O 31: Mini-Symposium: Manipulation and control of spins on functional surfaces I

Time: Tuesday 10:30–12:30 Location: R2

Invited Talk O 31.1 Tue 10:30 R2

What can we learn from atoms? — •Alexander Khajetoorians — SPM department, Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands

Based on scanning tunneling microscopy, magnetic atoms and films on surfaces have become a model playground to understand and design magnetic order, bottom-up. However, magnetic order in these model systems have been confined to the limits dominated by bistability. In this talk, based on the recently discovered concept of orbital memory and the anisotropic behavior of black phosphorus, I will illustrate new model atomic platforms to realize multi-modal landscapes and their resultant dynamics. I will first review the concept of energy-based neural networks and how they are linked to the physics of spin glasses in atomic systems. I will then highlight new examples based on the recent discovery of the so-called spin Q glass and the atomic Boltzmann machine. I will illustrate the creation of atomic-scale neurons and synapses, in addition to new learning concepts based on the separation of time scales and self-adaptive behavior. I will also discuss recent cutting-edge developments that enable magnetic characterization in new extreme limits, for example ESR-STM at the lowest temperatures available today, and the application of this platform. This work was performed with funding from NWO, with project number 680-47-534, and from the European Research Council (ERC) under the European Unions Horizon 2020 research and innovation programme (SPINAPSE: grant agreement No 8183).

O 31.2 Tue 11:00 R2

Quantum Stochastic Resonance in Fe atoms and Nanostructures — •Gregory McMurtrie[1], Max Hänze[1,2], Susanne Baumann[1], Luigi Malavolti[2], Susan N. Coppersmith[3], and Sebastian Loth[1,2] — [1]University of Stuttgart, Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]School of Physics, University of New South Wales, Sydney, Australia

Stochastic resonance [1], where noise synchronizes a system's response to an external modulation, is a widespread phenomenon found in systems ranging from the dynamic behavior of neurons [2] to the periodicity of glaciation [3]. Here we apply stochastic resonance to open quantum systems, namely atoms and nanostructures strongly coupled to a dissipative bath, which unlocks a path to resonant interaction that does not require coherence. In particular, applying modulation via a scanning tunneling microscope's tip gives control of the spin state evolution in this resonant regime of spin dynamics in both real-time and real-space on the atomic scale. This phenomenon has never been observed previously in atomic systems, and gives unprecedented insight into the interaction of quantum spins and their noise sources, even allowing transduction of picosecond-speed dynamics. [1] R. Benzi, J. Phys. A: Math. Gen 14, L453 (1981) [2] A. J. Bulsara et al. Theor. Biol. 152, 531-555 (1991) [3] P. N. Pearson et al. Paleontological Society Papers 18, 1-38 (2012)

Invited Talk O 31.3 Tue 11:15 R2

Artificial spin chains on superconductor surfaces — •Jens Wiebe — Department of Physics, Hamburg University, Germany

A magnetic chain on an s-wave superconductor hosting a spin spiral or strong spin-orbit coupling can potentially realize a one-dimensional topological superconductor with Majorana bound states on its edges [1-5]. Here, we investigate artificial spin chains, which have been built atom-by-atom, with respect to the emergence of such topologically nontrivial electron phases. By this approach we not only vary the substrate and adatom species [6,7,8], but also tailor the interactions between the Yu-Shiba-Rusinov states induced by the adatoms [8] which eventually results in the formation of multi-orbital in-gap bands for the chain. We correlate the electronic properties of these bands with the spin structures of the chains as revealed by spin-resolved scanning tunneling spectroscopy [9].

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[1] Klinovaja et al., PRL 111, 186805 (2013). [2] J. Li et al. PRB 90, 235433 (2014). [3] S. Nadj-Perge et al., Science 346, 6209 (2014). [4] M. Ruby et al., Nano Letters 17, 4473, (2017). [5] H. Kim et al., Science Advances 4, eaar5251 (2018). [6] L. Schneider et al., npj Quantum Materials 4, 42 (2019). [7] L. Schneider et al., Nature Commun. 11, 4707 (2020). [8] Ph. Beck et al., arXiv:2010.04031 [cond-mat.supr-con] (2020). [9] L. Schneider et al., Science Advances 7, eabd7302 (2021).

O 31.4 Tue 11:45 R2

Coupling of Yu-Shiba-Rusinov states on $2H$-$NbSe_2$ — •Eva Liebhaber[1], Lisa Rütten[1], Gaël Reecht[1], Kai Rossnagel[2,3], Felix von Oppen[1,4], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, Germany. — [2]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany. — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany. — [4]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany.

A magnetic impurity adsorbed on a superconducting substrate leads to the formation of Yu-Shiba-Rusinov (YSR) states inside the superconducting energy gap. YSR wave functions of two adjacent magnetic adatoms can hybridize and form symmetric and antisymmetric linear combinations. Increasing the number of adatoms leads to the formation of Shiba bands.
We investigate magnetic Fe atoms on the superconductor $2H$-$NbSe_2$ which is a layered van der Waals material. Its strong 2D electronic character leads to a large spatial extent of the YSR wave functions facilitating the coupling between them [1]. We assemble adatom chains using a superconducting tip and track the evolution of the YSR states. As the YSR states have been shown to be sensitive to the CDW [2] that coexists with superconductivity in $NbSe_2$ at low temperatures we further investigate the role of the CDW for the hybridization along extended chains.
[1] S. Kezilebieke *et al.*, *Nano Lett.* **18**, 2311 (2018)
[2] E. Liebhaber *et al.*, *Nano Lett.* **20**, 339 (2020)

O 31.5 Tue 12:00 R2

Hyperfine fields of magnetic adatoms on ultrathin insulating films — •SUFYAN SHEHADA[1,2], Manuel dos Santos Dias[1], Filipe Souza Mendes Guimarães[1], Muayad Abusaa[3], and Samir Lounis[1,4] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Department of Physics, Arab American University, Jenin, Palestine — [4]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

Individual nuclear spin states can have very long lifetimes and could be useful as qubits. Promising steps in this direction were realized on MgO/Ag(001) via STM detection of the hyperfine interaction (HFI) of Fe and Ti adatoms [1] and the electrical control of the nuclear polarization of Cu adatoms [2]. Here, we report on systematic first-principles calculations of the HFI for 3*d* adatoms (Sc–Cu) atop ultra-thin insulators (MgO, NaF, NaCl, h–BN and Cu_2N) [3]. We analyze the trends and the dependence of the computed HFI on the filling of the magnetic *s* and *d*-orbitals of the adatoms and on bonding type and strength with the substrate. Finally, we identify promising candidates for future experimental investigations with scanning probe techniques.
–Work funded by the Palestinian-German Science Bridge (BMBF–01DH16027) and Horizon 2020–ERC (CoG 681405–DYNASORE).
[1] Willke *et al.*, Science **362**, 336 (2018); [2] Yang *et al.*, Nat. Nanotechnol. **13**, 1120 (2018); [3] Shehada et al. ArXiv:2012.11639.

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