MA 46: Surface Magnetism

Time: Friday 9:30–12:30 Location: H19

MA 46.1 Fri 9:30 H19

Investigation of the magnetic structure of Eu on W(110) — •Patrick Härtl[1], Vijayalaxmi Sankeshwar[1,2], Markus Leisegang[1], and Matthias Bode[1] — [1]Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Indian Institute of Science Education and Research(IISER), Pune, Maharashtra 411008, India

Rare earth metal (REM) films are renowned for their complex magnetic properties, primarily governed by the element-specific sign and wavelength of the RKKY interaction. Due to the complexity of their cleaning procedures, the magnetic domain structure of REM surfaces has remained largely unknown until today and is an ongoing topic of debate. In this study, we investigate the structural, electronic, as well as the complex magnetic structure of Europium (Eu) films on W(110) using spin-polarized scanning tunneling microscopy (SP-STM).

In the bulk, Eu has a half-filled $4f$- and an empty $5d$-shell and adopts a body-centered crystal structure. In thin epitaxial films, however, a metastable hexagonal close-packed structure is expected, accompanied by helical spin ordering below $T_{\text{Néel}} = 91\,\text{K}$. With optimal preparation conditions, we successfully grew clean, smooth films. In the tunneling spectra of these Eu films we observed two intense peaks at positive bias voltages which we interpret as the unoccupied and exchange-split $5d_{z^2}$-like surface state. Beyond a critical film thickness, striped regions with a periodicity of $\approx 3\,\text{nm}$ were identified. Experiments with differently magnetized STM tips and the application of an external magnetic field up to $\pm 2.5\,\text{T}$ revealed the magnetic nature of the stripes.

MA 46.2 Fri 9:45 H19

The magnetic domain structure of Ho(0001)/W(110) — •Vijayalaxmi Sankeshwar[1,2], Patrick Haertl[2], and Matthias Bode[2] — [1]Indian Institute of Science Education and Research (IISER), Pune, Maharashtra 411008, India — [2]Experimentelle Physik II, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Rare-earth metal (REM) films exhibit diverse magnetic phenomena driven by the indirect RKKY coupling of localized $4f$ orbital moments, which promotes the formation of helical spin structures. Holmium (Ho), notable for its exceptionally high magnetic moment ($\approx 10\,\mu_\text{B}$), develops stable helical configurations across a wide temperature range [1]. In its bulk form, Ho crystallizes in a hexagonal close-packed structure, transitioning from a helical spin spiral state below $T_\text{N} = 131\,\text{K}$ to a conical magnetic state below $T_\text{C} = 20\,\text{K}$. At reduced thicknesses, theoretical studies predict the emergence of intricate magnetic textures, including block spin structures [2].

We present an investigation of epitaxial Ho films grown on W(110) using spin-polarized scanning tunneling microscopy (SP-STM). Through a detailed, thickness-dependent analysis of the structural, electronic, and magnetic properties, we observed large in-plane magnetic domains spanning several hundred nanometers, interspersed with worm-like striped patterns exhibiting periodicities of $\approx 20\,\text{nm}$ in the magnetic signal. Our findings provide valuable insights into the relationship between dimensionality and magnetic order in REM films.

[1] D. L. Strandburg *et al.*, Phys. Rev. **127**, 2046 (1962)
[2] E. Weschke *et al.*, Phys. Rev. Lett. **93**, 157204 (2004)

MA 46.3 Fri 10:00 H19

Influence of higher order interactions on the thermal behaviour of magnetic order in Mn/Re(0001) — •Leo Kollwitz[1], Moritz Alexander Goerzen[2,1], Hendrik Schrautzer[3,1], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, Kiel University, 24098 Kiel, Germany — [2]CEMES, Université de Toulouse, CNRS, France — [3]Science Institute and Faculty of Physical Sciences, University of Iceland, 107 Reykjavík, Iceland

Non-trivial multi-Q states, which consist of the superposition of periodically modulated spin textures, are known to arise in Mn monolayers on the Re(0001) substrate due to higher-order exchange interactions (HOI) [1]. However, to date little is known about the thermodynamic properties of these highly ordered phases. Here, we perform Monte Carlo simulations based on an atomistic spin model parametrized by density functional theory, in order to investigate thermal phase transitions in this material. It is found that the explicit consideration of HOI in the simulations leads to a significant decrease of the Néel temperature and to an introduction of a new transition between single-Q and multi-Q states at low temperatures. Recent experiments show that a similar transition occurs in $Co_{1/3}TaS_2$ [2]. By modelling the free energy landscape of the system in terms of thermal excitations, which are expressed in the eigenbasis of the Hamiltonian, we further identify the important degrees of freedom responsible for this additional entropy mediated transition.

[1] J. Spethmann *et al*, Phys. Rev. Lett. **124**, 227203 (2020)
[2] P. Park *et al*, Nat. Comm. **14**, 8346 (2023)

MA 46.4 Fri 10:15 H19

Anisotropic magnetic exchange in a metal-organic interface with $4f$ electrons: the case of Cu Phthalocyanine on $HoAu_2$ and $GdAu_2$ — •María Blanco-Rey[1,2,3], Rodrigo Castrillo[3], Frederik M. Schiller[3,2], and Laura Fernández[3] — [1]Universidad del País Vasco UPV/EHU, Spain — [2]Donostia International Physics Center DIPC, Spain — [3]Centro de Física de Materiales MPC-CSIC-UPV/EHU, Spain

Heterostructures formed by organic molecules on ferromagnetic substrates merge optoelectronic and spintronic functionalities. We have studied CuPc molecules deposited on monolayer-thick $REAu_2$ (RE=Ho, Gd) alloys, which exhibit long-range commensurability and vacuum level pinning of the LUMO. Many-body electron interactions renormalize the molecular levels. Here trivalent Ho and Gd species favour a downward shift of the HOMO, approaching ambipolarity [1]. The Curie temperatures are reduced from $\sim 20\,\text{K}$ to $\sim 15\,\text{K}$ due to CuPc, as the hybrid interfacial electronic structure affects the RKKY-mediated RE-RE exchange. The spin-orbit coupling of the RE leads to a dependence of the CuPc-RE antiferromagnetic exchange coupling constant $\mathcal{J}_{ex}$ on the field orientation, following the orbitally-dependent exchange (ODE) mechanism. ODE is enhanced by the large $L = 6$ value of trivalent Ho, yielding a ratio $\mathcal{J}_{ex}^{\parallel}/\mathcal{J}_{ex}^{\perp} = 4.2$, while the anisotropy is weak in the presence of Gd, with a half-field $4f$ shell [2].

[1] R. Castrillo et al, Nanoscale, 15, 4090 (2023).
[2] M. Blanco-Rey et al, Small, 20, 2402328 (2024).

MA 46.5 Fri 10:30 H19

Excitons design via topological spin-textures — •Karim Rezouali[1,2] and Samir Lounis[2,1] — [1]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany — [2]Peter Grünberg Institut, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Excitons are at the heart of many photonic and optoelectronic phenomena, including luminescence, lasing, and the operation of solar cells. Their study is essential for developing next-generation technologies, such as light-harvesting systems and quantum information devices. Here, we explore the impact of topological magnetism [1] on excitons by unveiling signatures of topology on the magnetic properties of excitons, their stability and manipulation. We address in particular skyrmions emerging in Pd/Fe/Ir(111) [2] surface, which affect the singlet and triplet exciton states hosted by a monolayer MoS_2 [3]. Our work promotes the use of skyrmions for the control and manipulation of excitons, which provides unprecedented opportunities for exciton-based devices.

[1] M. V. Berry, Proc. R. Soc. Lond. A 392, 45 (1984).
[2] N. Romming, A. Kubetzka, C. Hanneken, K. von Bergmann, and R. Wiesendanger, Phys. Rev. Lett. 114, 177203 (2015)
[3] M. Palummo, M. Bernardi, and J. C. Grossman, Nano Letters 15, 2794 (2015).

– Project funded by DFG (SPP 2137: LO 1659/8-1).

MA 46.6 Fri 10:45 H19

Observation of the sliding phason mode of the incommensurate magnetic texture in Fe/Ir(111) — •Wulf Wulfhekel[1], Hung-Hsiang Yang[1], Louise Desplat[2], Volodymyr Kravchuk[1], Marie Hervé[1], Timofey Balashov[1], Simon Gerber[1], Markus Garst[1], and Bertrand Dupé[2] — [1]Karlsruhe Institute of Technology — [2]Université de Liège

The nanoscopic magnetic texture forming in a monolayer Fe/Ir(111) is uniaxially incommensurate with respect to the Ir(111) substrate. As a consequence, a low-energy magnetic excitation is expected that

corresponds to the sliding of the texture along the incommensurate direction, i.e., a phason mode, that we confirm with atomistic spin simulations. Using Sp-STM, we observed this phason mode experimentally. It can be excited by the STM tip leading to a random telegraph noise in the tunneling current that we attribute to the presence of two minima in the phason potential due to the presence of disorder in the sample. This provides the prospect of a floating phase in cleaner samples and, potentially, a commensurate-incommensurate transition as a function of external control parameters.

15 min. break

MA 46.7 Fri 11:15 H19

Quantifying the interplay between local order and dynamics in a self-induced spin glass — •Lorena Niggli[1], Julian H. Strik[1], Anders Bergman[2], Mikhail I. Katsnelson[1], Daniel Wegner[1], and Alexander A. Khajetoorians[1] — [1]Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands — [2]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Spin glasses are a puzzling form of magnetic matter characterized by an amorphous spin texture in space. They exhibit ongoing magnetization dynamics that are often referred to as aging. However, direct experimental access to the spatially dependent magnetization and its link to aging, has been limited. Here, we study the spatiotemporal dy- namics of the self-induced spin glass state of Nd(0001) [1, 2]. To this end, we induce magnetization dynamics through magnetic field cycles and resolve the local order using spin-polarized scanning tunneling microscopy. We develop a new method to access the spatiotemporal dynamics based on a wavelet transformation. Using this, we quantify the Q-dependent local order in space and follow its evolution over time. Together this provides insight into the complex energy landscape of a (self-induced) spin glass. [1] Kamber et al., Science 368 (2020). [2] Verlhac et al., Nature Physics 18 (2022).

MA 46.8 Fri 11:30 H19

Bilayer triple-Q state driven by interlayer higher-order exchange interactions — •Bjarne Beyer, Mara Gutzeit, Tim Drevelow, Isabel Schwermer, Soumyajyoti Haldar, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany

Superpositions of spin spirals – so-called multi-Q states – are complex spin structures which are of fundamental interest and promising for future spintronic applications. A prominent example is the triple-Q state predicted more than 20 years ago [1] and only recently observed in Mn monolayers on the Re(0001) surface [2,3]. Here, we predict a triple-Q state as the magnetic ground state of a Mn bilayer on the Ir(111) surface using first-principles calculations based on density functional theory (DFT). In a bilayer two types of the triple-Q state can occur which differ by the spin alignment between the layers. Based on an atomistic spin model, we demonstrate that the triple-Q state favored by DFT is stabilized by the interplay of antiferromagnetic interlayer exchange and interlayer higher-order exchange interactions. In this bilayer triple-Q state nearest-neighbor spins within a layer and between layers exhibit tetrahedron angles and the topological orbital moments of the two Mn layers are aligned in parallel [4].

[1] P. Kurz *et al.*, PRL **86**, 1106 (2001).
[2] J. Spethmann *et al.*, PRL **124**, 227203 (2020).
[3] F. Nickel *et al.*, PRB **108**, L180411 (2023).
[4] V. Saxena *et al.*, arXiv:2408.12580 (2024).

MA 46.9 Fri 11:45 H19

Antiferromagnetic merons in a Mn monolayer on Ta(110) — •Tim Drevelow[1], Felix Zahner[2], André Kubetzka[2], Roland Wiesendanger[2], Stefan Heinze[1], and Kirsten von Bergmann[2] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstraße 15, 24098 Kiel, Germany — [2]Department of Physics, University of Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany

Non-collinear topological spin structures in ultrathin transition-metal films are interesting for spintronic applications. When hosted in antiferromagnets, they are robust to external perturbations, possess vanishing demagnetization fields, and the Skyrmion-Hall effect does not occur. Ultrathin Mn-layers are intrinsically antiferromagnetic and exhibit non-collinear spin structures, such as the conical spin structure in Mn on W(110) [1]. Here, using spin-polarized scanning tunneling microscopy and density functional theory, we discover a cycloidal spin spiral and a c(2×2) antiferromagnet in Mn mono- and double-layers on the Ta(110) surface, respectively. Micromagnetic simulations on the sublattice reveal a transition of spin spirals into antiferromagnetic, meronic spin structures of non-trivial topology near the interface to the collinear antiferromagnet of the film due to competing anisotropies of the Mn mono- and double-layer.

[1] Yoshida *et al.* Phys. Rev. Lett. **108**, 087205 (2012)

MA 46.10 Fri 12:00 H19

Magnetic bi-stability of columnar Transition-metal-oxide molecules on MgO films — •SUFYAN SHEHADA[1,2], Manuel dos Santos Dias[3], Muayad Abusaa[2], and Samir Lounis[1,4] — [1]Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, Arab American University, Jenin, Palestine — [3]Scientific Computing Department, STFC Daresbury Laboratory, Warrington WA4 4AD, United Kingdom — [4]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

At the heart of quantum information technology is the realization of stable atomic magnetic bits, which partly hinges on large out-of-plane magnetic anisotropy energy (MAE). Although the seminal work of Rau et al.[1] reported the maximum MAE for a 3d element by positioning a Co atom on MgO(100) [1], the system did not exhibit magnetic bistability. Motivated by that work, we explore via density functional theory (DFT) simulations columnar oxide molecules made of transition metals (TM-O), which might show large MAE while reducing the hybridization of the adatoms' electronic states with those of the substrate, increasing the chances of magnetic bi-stability. Following our initial investigations based on 3d elements [2], we address here the case of 4d atoms and focus on the scenario where the TM atoms are decoupled from the surface via an Oxygen atom.
–Work funded by (BMBF–01DH16027).
[1] Rau *et al.*, Science **344**, 988 (2014). [2] Shehada *et al.*, ArXiv:2403.05432, accepted in PRB (2024).

MA 46.11 Fri 12:15 H19

Tailoring magnetism in a 2D Van der Waals material with a chemical approach for magnonic applications — •Sourav Dey, Gonzalo Rivero, and José Baldoví — ICMol, University of Valencia, Valencia, Spain

The discovery of two-dimensional (2D) magnets offers an ideal platform for magnonics and spintronics at the limit of miniaturization given their high flexibility and tunability.The magnetic properties of this family of materials have been tuned by several approaches such as strain engineering, atomic layer substitution, or molecular deposition, among others. In the latter case, the effect of organometallic/inorganic complexes on the magnetic properties of 2D magnetic materials is still unexplored. To investigate this, we have selected two molecular qubits (quantum bits) with long coherence time such as CpTiCOT (Cp = η5-cyclopentadienyl, COT = η8-cyclooctatetraene) and VOPc (Pc = phthalocyanine) which are proved to be stable after the deposition on metallic substrate. Here, we analyze and interpret the magnetic properties of single-layer CrSBr after deposition of CpTiCOT and VOPc, via first-principles calculations. Our results predict a significant modulation of magnetic exchange in CrSBr after deposition due to the significant charge transfer from the molecules to 2D material, allowing us to corroborate both properties. Furthermore, a significant change in the magnon frequencies and group velocities was observed, which opened new avenues in designing smart molecular/2D materials where magnons can be fine-tuned by a chemical approach.