].
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Talks Tuesday Afternoon

Uniaxial Pressure Control o Charge Density Wave in ScV6Sn6

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Uniaxial Pressure Control of Charge Density Wave in ScV6Sn6

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ScV6Sn6 is a bi-layer Kagome system in which the structural degrees of freedom in the out-of-plane direction are suggested to play a major role in the stabilization of the charge density wave (CDW) order [1-3]. Here, we investigate the effects of uniaxial pressure along the c axis in this material. Our electrical resistivity measurements under c-axis uniaxial stress reveal a fast suppression of the CDW transition followed by a change in the CDW character at 0.9 GPa. In contrast, our x-ray diffraction measurements show that at near-zero stress, CDW reflections are initially enhanced by c-axis compression, with suppression occurring beyond 0.05 GPa. Our findings highlight the importance of the c-axis lattice parameter for the tuning and stabilization of the CDW order in this material.

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Talks Tuesday Afternoon

XMaS, The UK Materials Science Beamline At The ESRF

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XMaS/BM28 is a UK-National Research Facility funded by EPSRC and located at the ESRF, the European Synchrotron in Grenoble (France). The project is jointly managed by the Universities of Warwick and Liverpool. The beamline has been supporting UK materials scientists since 1997 in a wide range of disciplines spanning physics, chemistry, environmental sciences, materials and engineering but also medicine and cultural heritage.
XMaS was originally designed for the exploration of magnetic materials using scattering techniques that remains a core activity of the facility, benefiting from a large suite of sample environments available on the beamline (e.g. low/high temperatures, magnetic and electric fields ⋯). The recent facility upgrade has extended the energy spectrum of the facility from 2.035 keV up to 47 keV thus opening new opportunities for studies at the L-edges of 4d-transition metals and K-edges of light rare-earths (e.g. Sm, Nd ⋯).
In addition to the main synchrotron beamline, XMaS also provides access to two offline laboratories. The first one, equipped with a Cu micro-source and a 4-circle Huber diffractometer, is optimized for diffraction and reflectometry studies using a 2D MAXIPIX detector. The second one is used to perform electrical characterization as a function of temperature (2 - 800 K) and applied magnetic fields (up to 4 T).
Some case studies will be presented to illustrate the capabilities of the beamline. More highlights can be found in our annual Newsletter1. A complete description of the beamline is available at www.xmas.ac.uk. One can also follow us on the social media X (@XMaSBeam) or contact us directly at xmas@esrf.fr.

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Talks Tuesday Afternoon

Molecular and Electronic Structure at Electrochemical Interaces rom In Situ Resonant X-Ray Diffraction

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In electrocatalysis, reactivities are crucially affected by the structure at the electrochemical interface, the few Å thick region at the metal-liquid interface. A precise understanding of the charge and molecular distribution is a mandatory step for the comprehension of the underlying mechanisms. Nevertheless, up to now direct experimental methods probing electronic/molecular structure at the atomistic level in the electrochemical interface were lacking.
We recently proposed an original method [1,2] coupling in situ Surface Resonant X-Ray Diffraction (SRXRD) to DFT calculations. Following the Helmholtz description, we modelled the interface as a double layer, where an ionic plane in the liquid phase faces the oppositely charged metal surface.
After a preliminary attempt [3], allowing only a semi-quantitative description of the charge distribution at the interface, we have now introduced a realistic physical model [1] which gives access quantitatively to the molecular and electronic structure both in the crystal surface layers and in the close solution. The ionic layer is here described by chemically defined ions/molecules set in front of the metal. Their occupation rate, charge, position and Debye Waller factor are the parameters we have to solve by comparison with SRXRD spectra, thanks to a confidence factor. Because our system is neutral and our simulations are self-consistent, we also obtain the atomic charge distribution in the crystal surface layers.
We successfully applied our method to the archetypal Pt(111) system in an acidic medium, focusing on the potential region where no adsorbates are present. In situ SRXRD measurements were made

at the D2AM beamline (ESRF, Grenoble). The spectra were recorded at several reciprocal space positions and with different orientations of the polarization to probe the chemical bonds in and out of the surface plane.
Contrarily to the typical assumption of zero free charge on the Pt metal surface at this potential, our experimental data clearly reveal the presence of partially ordered water molecules and hydronium ions close to the negatively charged metal surface, signature of a significant interaction between the metal and water.
We believe that our original approach will significantly contribute to bridging the knowledge gaps surrounding electrocatalytic mechanisms comprehension and will be instrumental in enhancing theoretical predictions, which have lacked data from physical characterization techniques.

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Talks Tuesday Afternoon

MagStREXS: Magnetic Structures Through Resonant Elastic X-ray Scattering

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Resonant Elastic X-ray Scattering (REXS) is a powerful technique successfully employed to investigate a wide range of phenomena both in solids and thin films, including different charge, spin, and orbital orderings [1, 2]. In particular, REXS has proven to be a valuable method for the determination of magnetic structures, becoming a suitable complement to neutron techniques. However, the analysis of diffraction data collected in REXS experiments is, in general, very intricate and the lack of any tool to facilitate these calculations hinders the use of this technique by the non-specialists in the field.
MagStREXS is a crystallographic computing program aimed to ease the analysis of REXS diffraction data for the study of magnetic structures. This software is based on both theoretical concepts and computing tools developed in the context of magnetic crystallography [3, 4], applying them to the analysis of data collected with the different experimental possibilities available in the REXS technique. Being under active development at beamline P09 (PETRA III, DESY), a beta version of MagStREXS is available on DESY computing platform for the users to analyse their data.
In this presentation, the fundamental equations implemented in MagStRES will be discussed, together with the main features available in the software. Finally, some examples of magnetic structures determined with this software will be presented to illustrate the main capabilities available in the current version.

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Talks Wed Morning / 94

Hyperspectral Imaging of Ultrafast and Nanoscale Phase Transitions in quantum Materials

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Using light to drive phase transitions in quantum materials is an emerging tool for inducing material properties "on demand"[1]. However, while we have many methods to measure the average change in material properties on the femtosecond timescale, observing the spatial dynamics of the phase transition with femtosecond time resolution has remained challenging.

In this work, I will summarize our recent work to use coherent diffractive imaging to image light-induced phase transitions in the quantum material vanadium dioxide (VO2) on the femtosecond timescale. In particular, I will show how spectrally-dependent imaging at the oxygen K and Vanadium L edges can be used to obtain contrast and identify phase transitions [2,3] and how the use of X-ray lasers enables direct measurement of the phase transition pathway [4]. In addition, I will present some unpublished work on the stability of light-induced domains and the recovery pathway for the light induced phase transition.

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Talks Wed Morning

Laser-driven resonant soft-X-ray scattering or probing picosecond dynamics o nanometre-scale order

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Magnetic domains are fingerprints of the complex interactions within magnetic materials. In addition to a local magnetic order, these emergent textures exhibit lateral periodicities on the nanoscale with a specific orientation and distribution. Statically, the relevant magnetic interactions can be tailored by growing heterostructures of magnetic nanolayers and by applying external stimuli such as magnetic fields and temperature changes. However, the laser-driven dynamics of magnetic domains result from an intricate interplay of local and non-local processes in the depth and in the plane of the sample.

Here, we investigate the ultrafast dynamics of magnetic maze domains in a ferrimagnetic [Fe(0.4nm)/Gd(0.5nm)]116 multilayer sample by time-resolved resonant magnetic small-angle-X-ray scattering (SAXS). This technique is an ideal tool to probe the local and lateral magnetic order element selectively on the relevant femto- to picosecond time and nanometer length scale - but so far the use of this approach has been exclusive to installations at X-ray free-electron lasers. We utilize a novel, laboratory-based setup for transient SAXS experiments at the Fe L (707 eV) and Gd M (1189 eV) absorption edges with 9-ps-temporal resolution [1-4] to benefit from the strong magnetic contrast and large penetration depths at such high photon energies.

Upon photoexcitation, we observe distinctively different time scales for the quenching and recovery of the local magnetization compared to the changes in the domain periodicity. In contrast to previous work [5-7], we find both a transient decrease and increase in the domain periodicity for different pump-probe delays. Based on a detailed analysis of the time-resolved SAXS signal in reciprocal space and heat diffusion simulations [8], we understand these results as indicators for a strongly inhomogeneous magnetic order along the depth of the 100-nm-thick sample.

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Talks Wed Morning

Complementary Insights into Ultraast Element- and Lengthscale-specific Dynamics

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The properties and functionalities of solids, molecules and hybrid compounds used in modern technology is dictated by the interplay between the electronic, lattice and spin degrees of freedoms. Pump-probe techniques are ideal to selectively investigate their time evolution and disentangle complex processes. Their extension to the Extreme Ultraviolet and X-ray regime allows element specificity and the possibility to access meso- and nanoscopic length scales.
In this talk I will introduce two spectroscopy techniques aiming at accessing the mesoscopic range, inaccessible with common optical laser spectroscopies or X-ray and neutron scattering experiments. I'll start by showing how Extreme Ultraviolet (EUV) Transient Grating spectroscopy, pioneered at the FERMI free electron laser, accesses thermo- and magnetoelastic properties of matter. Then, I'll discuss its complementarity with the recently demonstrated extension to the hard X-ray. Finally, I will present EUV diffuse scattering as a complementary technique and address how it could potentially be performed at synchrotrons with ps time resolution.

Talks Wed Morning

Skyrmion Dynamics Using FMR In Resonant Elastic X-ray Scattering

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Magnetic diffraction using x-ray detected ferromagnetic resonance (DFMR) offers a powerful and novel technique for performing time-resolved measurements on individual spin textures [1,2]. DFMR combines FMR and circular dichroism in REXS as pump and probe, respectively. This allows us to study the element-, layer-, and mode-selective magnetisation dynamics by stroboscopic probing, utilizing the time structure of the synchrotron (~500 MHz). The radio-frequency field that drives the spin precession is synchronized with the x-ray pulses using the clock of the synchrotron such that each x-ray pulse measures the magnetisation cone at precisely the same point in the precession cycle [3].

We studied the FMR modes of both the conical and field-polarized phases in the chiral magnet Cu2OSeO3 [4]. Following the identification of these modes at different temperatures using broadband vector network analyser FMR, we used DFMR on the crystalline (001) Bragg peak to reveal the time-dependent spin configurations of the selected FMR modes. By being able to measure both

the amplitude and phase response of the spin system across the resonance, a continuous phase advance (by 180°) in the conical mode and a phase lag (by −180°) in the field-polarized mode is found. By performing dynamic measurements in the conical phase as a function of the linear polarization angle of the x-rays, i.e., successively probing the dynamics of the moments, we found an inversion of the dynamics along the conical axis upon inverting the applied field direction. By enabling time-resolved measurements of the phase and amplitude of individual magnetic structures, DFMR opens new opportunities for obtaining a deeper understanding of the complex dynamics of chiral magnets.
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Talks Wed Morning

Ultrafast Spin-Wave Soliton Coupling To Lattice Dynamics

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Spin waves are the fundamental excitations in magnetic systems. At low densities, they behave as independent quasiparticles that can mediate solid-state interactions such as superconducting pairing or can be used to transport information in technology. At sufficiently high densities, spin waves can condense into solitons that derive their stability from nonlinear spin precession. Nonequilibrium conditions via demagnetization with a femtosecond (fs) laser pulse provide an alternative generation mechanism for spin-wave solitons [1] and skyrmions [2] as seen by time-resolved soft x-ray magnetic scattering [1,2]. Spin-wave solitons nucleated in FePt nanoparticles of ~16nm size are characterized by an in-plane spin precession at the soliton boundary. We have recently shown that this spin precession perturbs the lattice by means of the magneto-elastic coupling [3]. Here we show new experiments performed at the European XFEL that identify the formation of spin-wave soliton in the smaller FePt particles with the average size of 7 nm. Such a spin-wave soliton would have the smallest size of 5 nm, and the fastest precession frequency of 0.12 THz, observed so far. This new information allows us to address the scaling of spin-wave soliton in the FePt nanoparticles, as well as the aspects of spin-lattice coupling and other related non-equilibrium magnetic phenomena in material with exchange length approaching the atomic scale.
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Talks Wed Morning

Single-shot antierromagnetic switching in exchange biased IrMn/CoGd bilayer

Authors: Gregory Malinowski[1]; Jinxiao Lin[1]; Julius Hohlfeld[1]; Michel Hehn[1]; Nicolas Reyren[2]; Philippe Ohresser[3]; Stéphane Mangin[1]; Vincent Cros[2]; Yann Le Guen[1]; Zongxia GUO[3]

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Ultrafast manipulation of magnetic order has challenged our understanding of the fundamental and dynamic properties of magnetic materials. Until now, single-shot magnetic switching has been limited to ferrimagnetic alloys, multilayers, and engineered ferromagnetic heterostructures [1-2]. In ferromagnetic (FM)/antiferromagnetic (AFM) bilayers, the exchange bias field (He) arises from interfacial exchange coupling and reflects the microscopic orientation of the antiferromagnet [3]. In our previous studies, we demonstrated single-shot switching of the antiferromagnet using a single femtosecond laser pulse in IrMn/CoGd bilayers (ref). We have shown that the exchange bias field can be manipulated across a wide range of laser fluences, layer thicknesses, and compositions [4]. We will show in the presentation that using element-specific circular dichroism X-ray resonant magnetic scattering (CD-XRMS), we can directly probe the depth and temperature dependence of uncompensated antiferromagnetic spins at the IrMn/CoGd interface. A time-resolved CD-XRMS experiment is scheduled at the FERMI free-electron laser facility to further investigate the ultrafast switching dynamics of Co and Mn in an element-selective manner. These dynamics are expected to reinforce our observation of ultrafast exchange bias switching. Our results present the fastest and most energy-efficient method for setting the exchange bias to date, opening new avenues for ultrafast spintronic device applications.

Talks Wed Afternoon

Ultrafast Control of Electron-Phonon Coupling in LNSCO and LESCO

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The emergence of d-wave superconductivity from the Mott insulating state in the cuprates is widely understood to result from the action of strong electron-electron interactions. Nevertheless, the parallel role of the electron-phonon interaction in defining the cuprate phase-diagram is highlighted by the ubiquitous presence of charge-density-wave correlations in these materials. Although non-equilibrium studies have reported the observation of a transient superconducting state generated in response to the resonant pumping of select phonon modes [1], relatively little is understood about the dynamic properties of the electron-phonon interaction itself. Using time-resolved resonant x-ray scattering from $La_{1.65}Eu_{0.2}Sr_{0.15}CuO_4$ we studied the dynamic evolution of charge-density-wave order in response to ultrafast optical excitation, as a function of temperature and excitation fluence [2]. In a recent follow-up investigation, we tracked the corresponding structural dynamics across a wide doping range in both $La_{1.6-x}Nd_{0.4}Sr_xCuO_4$ and $La_{1.8-x}Eu_{0.2}Sr_xCuO_4$, which demonstrates that the transfer of energy from the transiently excited electronic system to the lattice becomes more rapid by at least one order of magnitude when entering the charge-density-wave phase. Most intriguingly, we demonstrate that the electron-phonon interaction strength can be renormalized by manipulating electronic degrees of freedom alone, thereby allowing ultrafast control of the electron-phonon coupling in these cuprates.

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Talks Wed Afternoon

Twists and Turns: Exploiting Azimuthal Dependences in the Ultrafast Time Domain

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Ultrafast spin manipulation carries great potential for future information technology. Ferromagnets, which are commonly studied in this context, are limited by the dissipation of angular momentum. This is not the case for antiferromagnets, which offer both the prospect of faster and more efficient spin dynamics, as well as the possibility to exploit magnetic properties that are unavailable in ferromagnets. One such property is the internal arrangement of the spins. Controlling this arrangement can alter how the antiferromagnet stores data, interacts with neighboring materials, and more.
Resonant X-ray diffraction is commonly used to study spin arrangements in antiferro-magnets, and the azimuthal dependence of diffracted intensity can be collected. This information is particularly important when the Ewald sphere is limited by the use of soft X-ray resonance, so only a few reflections can be recorded.
Here I will discuss femtosecond soft X-ray resonant diffraction studies of antiferromagnetic spin dynamics. In these projects we take advantage of azimuthal angle dependences to disentangle the rearrangement of spin order from the "usual"demagnetization. We demonstrate deterministic ultrafast control of the spin arrangement, and we use the dynamic azimuthal data to retrieve intrinsic material properties associated with the spin dynamics.
The materials of focus are Lanthanide-based intermetallics [1-3].

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Talks Wed Afternoon

Ultrafast dynamics of magnetic anisotropy and magnetic structure in ferrimagnetic CoTb thin films

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Since the discovery of ultrafast demagnetization occurring on sub-picosecond timescales [1], numerous intriguing phenomena have been observed, especially in ferrimagnetic rare-earth (RE)–transition metal (TM) alloys [2]. In these materials, the two sub- systems exhibit distinct ultrafast magnetization dynamics when subjected to a femtosecond infrared pulse. For exemple, this has also been observed in CoTb thin films [3], but Co and Tb were probed separately so far, preventing the study of a possible difference in the onset of the Co and Tb demagnetization as seen in other alloys [4]. Furthermore, the optically-induced change of the magnetic structure observed in [3] highlights the need for systematic measurements.

We performed time-resolved Small-Angle X-ray Scattering (Tr-SAXS) at the DIPROI beamline (FERMI) to study CoTb alloys after femtosecond laser excitation. Using FERMI's dual-wavelength X-ray pulses, we probed simultaneously Co 3d and Tb 4f electrons at their respective absorption edges (58.9 eV and 150.5 eV), enabling element-specific, nanometer-resolved magnetization dynamics. By fitting the azimuthal integration of the scattered intensity we can extract the dynamics of the magnetization amplitude, domain size and domain size distribution for both TM and RE. We observed two demagnetization regimes: a fast sub-ps quenching and a slower picosecond-scale reduction, linked to anisotropy changes. Additionally, we detected a 2% domain size reduction within 500 ps and the emergence of a surface acoustic wave mediated by sample roughness [5].

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Talks Wed Afternoon

Magnetic Field Dependent Ultraast Control o an Antierromagnet

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Antiferromagnetic (AF) spintronics is a promising route towards more efficient and stable devices, because antiferromagnets are less susceptible to external fields and foster a broad range of magnetic interactions with the potential for higher speeds and energy efficient manipulation. However, their self-cancelling magnetic moment makes the interaction with magnetic order challenging. One way to achieve this is to utilize the magnetic anisotropy (MA) to manipulate the spin arrangement which was demonstrated recently using ultrafast optical excitation [1]. External magnetic fields, as regularly used in ferromagnetic materials, can also have a strong influence on MA, providing an additional control knob on the AF magnetic order. Therefore, understanding the interaction of laser excitation induced transient MA with magnetic fields is of strong interest. To this end, we perform femtosecond time-resolved resonant soft X-ray diffraction (RSXRD) in the prototypical A-type antiferromagnet GdRh2Si2. Consistent with our previous study, we observe an ultrafast rotation of the

AF arrangement of Gd 4f spins followed by coherent oscillations of the AF order as a consequence of a light-induced change in the MA potential.
Remarkably, while the AF order undergoes a spin-flop transition upon increasing magnetic field, the oscillations persist and their frequency increases while the amplitude of reorientation upon photoexcitation reverses its direction. To understand our observations, a phenomenological model is built based on the MA potential and Zeeman energy as two competing mechanisms, which reproduces the key features of the observed ultrafast dynamics. Our results demonstrate magnetic field control of the MA potential and may offer a new way towards deterministic control of spin order using combined electromagnetic and magnetic fields.
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Talks Wed Afternoon

Variable out-of-plane magnetic field or soft x-ray resonant magnetic reflectivity

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It has been known that soft x-ray magnetic reflectivity is a technique for studying the magnetization profile, and therefore interfacial effects, in thin films with perpendicular magnetic anisotropy [1]. This specificity is related to the photon wavelength in the energy range, which allows measuring the reflectivity at very large angles and therefore being sensitive to the out-of-plane component of the magnetization [2]. Until now, studies were limited to magnetic layers whose magnetization was close to saturation at remanence [1,3,4].
We report on the implementation of a new magnetic device in the RESOXS chamber dedicated to x-ray resonant magnetic scattering and reflectivity in the soft x-ray range at the SEXTANTS beam line at SOLEIL. Based on five water cooled coils, it allows not only to applied the magnetic field in all the directions in the sample plane but also perpendicular to it. The amplitude of the field can be varied from -0.7 to +0.7T in the sample plane, which represents an increase by a factor 3.5 with respect to the initial device, and from -0.4 to +0.4T out-of-plane (-0.7 to 0.7 is aimed shortly) which is unique in the world to the best of our knowledge. The magnetization device allows reflectivity measurements over a large angular range, from 0 to 72° in the horizontal plane. The device capabilities (Fig. 1a) are illustrated by out-of-plane hysteresis loops exhibiting inversion sequences of 2- and 5-layer magnetic heterostructures at large and small applied field, respectively (Figs. 1a and 1b). Figure 1c displays the magnetic asymmetry variations at 3 particular field values for the latter. A reorganization of a skyrmion lattice induced by out-of-plane field was also evidenced (Fig. 1e) using CD-REXS [5].

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Talks Wed Afternoon

Helimagnetic Order in MnGe Thin Films Probed by RXMR

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MnGe is a cubic helimagnet belonging to the B20 family of compounds known to host skyrmion phases. MnGe exhibits the shortest helical wavelength among these compounds that varies between 3 nm at low temperature, up to 6 nm at the ordering temperature near 200 K. While skyrmions have not been observed in this material, there are reports of a unique topological magnetic phase consisting of localized three-dimensional spin textures called spin-hedgehogs at low temperature [1]. Other studies claim that this phase is not topological, but rather a multi-domain helical state [2,3].

We present a study of MnGe(111) films where the thickness is comparable to the helical pitch. In this thickness limit, the twisting of the magnetic textures at the surfaces play an important role in the stability of the magnetic phases. The growth of MnGe films was facilitated by the development of atomically smooth non-magnetic B20 CrSi buffer layers on Si(111) substrates, which replaced the need for the magnetic B20 MnSi or FeGe layers used by others [1,2]. MnGe films with thicknesses between 2.5 nm and 23 nm were measured by resonant X-ray magnetic reflectometery (RXMR). For the thicker films, RXMR shows helical magnetic order that has a wavelength that is shorter than bulk, and with wavevector along the film normal. At low temperature, no evidence of topological textures was found. For film thicknesses below 9 nm, we discovered evidence for a reorientation of the helical state from out-of-plane to in-plane, revealing the influence of surfaces twists in this material.

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Talks Wed Afternoon

Current-driven Magnetisation Reversal in CoFeTaB/Pt Probed By X-ray Magnetic Reflectivity

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ABSTRACT
Electrical control of magnetisation offers a promising alternative to conventional external magnetic fields for manipulating magnetic materials. This work investigates the current driven magnetisation

reversal in CoFeTaB/Pt taking advantage of the magnetisation direction and the polarisation dependence of the X-ray scattering cross-section [1]. A current is applied perpendicular to the scattering plane to induce magnetisation reorientation within the plane [2]. Hysteresis curves are measured during the current cycle using both positive circular (pc) and negative circular (nc) polarisation at Fe-L3 resonance. The asymmetry ratios ((Rpc-Rnc)/(Rpc+Rnc)) derived from the X-ray magnetic reflectivity (XRMR) measured during the current cycle indicate transitions between two magnetic states. The XRMR measurements are performed in these magnetic states with circular polarisation as a function of angle. The asymmetry ratios in this case show slight variations in both magnetic states. The measurements with linear polarisation (sensitive to the out of scattering plane components of magnetisation) show significant asymmetries, suggesting a substantial perpendicular magnetisation component in the current-driven states and hence, incomplete magnetisation switching with applied current [3]. The optical modelling suggests that the magnetisation switching occurs primarily in the region close to the interface. Therefore, the interfacial magnetisation is probed by proximity-induced magnetism in the Pt layer. The XRMR measurements at Pt L3 edge during a current cycle reveal a hysteresis curve with sharp transitions between two magnetic states. The measurements on field driven hysteresis curves show that the Pt moments are aligned transverse to the bulk CoFeTaB magnetisation. The application of electric current results in the reorientation of this transverse magnetisation only, resulting in the incomplete magnetisation switching of the film.
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Talks Wed Afternoon

Spiral Spin Structure in Dy-Doped Spinel-Ferrite

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Noncollinear spin structures have received tremendous interest in recent years as they provide a versatile platform for spin control and manipulation desirable for spintronics1. Realization of noncollinearity in ferrimagnetic insulators is of particular interest as the combined effect of both ferro- and antiferromagnetic orders opens up opportunities for their potential utilization in low-damping spintronic devices with desirable magnetic order and minimal stray fields2.

Inverse spinel nickel ferrite is a classical ferrimagnetic insulator with a collinear in-plane magnetic structure3. The substitution of Zn and Al in the nickel ferrite (NiZAF) makes it an excellent choice especially for low-damping spintronics4. However, the realization of noncollinearity together with low-damping has remained challenging so far. Here we show
the evidence of noncollinearity in the ultrathin films (3-5 nm thickness) of NiZAF induced by the rare earth ion Dy3+-doping. Motivated by our in-house laboratory measurements (SQUID and MOKE)

and XMCD experiments using synchrotron x-rays, we performed soft x-ray resonant magnetic reflectivity (XRMR)5 and related simulations to probe the magnetic depth profile. The magnetic asymmetry analysis for the Fe-L3 edge (Fig. 1a) using Dyna software shows nice agreement for a model considering an in-plane spiral-type spin structure with weak out-of-plane magnetization component, confirming the noncollinear (and noncoplanar) spin- configuration in the Dy-doped NiZAF. This spiral spin structure for the Fe-spins is sketched in Fig. 1b. We attribute the stabilization of such noncollinearity to the formation of a local strain field created by the Dy3+ (evidenced by Dy-L3 EXAFS analysis) thereby involving local space- inversion symmetry breaking and emergence of asymmetric Dzyaloshinskii-Moriya interaction.This is supported by our first-principle DFT calculations.
The realization of noncollinear spin structure in the insulating spinel-ferrite opens further pathway to explore the possibility of chiral magnetic domain and topological spin textures (e. g., skyrmions) potential for the oxide-based spintronic applications.
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Talks Thursday Morning

Magnetic REXS and absorption imaging at different lengthscales

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Magnetic REXS (RMXS) has been used for many years as a complementary tool to neutron scattering for the determination of magnetic structures. Although limited in many cases by the small size of the Ewald sphere, RMXS has two great advantages over neutron scattering: firstly, an exquisite control of the incident and scattered polarisation, analogous to neutron spherical polarimetry (NSP) but without the requirement of zero magnetic field on the sample; and, secondly, beam spots in the range of tens of micrometers, enabling one to isolate and study individual domains in multi-domain samples and to image them as a function of parameters such as temperature, magnetic and electric fields. These approaches were successfully applied to the field of multiferroics1,2, where one encounters particularly rich phase diagrams that are highly suitable for RMXS imaging at these length scales. In these studies, limited attention was often paid to the underlying spectroscopy: a common approach was to maximise the magnetic resonance signal and assume that this arose principally from a E1-F(1) term with spherical symmetry.

Later, a growth of interest for real-space topological structures such as skyrmions prompted a significant evolution of this approach. The highly disordered nature3,4-6 or sometimes the complete absence of a magnetic lattice or propagation vector drove the requirements for much higher resolution in real space, down to a few nanometres. Moreover, individual topological structures are much larger than the structural unit cell, which means that most of the magnetic scattering occurs at small angle even with soft X-rays. A natural connection can then be made, via the optical theorem and the Kramers–Kronig relation, between RMXS and related scattering techniques and X-ray absorption spectroscopy (XAS) and imaging. In particular, the well-developed spectroscopic framework developed in the context of XAS is increasingly being employed for RMXS and RMX imaging, very often in conjunction with real-space reconstruction of RMX images via holography7 and ptychography.

The current worldwide trend in synchrotron radiation source upgrades is heralding a true revolution in the way we think about magnetic scattering. Dichroic small-angle RMXS imaging in 2D (ptychography) and 3D (laminography) will become routine, thanks to powerful real-time image

reconstruction techniques. Two challenges can be envisaged in the near future: to design suitable sample environments (especially difficult with soft X-rays) and to exploit the full spectroscopic and tensorial framework beyond the 'pretty pictures'.

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Talks Thursday Morning

Helicities o Magnetic Skyrmion Lattices Studied by Circularly Polarized Resonant X-ray Scattering

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In noncentrosymmetric magnetic materials, various types of nontrivial magnetic structures are realized as a result of competing interactions of symmetric magnetic exchange interaction, Dzyaloshinskii-Moriya type antisymmetric exchange interaction, and Zeeman energy in external magnetic fields, especially in Gd and Eu compounds with weak crystal field anisotropy. In many cases, they are non-collinear or non-coplanar structures associated with incommensurate spiral ordering. In this talk, we focus on the tetragonal EuTGe3 family without an inversion center but with mirror planes including the c-axis (space group I4mm). From our recent studies on EuIrGe3, EuNiGe3, and EuRhGe3, using circularly polarized resonant X-ray diffraction to investigate magnetic helicities, it was clarified that each compound exhibits distinctive ordering phenomena reflecting competing interactions. In EuIrGe3, successive transitions take place from sinusoidal (m || c) to cycloidal (m || ac or bc) structures with a tiny reorientation of the propagation vector from q=(0, 0, 0.792) to (0.017, 0, 0.792). Each of the four cycloidal domains has its own helicity. In EuNiGe3, single-q helical ordering at zero field with q=(0.26, 0.053, 0) transforms into a triple-q distorted triangular skyrmion lattice state in a magnetic field. Surprisingly, the original helicity at zero field is reversed to form a skyrmion lattice with unified helicity. In EuRhGe3, in contrast, the helical order propagating along the c-axis is free from the antisymmetric interaction.

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Talks Thursday Morning

Microscopic Interactions in Skyrmion Hosts Via Spatiotemporal Lattice Dynamics

Talks Thursday Morning

Soft X-ray C orrelation S pectroscopy a t F ourth G eneration Synchrotron Source to Investigate Domain Fluctuations in Ho

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Non-colinear spin structures have gained interest due to their connection to multiferroicity. One of most well-known examples of such materials is the helical antiferromagnetic Holmium. The occurrence of domain-wall fluctuations over a wide range of time scales has been observed [1]. These fluctuations show a slow dynamic on the order of nanoseconds to seconds and are important to understand thermally-activated magnetization reversal processes. In order to probe these dynamics, techniques with nanometer spatial resolution and nanosecond temporal resolution are necessary and thus making X-ray photon correlation spectroscopy (XPCS) the ideal method. However, the temporal resolution in the soft X-ray range is often-case still limited, among others due to the detector as well the lack of coherent soft X-ray scattering beamlines in fourth-generation sources. Until now, the dynamics of Ho on the micro- to nanosecond scale has therefore not been investigated yet.

In order to increase the temporal resolution in XPCS, we have recently commissioned a mobile resonant scattering endstation at the new coherent scattering beamline SoftiMAX at the fourth-generation synchrotron source MAX IV, Sweden. Even with a slow readout CCD, this setup combined with the high coherent flux provided new intriguing insights into the dynamics of domain fluctuations: Over only a small temperature range of 10 K the dynamics change by more than two orders of magnitude. In the long-term, the goal of this instrument is to push the resolution down to the nanosecond scale and enable single-shot XPCS in the soft X-range at synchrotrons.

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Talks Thursday Morning

Investigating Charge Density Waves with Resonant Scattering

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High-Tc superconductors represent one of the most intriguing challenges of condensed matter physics. Over the years, plenty of effort has been devoted to address two fundamental questions: What is the microscopic mechanism for superconductivity and how can the superconducting transition temperature be elevated?
Although these questions remain still unanswered, it has been revealed that in several unconventional superconductors the superconducting phase co-exists and sometimes competes with other types of order like charge density waves (CDW), nematic order and several forms of magnetic order.
Consequently, a possible way to optimize superconductivity could arise from tunning the relationship between superconductivity and other existing ordered phases. To be able to accomplish this, identifying and understanding ordered phases in unconventional superconductors is essential.
In this talk it will be presented how over the last decade Resonant X-ray Scattering has emerged as a unique tool to investigate CDW and more precisely how the new generation of Resonant Inelastic X-Ray Scattering (RIXS) beamlines have contributed to these studies.

Talks Thursday Morning

Resonant Scattering Investigations o Density Wave Ordering in the Bilayer Nickelate La3Ni2O7

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The discovery of high-temperature superconductivity in La3Ni2O7 under has motivated the investigation of parent or competing phases which could shed light on the underlying pairing interaction and phase diagram. Here, we employ resonant elastic and inelastic soft x-ray scattering and polarimetry on thin films of bilayer La3Ni2O7 to reveal the existing of a spin density wave (SDW) which forms unidirectional diagonal spin stripes with moments lying within the NiO2 plane and perpendicular to the SDW wavevector. These stripes form anisotropic domains with shorter correlation lengths perpendicular versus parallel to the SDW wavevector, revealing nanoscale rotational and translational symmetry breaking analogous to the cuprate and Fe-based superconductors [1]. In addition, we also investigate another polymorph of La3Ni2O7, a repeating monolayer-trilayer structure (so-called "1313") and compare the magnetic excitations and ordering between the two polymorphs.

Talks Thursday Morning

Anisotropic Mesoscale Spin Structures In Non-Centrosymmetric Magnets Unveiled By Resonant Small-Angle X-ray Scattering

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Resonant elastic small-angle soft x-ray scattering (SAXS) is a unique and powerful tool that offers ultimate reciprocal-space resolution, enabling the study of long-periodic spin textures in noncentrosymmetric magnets. Its distinctive sample environment facilitates the exploration of previously uncharted spin texture transformations and allows for the extraction of small parameters that are inaccessible through other methods [1,2]. In this comprehensive study, we present recent SAXS studies on the noncentrosymmetric magnets Co8Zn8Mn4 and FeNiPdP.
Co8Zn8Mn4 is a cubic chiral magnet that hosts Bloch-type skyrmions at room temperature. Here, we employed SAXS in a vector magnetic field to control the propagation vector of magnetic spirals in order to extract the magnitude of anisotropic exchange interaction (AEI) as a function of temperature [2].

FeNiPdP (space group I$\bar{4}$m2) has demonstrated the ability to host antiskyrmion spin textures [3] at room temperature [4]. Furthermore, due to the interplay between anisotropic Dzyaloshinskii-Moriya interaction and dipolar interaction, these textures can transform into elliptic Bloch-type skyrmions or non-topological magnetic bubbles when subjected to magnetic fields applied at an angle to the sample's c-axis. Previous studies using Lorentz transmission electron microscopy (LTEM) were limited to investigating tilting angles of up to approximately 45 degrees. In contrast, advancements in soft x-ray instrumentation now allow for the investigation of nanometric magnetic modulations under extreme sample conditions through resonant SAXS.

These comprehensive studies using SAXS not only reveal the rich and exotic magnetic phase diagrams of noncentrosymmetric magnets but also enhance their tunability, providing a significant platform for further fundamental research and potential applications in energy-saving technologies.

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Talks Thursday Morning

From π-CSL to fan:a topological phase transition in one dimension

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: In the centre of our here presented work was the Heusler compound Mn1.4PtSn characterized by anisotropic DMI and known to host various chiral spin textures. In this study, we employed a combination of REXS and micromagnetic simulations to reveal distinct features consistent with a fan-like [1] spin structure and its field driven evolution under increasing in-plane magnetic fields. Starting from the chiral ground state (π-CSL [2]) of Mn1.4PtSn, this field-induced transition is accompanied by a change in the quasi-one-dimensional magnetic topology via symmetry breaking. The resulting fan state exhibits oscillatory spin arrangements confined to a finite angular range about the field direction and lacks topological winding.
Fan structures are traditionally observed in non-chiral systems such as Yoshimori-type helimagnets, where competing nearest- and next-nearest-neighbor exchange interactions stabilize helices of both chiralities [2]. These can smoothly transform into fan phases under transverse magnetic fields without an energy penalty [1,4]. In contrast, the emergence of a fan-like spin texture in chiral magnets such as Mn1.4PtSn is unusual. Here, DMI enforces a fixed chirality, making the fan energetically unfavorable by the DMI [1]. Historically, this has excluded fan states from consideration in DMI-active systems.
Only recently, LTEM studies on the monoaxial helimagnet MnNb3S6 have reported domain-like patterns reminiscent of fan structures [6,7]. However, due to limited spatial resolution and similarities with stripe phases, these observations remain inconclusive [8]. Building on these findings, we present the first unambiguous experimental identification of fan-like magnetic textures in a chiral magnet, resolving ambiguities that have limited previous observations.

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Talks Friday Morning

Polarisation Analysis In Coherent X-ray Scattering Measurements

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Methods using coherent X-ray beams have blossomed with 3rd generation facilities and are now benefiting from the huge brilliance increase of 4th generation facilities. The interest in combining the REXS contrast with X-ray coherence has been recognised very early [1].
Coherence-based methods rely on the measurement of a portion of the reciprocal space with a 2D detector. Data analysis tools, developed for the vastly dominant case of Thomson scattering, assume a uniform polarisation of the scattered X-rays. This assumption does not hold when REXS is involved, except in a few particular cases, due to its complex polarisation dependence [2]. Extraction of the REXS contrast then requires varying the polarisation of the incident beam and/or analysing the scattered beam, which is routinely done with point detectors but not with 2D detectors.

I will present a few ideas and results about the possibility to perform a polarisation analysis with a physical analyser and with an algorithmic analyser [3].

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Talks Friday Morning

X-Ray Beams with Orbital Angular Momentum: Resonant Scattering and Coherent Imaging

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The interaction of polarized light beams with magnetic materials defines the rich set of tools in magneto-optics, covering photon energies from infra-red to hard x-rays. Circular polarization imprints a well-defined handedness on the photon beam, associated with a spin angular momentum (SAM) $\sigma = \pm 1$. It remains less common to exploit the orbital angular momentum (OAM) of value L ($\epsilon \mathbb{Z}$) carried by light vortices, i.e. by photon beams characterized by a helical wavefront determined by the azimuthal angular dependence of the electric field phase. Nonetheless, the use of OAM beams in the visible range has found important applications over the last three decades [1].

More recently, the generation of OAM beams at shorter wavelengths, from XUV to hard x-rays [2-7], is also finding an increasing number of applications, often based on extrapolations of previous work carried out in the visible range. For instance, as it happened for the SAM, it was shown that the handedness imposed by the OAM can be exploited to perform x-ray spectroscopic studies of magnetic materials [4] and of chiral molecules [5], and a recent ptychography study [6] showed that the attainable spatial resolution in the reconstructed XUV images increases with ℓ.

We will review recent extensions of OAM beams from visible to shorter wavelengths, with focus on potential applications in element-selective x-ray spectroscopy and imaging at synchrotron and free-electron laser sources [7].

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Talks Friday Morning

Soft X-ray Transmission Holography at ESRF

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The soft X-ray beamline at ESRF (ID32) provides X-rays in the energy range 400 eV –1800 eV to perform polarization dependent spectroscopic studies of magnetic and electronic properties of matter, with the main end-stations specialized in X-ray Resonant Inelastic Scattering (RIXS) and X-ray Magnetic Circular Dichroism (XMCD) measurements. In addition, a small side-station located in the experimental room designed to host specific and/or user end-stations is dedicated to transmission holography experiments on magnetic samples, with time-resolved and 3D magnetic holotomography capabilities.

The end-station is equipped with a fast scientific grade fully in-vacuum sCMOS camera from Axis Photonique (developed by synchrotron SOLEIL), provides a 0.4 T magnetic field along the beam direction and a combination of sample rotations and translations enabling a variety of holographic measurements to be performed.
Examples on studies of magnetic vortices, Landau domain wall structures and 3d magnetic tomoholography together with a detailed description of the experimental setup will be given.

The Extremely Brilliant Source (ESRF upgrade phase 2) has boosted the partial degree of coherence of the ID32 source by a factor 10, approaching 50%, satisfactorily preserved throughout the numerous beamline optical elements. The examples listed above will illustrate how challenging coherent scattering experiments on magnetic materials can be better (or more easily) performed on a beamline optimized for magnetism rather than coherence.

Talks Friday Morning

Magnetic nano-domain microscopy and topology-sensitive modelling in Fe_3GeTe_2

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ABSTRACT

Fe_3GeTe_2 (FGT) is a layered ferromagnetic solid with a Curie temperature of TC ≈ 205K. It is a layered material with out-of-plane magnetic anisotropy. We have performed microscopy investigations of the magnetic nano-domain structures in thin flakes of FGT. The data are acquired using the Fourier Transform Holography (FTH) technique with circular dichroism contrast at the iron L3 edge [1]. These studies complement measurements by scanning x-ray techniques [2], but the extension over a large range of temperatures and applied magnetic fields (B) allows for the creation of specific initial states by cooling from the paramagnetic phase through TC. We observe labyrinthine domains as well as small objects that are identified as Skyrmions. At low temperature, various structures emerge with increasing B field, and the patterns are readily erased by fields exceeding the coercivity. At high temperature, the Skyrmions are denser and re-emerge after reducing the B field.
The experimental study is complemented by modelling calculations based on band structure models with spin-orbit interactions explicitly considered [3]. The corresponding patterns match, and the trends on Skyrmion density in changing B fields are found to be qualitatively different for temperature well below TC and close to TC. This study allows us to conclude on the controllable transformation between these topological states in relation to the temperature dependence of the electronic band structure in FGT.

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Talks Friday Morning

X-ray/XUV Coherence Isolated Diffraction Imaging

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Coherent X-ray imaging is widely used to image nanoscale structures with high spatial resolution [1], and more recently to spatiotemporal dynamics [2]. However additional stochastic dynamics or birefringence of the sample lead to secondary scattering terms in diffractive signals. At high intensities in pump-probe experiments it is even possible to generate additional non-linear frequency shifted signals. Due to mutual incoherence of the probe signal and these additional components, these kinds of signals do not appear in the reconstructions of Fourier Transform Holography (FTH) and Coherent Diffraction Imaging (CDI) but can be of great significance to understanding the material properties. Recent efforts have shown the possibility of tracking fluctuations [3] to improve reconstruction or isolate the additional components through multi-wavelength CDI [4–6].

Here we present a framework called Coherence Isolated Diffraction Imaging (CIDI) to address these issues [7]. Leveraging the property of mutual incoherence, CIDI is capable of isolating additional signals from the diffracted probe and reconstructing both components separately from a single dataset. We demonstrate the working principle of CIDI and show the applicability of the method to isolate stochastic dynamics in nanoscale quantum materials, birefringent systems and ultrafast nonlinear processes in the X-ray domain.

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Talks Friday Morning

Spectroscopic Bragg Coherent Diffraction Imaging oSingle Nanoparticles

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Characterizing nanoscale displacement fields, compositional variations, and defects in heterogeneous catalysts remains a central challenge in materials science and energy-conversion research.

Bragg coherent diffraction imaging (BCDI) [1] can deliver three-dimensional strain maps with nanometre resolution, yet chemical inhomogeneities often blur the distinction between strain and compositional contributions. This is an especially acute issue for chemically heterogeneous structures such as NiFe and PtPd, climate-critical alloyed bimetallic catalysts used in CO_2 hydrogenation. This underscores the need for high-resolution chemical and spatial analysis of catalysts during catalytic reactions.

We are therefore developping a nano-focused 3D spectroscopic Bragg coherent imaging technique at the nanoprobe ID01-EBS beamline of The European Synchrotron (ESRF). By combining BCDI with multiwavelength anomalous diffraction (MAD) [2], the spectro-BCDI technique will be used to reveal both chemical (oxidation states and bond structure) and structural (lattice strain, defect(s), morphology, composition) information of nanocatalysts under in-situ conditions to extract a mechanistic understanding for designing both effective and selective catalysts. By applying 3D spectroscopic BCDI, we aim to uncover critical information about the dynamic behavior of catalysts under working conditions. Nano-focused diffraction anomalous fine structure (DAFS) and fluorescence spectroscopy are applied as well [3].

This talk will present the application of the spectro-BCDI technique through simulations, complemented by experimental results.

Talks Friday Morning

Lensless coherent imaging o nanoscale magnetic domains in 2D van-der-Waals materials

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Here, we present lensless coherent soft X-ray imaging of magnetic domains [1] in two-dimensional (2D) van der Waals (vdW) materials[2] at low temperatures and under strong magnetic fields. By integrating micron-scale flakes of 2D materials onto nano-fabricated holography masks—either through deterministic transfer in an inert-air glove box or via focused ion beam lamella preparation—we expand the applicability of soft X-ray holography to this emerging class of materials. This robus and versatile approach, illustrated in Figure 1, also enables the study of air-sensitive systems. We apply it to probe complex magnetic domain structures and non-collinear spin configurations in various 2D vdW compounds at temperatures as low as 20 K and magnetic fields up to 2 T.

In addition to Fourier transform holography, we utilize holography-assisted phase retrieval [3] to enhance spatial resolution. Our results highlight the potential of lensless soft X-ray imaging—leveraging circular and linear dichroism, as well as element-specific contrast—to reveal nanoscale magnetic and electronic phenomena in 2D magnetic materials and related device architectures.

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AMaChaS –Advanced Materials Characterization System, MSCA-IF EU project # 101018445.
Stemin2D-Sync –MINECO project MCIN/AEI PID2023-146354NB-C43,C41Figure 1: Methodology flow for lensless

Talks Friday Morning

Final Wrap up - Discussion and REXS conference outlook

Local and International Committee Chairs

Poster session Tuesday

Structural origin of resonant diffraction in RuO2

Connor A. Occhialini[1,2], Christie Nelson[1], Alessandro Bombardi[3], Shiyu Fan[1], Raul Acevedo-Esteves[1], Riccardo Comin[4], Dmitri N. Basov[2], Maki Musashi[5], Masashi Kawasaki[5], Masaki Uchida[6], Hoydoo You[7], John Mitchell[7], Valentina Bisogni[1], Claudio Mazzoli[1], Jonathan Pelliciari[1]

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Metallic RuO2 has been the subject of intense scrutiny following reports of anomalous antiferromagnetic (AFM) order [1,2] and the subsequent theoretical development of altermagnetism [3]. Despite being initially regarded as a representative altermagnet, recent studies have called into question the existence of magnetic order – in any form – in bulk RuO2 [4-6]. Here, we closely re-examine the origins of the reported resonant diffraction at the Ru L-edges [2], which provided the initial evidence of AFM order in thin films. Previous reports studied the Bragg-forbidden Q = (100) reflection, where the expected AFM and Templeton-Templeton (TT) scattering contributions from the rutile structure overlap exactly and cannot be disentangled. We thus investigate the distinct Bragg-forbidden Q = (001) versus temperature, azimuthal angle and incident energy, where AFM and TT scattering contributions can be clearly separated. We find that the resonant diffraction signal is fully consistent with TT scattering, as supported by azimuthal angle dependence and non-magnetic FDMNES calculations. Using the calculated resonance profiles for the TT and AFM contributions, we provide an estimated bound on the local ordered AFM moments of $|m| < 0.1$ μB/Ru. Analogous measurements on high-quality (001) RuO2/TiO2 thin films grown by molecular beam epitaxy support the same conclusions. Combined with other recent reports, these results are consistent with the absence of k = 0 AFM order in RuO2. This work is timely as space groups supporting altermagnetism are likely to present a similar phenomenology in resonant diffraction with overlapping TT and AFM contributions at forbidden reflections.

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Poster session Tuesday

Structural origin of resonant diffraction in RuO2

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Resonant diffuse scattering in metallic VO2

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Metal-Insulator transitions are among the most active topics in condensed matter physics. The electronic transition takes place concomitantly with a structural transition, making it hard to disentangle the underlying mechanism. Two scenarios are possible and are at the core of an unresolved and longstanding debate: i) the transition is driven by purely electronic interactions or ii) it is driven by electron-phonon coupling.
Using VO2 as case study, we investigated the nature of electronic and structural fluctuations within the metallic state by measuring resonant and off-resonance diffuse scattering. We found strong, pre-transitional structural fluctuations above Tc, which show no enhancement on resonance. Our results hint that structural and electronic fluctuations are strongly coupled in metallic VO2, supporting electron-phonon coupling as the driver of the metal-insulator transition.

Poster session Tuesday

REXS experimental stations at beamline P09 at PETRA III at DESY

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At PETRA III at DESY, at beamline P09, two experimental stations are dedicated to resonant X-ray diffraction (REXS), each one equipped with different diffractometers to accomodate either light- or heavy-weight sample environments. Low temperature experiments can be performed in combination with either magnetic fields up to 14 T or high pressure until 20 GPa allowing it to investigate a diversity of long range ordered phases in strongly correlated and magnetic materials. State-of-the-art polarization control and analysis are available in a wide range of energy from 3.0 to 13.5 keV, for which dedicated data analysis pipelines are available for fast analysis of the Stokes parameters, allowing it either to disentangle between different order parameters or eventually perform full magnetic structure determinations. Hereby, I will present an update of the REXS capabilities at beamline P09 at PETRA III and some related recent highlights.

Many-Body Interactions in Room-Temperature Van der Waals Magnet Fe5GeTe2

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The complex ground states of recently discovered two-dimensional (2D) magnets with Curie temperatures near room temperature present exciting opportunities for functional spintronic devices, but remain poorly understood. We investigate the electronic and magnetic excitations in the van der Waals ferromagnet Fe5GeTe2 (Tc=300K) using angle-resolved photoemission spectroscopy (ARPES) and resonant inelastic X-ray scattering (RIXS). ARPES measurements reveal a pronounced kink in the band dispersion below the Curie temperature, indicating strong many-body interactions. Complementary RIXS spectra exhibit multiple energy loss features and point to electron-magnon coupling. These findings highlight the interplay between electronic structure and magnetic excitations in Fe5GeTe2 and its potential in room-temperature 2D spintronic applications.

Poster session Tuesday

The Materials and Magnetism Beamline, I16 a t Diamond Light Source

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I16 is a high flux, high resolution x-ray beamline based at the Diamond Light Source. The beamline operates in the 2.7-15 KeV range and it is a diffraction facility optimized for the study of resonant and magnetic scattering processes from single crystal samples [1]. Resonant elastic X-ray scattering is ideal to characterize electronic, magnetic, and structural properties of materials thanks to the enhanced sensitivity to otherwise weak scattering processes providing spectroscopic information and chemical selectivity. I16 main instrument is a large 6-circles K-diffractometer able to accommodate a variety of ancillary environment. The beamline offers full control of the incident photon polarization over most of its energy range. This is combined with large photon counting area detectors and an in vacuum linear polarization analyser installed on the K diffractometer that is used to isolate and enhance specific scattering processes related to ordering phenomena.

Using circular light of opposite helicity allows the investigation of chiral magnetic structures, inversion domain in multiferroic materials and permits to separate collinear and non collinear magnetic textures in real and reciprocal space. Other phenomena routinely investigated on I16 include charge density wave, metal-insulator transitions, orbital ordering, and subtle structural transitions. The beamline has been highly successful in examining weak scattering phenomena in small crystals, films, and multilayers between 6-800 K, often in combination with other generalised thermodynamic variables like electric or magnetic fields, and strain [2-5]. X-ray Bragg Coherent Diffraction Imaging is also possible at the beamline and allows researchers to peer into the inner structure of nanocrystals, with unparalleled detail and resolution by recording the interference patterns resulting from the interaction of a coherent beam with the lattice.

In this poster presentation, some of the new capabilities and features of the beamline will be shown, and recent results establishing the capabilities of the beamline will be highlighted.

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Poster session Tuesday

Ultrafast Diagnostics for Soft X-Ray Applications

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We provide a comprehensive overview of our current line of detectors designed for soft-X-ray detection in synchrotron and laser science. We will cover a variety of detector types, including streak cameras and sCMOS cameras, highlighting their respective performance metrics, integration capabilities, and use cases in synchrotron beamlines, and laboratory setups. We also discuss recent advancements in compressed ultrafast photography (CUP), a new computational imaging technique that integrates compressed sensing with streak imaging for single-shot 2D ultrafast imaging. To prove the concept, we designed and manufactured a patterned ultraviolet photocathode and integrated it into a streak camera. This new system exhibits a sequence depth of up to 1500 frames with a size of 1750 × 500 (x, y) pixels at an imaging speed of 0.5 trillion frames per second. This system can be easily adapted to soft x-ray, showing its potential for imaging and characterization at synchrotrons.

Poster session Tuesday /

Looking for Magnetoelectricity in Single-Phase Multiferroic Oxides using RMXS

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The search of magnetoelectric (ME) multiferroic (MF) materials, where magnetic order combines with ferroelectricity (FE) and both are coupled to each other, is an issue of keen interest in condensed matter physics and in spin-related emerging communication technologies. However, the low magnetic ordering temperatures of spiral multiferroics (typically < 100 K) critically restrict their potential use for spintronics and low-power ME devices. In the last years, we have investigated various single-phase spiral MF oxides with promising ME properties, like the (Mn1-xCox)WO4 and YBa(Cu1-xMx)(Fe1-yM'y)O5 families.
YBaCuFeO5 shows a commensurate k1 antiferromagnetic (AF) phase that is followed by an incommensurate spiral magnetic order (k2) with the easy axis in the ac-plane. Spontaneous electrical polarization has been reported associated with the spiral magnetic order in polycrystalline samples, whose onset temperature (TN2=TS) shows an extraordinary tunability and can be increased by more than 170 K –up to far beyond room temperature– by manipulating the Cu/Fe chemical disorder in bipyramids. By means of Resonant Magnetic X-ray Scattering (RMXS) investigation at the transition metal K absorption edges on several high-quality YBCFO single crystals we aimed at conclusively confirming the proposed spiral magnetic order (indistinguishable from the sinusoidal solution from unpolarized neutron diffraction) and to examine their ME behaviour analysing the response of the magnetic chiral domain distribution to an externally applied electric field.
RMXS was also used to investigate the spiral/collinear magnetic orders in a Mn0.85Co0.15WO4 MF single crystal. For this critical composition we found that (above the FE cycloidal phase) Co and Mn arrange antiferromagnetically (AF4) but with their spins respectively pointing along different directions. While Co moments tend to follow their strong magnetocrystalline anisotropy axis, the nearly isotropic charge density distribution around Mn2+ cations allows them to adopt a variety of complex magnetic structures bearing distinct anisotropies. The macroscopic FE this compound exhibits would then mainly stem from the inverse Dzyaloshinskii-Moriya term associated to Mn spins. This effect got observed by looking at variations in the scattered light polarization as a function of the E-field applied across the wolframite crystal.

Poster session Tuesday

Controlling Spin Periodicity in a Helical Heisenberg Antiferromagnet

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The ultrafast manipulation of spin structures is a promising route toward the next generation spintronic devices. To this end, antiferromagnets are especially promising, as they can harbor faster spin dynamics compared to ferromagnets due to the inter-sublattice exchange of angular momentum.

Europium (Eu)-based antiferromagnets are important candidate materials, since Eu2+ carries a large magnetic moment, and its localized 4f spins may be efficiently manipulated via the conduction electrons, which mediate the RKKY coupling. [1]

In this work, we study the Helical Heisenberg antiferromagnet EuCo2P2 [2] using resonant soft X-ray diffraction (RXD). By probing the magnetic Bragg reflections, we are experimentally sensitive both to the antiferromagnetic (AF) order parameter and to the 4f spin periodicity. We measure their response under three distinct perturbations: (a) femtosecond laser excitation (ultrafast RXD), (b) external magnetic fields, and (c) temperature variation.

Employing a Heisenberg model, our experimental data are shown to directly encode changes in the 4f-4f exchange coupling constants. We therefore directly reveal how they respond to each of the perturbations we apply. We further probe the response of the crystal lattice under the same conditions as the spin order and draw a relation between the dynamics of the two.

These results offer insight into different routes to control AF spin order and its couplings.

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Poster session Tuesday

Ultrafast dynamics of chiral spin structure in synthetic antiferromagnet

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In synthetic antiferromagnetic multilayers (SAFs), chiral magnetic structures such as spin spirals and skyrmions have been stabilized at room temperature by precisely tuning the effective perpendicular magnetic anisotropy, the Dzyaloshinskii-Moriya interaction, and the Ruderman-Kittel-Kasuya-Yoshida (RKKY) interlayer coupling [1-3]. In this study, we investigate the dynamics of chiral spin spirals on ultrashort timescales after femtosecond laser pumping in SAFs. The access to ultrafast magnetization dynamics, inaccessible by standard techniques due to zero net magnetization, has been enabled by the use of time-resolved circular dichroism in x-ray resonant magnetic scattering (CD-XRMS) [4]. A pair of two-dimensional X-ray scattering patterns for left and right elliptical polarization (EL and ER) have been recorded for each delay. In contrast to our previous findings in ferromagnetic multilayers, the magnetization (EL+ER) and dichroism (EL-ER) signals exhibit notably similar ultrafast dynamics, with demagnetization occurring on a timescale of ~180 fs, followed by rapid remagnetization within ~500 fs. This similarity in ultrafast dynamics can be attributed to the continuous rotation of magnetization in the spin spiral of SAFs, which evolves smoothly in space without forming sharp domains or alternating domain walls. The ultrafast response and stability in its topological character highlight the potential of SAF-based chiral magnetic structures for future high-speed, energy-efficient data storage and processing applications.

Poster session Tuesday

XRMS study of stripe domains in amorphous NdCo5 thin films with an in-plane anisotropy induced by oblique angle deposition

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Magnetic stripe domains have interesting properties, like unidimensional periodicity and rotatable anisotropy [1], which makes them suitable for spintronics applications like reconfigurable spin wave guides [2] or domain wall racetracks [3]. The understanding of the mechanisms that permit these kinds of applications requires a complete characterization of the magnetic stripes. X ray Resonant magnetic scattering (XRMS) seems an ideal tool for this purpose due to its sensitivity to magnetic stripe domains characteristics [4] with no restrictions of field intensities or temperature, and with enough intensity to allow magnetic stripe dynamics [5]. In this work, we present XRMS measurements of the stripe domain configuration in amorphous NdCo5 thin films, 65 nm thick, with weak perpendicular magnetic anisotropy (PMA) used as hard magnet substrate for different magnetic applications [1,2]. These thin films increase their PMA energy with film thickness, being close to the maximum value at the thickness studied. The films are deposited by magnetron sputtering with an oblique angle incidence for the Nd atoms (30°) which induces a magnetic easy axis in the plane. Several features appear in the XRMS stripe pattern of the films that are connected to their magnetic morphology: The shape of the XRMS peaks related to the periodicity of the stripes changes in width depending on the orientation of the beam with respect to the in-plane magnetic easy axis. The peaks have a small but visible transfer moment component, q, parallel to the plane of incidence which is absent in samples where the oblique incidence effect is reduced by rotating the sample during film deposition. The evolution of these features was measured as a function of the applied field. This experiment demonstrates the high sensitivity of XRMS to magnetic features that are not obvious to deduce with other magnetic moment sensitive techniques.

Poster session Tuesday

udkm1Dsim –a Python toolbox for simulating 1D ultrafast dynamics in condensed matter

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The investigation of electronic, magnetic, and structural dynamics in solid-state physics has made significant progress during the last decades due to the increasing availability of ultrashort electron and light pulses in a broad spectral range from THz to hard X-rays at large-scale facilities as well as in the laboratory. One of the primary goals of these experiments is to follow the coupling of different degrees of freedom on the relevant time and length scales. To understand and interpret such experimental data, scientists rely on a pool of simulations for modeling and fitting, which are available as software toolkits or as published formalisms. The implementation of these formalisms or the usage and adaption of available external software packages is very time-consuming, and each piece of software covers only very limited aspects of real-world, time-resolved experiments. To that end, the need for a generic, modular, and open-source toolbox that combines different functionalities is obvious.
The udkm1Dsim toolbox [1] allows for creating arbitrary one-dimensional (1D) structures made of crystalline and/or amorphous layers, including stoichiometric mixtures, typically on the nanometer length scale. These 1D structures hold all relevant material information, such as structural, elastic, thermal, magnetic, and optical parameters. The toolbox allows for calculating thermal, structural, and magnetic dynamics on these 1D structures utilizing an N-temperature model (NTM) and multi-layer absorption formalism, a linear masses-and-springs model, as well as an interface for user-defined magnetization dynamics and a Landau-Lifshitz-Bloch (LLB) model, respectively. Different types of light-scattering theories can be applied to retrieve the static as well as the transient response from these sample structures due to the dynamics mentioned above, similar to actual pump-probe experiments. Currently, kinematical and dynamical X-ray theories, which can also include polarization-dependent resonant magnetic scattering, are supported. With that, the generally non-linear dependence of the actual observable (scattered light intensity) and the physical quantity of interest (temperature, strain, magnetization, ...) can be revealed.
The udkm1Dsim is freely available at github.com/dschick/udkm1Dsim, including complete version control, issue and feature tracking, as well as project management capabilities to facilitate better collaboration between users and developers. This also includes automatic code validation and unit testing, as well as source-code-based generation of the documentation at udkm1Dsim.readthedocs.org as part of the continuous integration (CI) concept.

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PolSpecX: Simulation and Analysis Tool for Polarised X-Ray Absorption Spectroscopy

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PolSpecX [1] is an integrated software tool designed for the simulation and analysis of X-ray magnetic circular dichroism (XMCD) and X-ray magnetic linear dichroism (XMLD) spectra of 3d transition metal elements at the L_2 and L_3 absorption edges. Leveraging the capabilities of Quanty [2-4] for multiplet calculations, PolSpecX enables accurate theoretical modelling of dichroic spectra under various electronic and magnetic configurations. In parallel, the tool provides a robust framework for the analysis of experimental data acquired from the magnetic materials beamlines at Diamond Light Source [5], or in principle any beamline using the NeXus file definition. Key features include automated subtraction of polarized spectra, background correction, application of XMCD sum rules for quantitative magnetic moment extraction, and direct comparison between simulated and measured spectra. By bridging advanced theoretical simulations with high-quality synchrotron data analysis, PolSpecX offers a comprehensive platform for researchers investigating the electronic and magnetic properties of correlated electron systems. Such a platform will enable visiting scientists to quickly assess the quality of their data and concentrate on the scientific goals of their beamtime.

Here we will show the web-based interface, explain the user-friendly design choices and highlight some preliminary comparisons between beamline data and simulation.

Poster session Tuesday

Recent Research and Developments on the Scattering Endstation of i10 Beamline of Diamond Light Source

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ABSTRACT

The Beamline for Advanced Dichroism Experiments delivers a soft X-ray beam in the 0.4–1.6 keV energy range. The availability of all polarisation states, combined with the pronounced dichroic effects characteristic of the soft X-ray regime, has facilitated advanced research on magnetism in novel nanostructured systems. The beamline features two endstations, scattering and absorption, each utilising distinct interactions between magnetic materials and incident X-rays to probe material properties.

The scattering endstation is equipped with a 2-circle diffractometer called RASOR [1]. The resonant elastic scattering measurements on RASOR range from magnetic reflectivity studies to soft X-ray diffraction probing magnetic ordering in crystals and multilayers. The scattered beam is detected either by a photodiode or one of the area detectors which may be fixed or movable. The detector arm includes a polarisation analyser which can be used with multilayers optimised for specific elemental absorption edges.

A Janis liquid helium cryostat enables measurements at sample temperatures down to 12K. A phi rotation can be added which allows rotation of the sample in situ about its surface normal. Its use, however, limits the minimum achievable sample temperatures to approximately 50K. The measurements can be performed under applied electric and magnetic fields. Various configurations of electromagnets and permanent magnets are available, providing field strengths upto 0.2T. A Halbach array is currently under commissioning which will allow in vacuum roration of the magnetic field in all three dimensions.

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Poster session Tuesday

Soft X-ray Coherent Magnetic Imaging of 2D van-der-Waals materials at low temperatures and under high-applied magnetic fields

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ABSTRACT

We have used soft x-ray Fourier Transform holography and holography-assisted phase retrieval approaches[1] to image magnetic domain configurations in 2D van-der-Waals materials. Our results demonstrate imaging with a spatial resolution on the 20-25nm range at low temperatures and under high-applied magnetic fields[2] using the magnetic resonant scattering instrument “MaReS” at the BOREAS beamline of the ALBA Synchrotron[3].

Our poster will also briefly discuss on-going efforts in using Heraldo coherent imaging approaches in a tilted geometry for trying to also image in-plane magnetization components in addition to out-of-plane magnetization components accessed in the more usual normal incidence configuration, as well as on-going work and future directions of instrumentation improvement.

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