# O 20: Poster: Spins and Magnetism at Surfaces

Time: Monday 18:00–20:00 Location: P2/EG

O 20.1 Mon 18:00 P2/EG

**Aging behavior in a self-induced spin glass** — Lorena Niggli, •Julian H. Strik, Anand Kamlapure, Mikhail I. Katsnelson, Daniel Wegner, and Alexander A. Khajetoorians — Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands

Elemental neodymium has been shown to be a so-called self-induced spin glass, which, unlike conventional spin glasses, shows glassy behavior solely from frustrated magnetic interactions and in the absence of disorder [1]. Additionally, in contrast to most conventional spin glasses, neodymium has a disorder to order transition. As the temperature increases it goes from the self-induced spin glass phase to a multi-Q long range ordered phase resulting from competing long-range interactions on different length scales [2]. This disorder to order transition might have profound effects on the metastable states and aging dynamics in the low temperature phase. In this study, we use spin-polarized scanning tunneling microscopy combined with varying external magnetic fields to investigate the aging dynamics in the spin glass phase, and quantify this in terms of the various local spin-spin correlations (Q-states) observed. These observations may have interesting implications on the aging behavior in self-induced spin glasses, which might differ from conventional spin glasses.

[1] U. Kamber et al., *Science* **368** (2020).
[2] B. Verlhac et al., *Nat. Phys.* **18** (2022).

O 20.2 Mon 18:00 P2/EG

**Tuning the frequency response of stochastically switching orbital states of Fe and Co atoms on black phosphorus** — •Kira Junghans, Hermann Osterhage, Werner M. J. van Weerdenburg, Niels P. E. van Mullekom, Ruben Christianen, Eduardo J. Domínguez Vázquez, Hilbert J. Kappen, and Alexander A. Khajetoorians — Radboud University, Nijmegen, The Netherlands

The concept of the atomic Boltzmann machine (BM) is based on the recently discovered idea of orbital memory [1,2]. Orbital memory is characterised by two stable valency configurations [2,3]. By applying a bias voltage to a scanning tunneling microscopy (STM) tip above a threshold, stochastic switching between the states can be induced. The favorability of the individual states depends strongly on the applied bias voltage.
Unlike coupled spins under exchange, leading to bistability, coupled atoms that exhibit orbital memory show multi-stability in their stochastic dynamics. This multi-well energy landscape serves as a basis for the BM and realizing multiple time scales.
Here, we show that single Fe and Co atoms respond frequency and amplitude dependent to an AC component of the applied bias. In addition, we present how the stochastic behavior of coupled atoms in the multi-well regime respond to a harmonic drive voltage.

[1] B. Kiraly et al., Nat. Nanotechnol. 16, 414 (2021).
[2] B. Kiraly et al., Nat. Commun. 9, 3904 (2018).
[3] B. Kiraly et al., Phys. Rev. Research 4, 33047 (2022).

O 20.3 Mon 18:00 P2/EG

**Development of a gate-tunable graphene substrate for spins on surfaces** — •Paul Greule[1], Máté Stark[1], Wantong Huang[1], David Collomb[1], Daria Sostina[2], Christoph Sürgers[1], Wolfgang Wernsdorfer[1], and Philip Willke[1] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute of Quantum Materials and Technologies (IQMT), Karlsruhe Institute of Technology, Karlsruhe, Germany

Single spins on surfaces constitute a promising architecture for future quantum technologies as quantum sensors and possible qubits for quantum information processing. The recent combination of electron spin resonance (ESR) and scanning tunneling microscopy (STM) emerges as a new technique to coherently manipulate spin states on a single atom level [Y. Chen et al., Adv. Mater. 2022, 2107534]. Nevertheless, this architecture does not provide yet any method to continuously tune the coupling between single electron spins. Here, we want to introduce graphene field-effect transistors as a new substrate for ESR-STM on single molecules. Gated graphene devices enable tuning of the charge carrier density of the substrate as already shown by means of scanning tunneling spectroscopy (STS) [Y. Zhang et al., Nature Phys. 5, 722-726 (2009)]. This constitutes a promising way to manipulate the substrate-mediated exchange coupling between single spin centers. We present the development of gated graphene devices for STM using single layer graphene. Moreover, we characterize the samples with in-situ transport measurements and show first topographic and spectroscopic STM measurements.

O 20.4 Mon 18:00 P2/EG

**Magnetic phase diagram of a YSR-molecule** — •Benjamin A. Verlhac[1], Niels van Mullekom[1], Werner M.J. van Weerdenburg[1], Hermann Osterhage[1], Manuel Steinbrecher[1], Katharina J. Franke[2], and Alexander A. Khajetoorians[1] — [1]Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands — [2]Fachbereich Physik, Freie Universität Berlin, Germany

Yu-Shiba-Rusinov (YSR) states arise from the exchange coupling between a local spin and a superconductor. However, characterizing this exchange interaction, related to Kondo screening, requires a study in magnetic field to understand its interplay with other energy scales, as well as the role of higher spin degrees of freedom. To date, most studies of YSR states have been limited to bulk superconductors, which easily quench in the presence of modest magnetic fields. Here, using high resolution milliKelvin scanning tunneling microscopy and spectroscopy, we characterize the magnetic phase diagram of a molecule on the surface of a thin film superconductor. We observe non-trivial changes in the YSR excitations in applied magnetic field, that cannot be described by the prototypical spin 1/2 model. These variations occur while the superconducting gap remains robust. We relate the changes to the various properties of the molecule, including the role of multiple channels and magnetic anisotropy. We additionally propose a model to understand the various behaviors in the excitation. These results provide an in-depth and detailed approach to understand the role of high spin systems in the presence of Kondo and YSR states.

O 20.5 Mon 18:00 P2/EG

**Electronic Structure of Chromium(II)-Bromide Islands on Niobium Diselenide** — •Xianzhe Zeng[1], Haonan Huang[1], Sujoy Karan[1], Klaus Kern[1,2], and Christian Ast[1] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany — [2]Institut de Physique, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Chromium(II) bromide is an inorganic two-dimensional (2D) van der Waals material. With molecular-beam epitaxy (MBE), superconducting islands can be formed after evaporating chromium(II) bromide onto a niobium diselenide substrate. Measurements have been conducted on the islands and at the edge of the islands with low-temperature scanning tunneling microscopy and spectroscopy. At the edge of the islands, a subgap peak could be identified from the dI/dV spectrum, suggesting the existence of an in-gap state. Our discovery is the first observation in the chromium(II) bromide-niobium diselenide heterostructure system, providing an interesting comparison with the reported Majorana zero energy mode at the edge of chromium(III) bromide islands growing on the same substrate.

O 20.6 Mon 18:00 P2/EG

**Josephson diode effect due to single magnetic atoms** — Martina Trahms[1], Larissa Melischek[2], Jacob F. Steiner[2], •Bharti Mahendru[1], Idan Tamir[1], Nils Bogdanoff[1], Olof Peters[1], Gaël Reecht[1], Clemens B. Winkelmann[3], Felix von Oppen[2], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [3]Université Grenoble Alpes, CNRS, Institut Neél, 25 Avenue des Martyrs, 38042 Grenoble, France

Properties of Cooper-pair tunneling through a Josephson junction can be described by the phase difference between two superconductors. In a current-biased Josephson junction, the phase dynamics can be accessed via switching and retrapping currents. Here, we investigate Josephson junctions formed by a superconducting Pb tip and a Pb surface in a scanning tunneling microscope. While pristine Pb-Pb junctions are hysteretic but symmetric in the biasing direction, we observe asymmetric retrapping currents in the presence of single magnetic atoms placed in the junction. The behavior thus mimics diode properties in the re-

trapping current. We model the phase dynamics of these junctions by an extended resistively and capacitively shunted Josephson junction (RCSJ). We find the asymmetric retrapping current originates in a non-ohmic dissipative channel due to the particle-hole-symmetry-broken Yu-Shiba-Rusinov (YSR) states. By investigating different magnetic adatoms on different Pb surfaces, we carve out a general relation of asymmetric YSR states and asymmetric retrapping currents.

O 20.7 Mon 18:00 P2/EG

**Organometallic sandwich complexes as model spin 1/2 impurities on superconductors** — •Adithya Sadanandan[1], Lukas Arnhold[1], Nicolaj Betz[1], Andrea L Sorrentino[2], Giulia Serrano[2], Roberta Sessoli[2], Susanne Baumann[1], and Sebastian Loth[1] — [1]University of Stuttgart, Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]University of Florence, Department of Chemistry 'Ugo Schiff', INSTM Research Unit, Florence, Italy

Self-assembled layers of organometallic sandwich complexes containing transition metal atoms enable selective control of the spin delocalization and hybridization of the molecules with the electron bath of surfaces [1,2]. We study small self-assembled rafts of [CpTi(cot)] sandwich complexes on epitaxial Pb islands on Si(111). [CpTi(cot)] features a single electron in the d orbitals and long coherence times in solution [2] making it an interesting candidate for molecular qubits and a well-defined spin 1/2 system. Using low temperature scanning tunnelling microscopy (STM) we find weakly bound Yu-Shiba-Rusinov states (YSR) in the superconducting gap and a crossover between Kondo screening and spin excitations when superconductivity is quenched by a magnetic field. The simple level structure of [CpTi(cot)] makes it possible to model this system with an Anderson impurity model [3] and deduce the dynamics of the YSR states.

[1] M. Briganti et al., Nano Lett. 22 8626 (2022).
[2] L. C. Camargo et al., Angew. Chem. Int. Ed. 60 2588 (2021).
[3] H. Huang et al., Commun Phys. 3 199 (2020).

O 20.8 Mon 18:00 P2/EG

**Electrospray deposition for STM sample preparation in UHV** — •Caroline Hommel, Lukas Spree, Dasom Choi, Luciano Colazzo, and Andreas Heinrich — Center for Quantum Nanoscience, 52 Ewhayeodae-gil, Daehyeon-dong, 03760 Seoul, South Korea

Lanthanide single molecule magnets are promising materials for future spintronics applications, such as ultrahigh density memory devices. Using several methods, we have succeeded in synthesizing different double-decker phthalocyanine complexes (M-$Pc_2$; M = Y, Er, Tb) and depositing them on a metal substrate in ultra-high vacuum (UHV) for scanning tunneling microscopy (STM) analysis. Due to their flat geometry they are very well suited for surface deposition. Based on the very well-known chemical properties of the phthalocyanine ligands, it is possible to functionalize them for various purposes. M-$Pc_2$ form ordered structures on the surface, which could be further enhanced by long chain alkane groups on the phthalocyanine ligands. However, such large organic molecules cannot be sublimated without fragmentation. Using electro spray deposition (ESD), thin films of thermally unstable molecules can be deposited directly in UHV. Various parameters, such as pressure, time, and solvent play a role in this process. The influence of the parameters on the deposition will be investigated for M-$Pc_2$ molecules and their chemical derivatives.

O 20.9 Mon 18:00 P2/EG

**Scanning tunneling spectroscopy of a spin-crossover complex on a superconductor** — •Marten Treichel[1], Florian Gutzeit[2], Jan Homberg[1], Rainer Herges[2], Richard Berndt[1], and Alexander Weismann[1] — [1]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany — [2]Otto-Diels-Institut für Organische Chemie, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

A spin-crossover complex based on Ni-porphyrin is studied on superconducting Pb(100) using scanning tunneling spectroscopy at 0.3 K. A pronounced molecule-induced surface faceting is found with molecular chains located at multiple substrate steps. The step orientations deviate from the high-symmetry directions of the substrate and appear to be imposed by molecular interactions. Monatomic substrate steps remain undecorated. Conductance spectra reveal spin-flip excitations with clear spatial variations. The data suggest that neighbor molecules are rotated by 90° with respect to each other. We find that an $S = 1$ quantum spin model with the hard axis tilted away from the surface normal reproduces spectra measured in magnetic fields up to 9 T.

O 20.10 Mon 18:00 P2/EG

**Strong exchange interaction between open-shell nanographenes and TbAu2** — •Nicolò Bassi[1], Feifei Xiang[1], Jan Wilhelm[2], Roman Fasel[1], and Pascal Ruffieux[1] — [1]Empa-Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland — [2]Institute of Theoretical Physics, University of Regensburg, Regensburg, Germany

Rare-earth intermetallic compounds belong to a family of novel substrates, which is becoming a promising platform to control properties of nanomaterials via specific surface-adsorbates interactions. Different combinations, including GdAu2(1), LaAu2(2) and TbAu2(3),have been so far studied. They are all characterized by a ordered hexagonal superstructure with similar lattice constants. Here, we investigate various open-shell nanographenes on TbAu2 alloy by means of STM and STS combined supported by ab inito simulation. For on surface synthesized 7-AGNRs, we find that the predicted spin properties of the end states are indeed conserved on TbAu2. Here, 7-AGNRs are uncharged and the occupied and unoccupied end states have a spin polarization-induced energy splitting of 1.4 eV. In addition, we investigated phenalenyl, the smallest open-shell molecule with spin S = 1/2, at monolayer coverage. Low bias spectroscopy reveals a splitting of the peak of more than 20 mV, which we assign to the exchange interaction between the molecular spin and Tb atoms of the surface layer. These results open new perspectives for studying different open-shell molecules on a magnetic substrate.1 ACS Nano 4, (2010). 2 Phys. Rev. B 88, 125405 (2013). 3 J. Phys. Chem. Lett. 11, (2020).

O 20.11 Mon 18:00 P2/EG

**Observation of in-gap states on 4f-shell magnet-superconductor hybrid system** — •Yu Wang, Felix Friedrich, Artem Odobesko, and Matthias Bode — Physikalisches Institut, Experimentelle Physik II, Universitaet Wuerzburg, Am Hubland, D-97074 Würzburg, Germany

Magnetic impurities assembled on s-wave superconductor are the prototypical system for the realization of MZMs at the chain ends. Particularly the magnet-superconductor hybrid system of one-dimensional magnetic chains on superconductors has been well demonstrated theoretically and experimentally. Nowadays, various 3d-shell transition metals (Cr, Mn, Fe, Co, Ni) on clean Nb (110) have been studied [1-3]. Among them, only Mn and Fe chains exhibits benchmarks of topological superconductivity with MZMs at the chain ends. In addition to 3d-shell metals as magnetic impurities, 4f-shell magnetic metals could be another option. Among them, Gd shows the highest potential because it has the highest magnetic moment (s = 7/2) in 4f-shell. In this study, we will show that Gd dimers on Nb (110) behave similar as Fe/Mn with two pairs of in-gap states. It could be possible to realize MZMs on Gd chain ends in the future.

[1] D. Crawford and E. Mascot, arXiv: 2109.06894v1 [cond-mat.supercon], (2021)
[2] L. Schneider *et al.*, Nature Physics **17**, 943 (2021)
[3] A. Odobesko *et al.*, Physical Review B **11**, 99 (2019)