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IFMP
Institut für Festkörper- & Materialphysik

Fakultät Physik

Datum: 29.06.20

IFMP-Sonderseminar

Date: **Monday, 6. July 2020**
Time: **13:30**
Where: **Video conference on Zoom**
Link: https://tu-dresden.zoom.us/j/9716539701?pwd=NHljVU9QazJTZjJSTWt6Y1d4YlhJQT09
(Meeting ID: 971 653 9701 Meeting Password: 0e!nLG)

Speaker: **Prof. Dr. Denis Vyalikh**
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Title: **4f-electron systems**

Abstract:

For a long time, rare-earth (RE) intermetallic materials have attracted considerable interest because of their rich and exotic properties including complex magnetic phases, valence fluctuations, heavy-fermion and Kondo behavior and non-Fermi-liquid properties. At the heart of the involved physics is the delicate interplay between itinerant electrons and the lattice of localized 4f states. Our synchrotron-based experiments aim to explore the peculiarities of f-d interaction, to reveal the fine electronic structure at a meV scale near the Fermi level, and to investigate the magnetic properties of the 4f-systems. To this end, we combine different spectroscopic techniques that allow to construct a comprehensive picture of the studied phenomena on the basis of the obtained results. We actively use ultraviolet (UV) and X-ray photoelectron spectroscopies, angle- resolved photoelectron spectroscopy (ARPES), spin- and time-resolved photoelectron spectroscopies as well as magnetic dichroism experiments and photoelectron diffraction. In this talk, I will give an overview of the most interesting experimental results which were mainly obtained by UV-ARPES. In spite of its surface sensitivity, UV-ARPES allows not only to gain deep insight into the rich physics of rare-earth systems driven by f-d interactions at the surface, but also to probe bulk-derived states. With the help of our combined spectroscopic techniques we are able to comprehensively discriminate and investigate the electronic and magnetic properties at the surface and in the bulk of the considered 4f-material.

In the past years, we systematically studied the family of the RET_2Si$_2$ compounds where RE = Yb, Ce, Eu, Gd, Tb, Dy, Ho and T=Co, Rh, Ir, and addressed essential and hotly discussed topics at the core of strongly correlated and magnetic 4f electron systems. The most important findings can be summarized as follows:

(i) Direct observation of crystal-electric field (CEF) splittings of the 4f states in Yb- and Ce-based systems and their complex dispersion induced by f-d hybridization near the Fermi level;
(ii) Insight into the temperature-dependent properties of the 4f-derived Fermi surface in Kondo lattices; Disclosure of its topology and spectral features reflecting f-d coupling at the surface and in the bulk from ARPES experiments;
(iii) Clear evidence of the interplay between Dirac fermions and heavy quasi-particles in 4f-systems;
(iv) Manifestation of strong ferromagnetic properties at the Si-terminated surfaces of the antiferromagnets $EuRh_2Si_2$, $GdRh_2Si_2$, $HoRh_2Si_2$ and the mixed-valent compound $EuIr_2Si_2$. The unusual ferromagnetism at the Si-surface in these materials is caused by exchange interaction between itinerant two-dimensional (2D) electron states and the ordered 4f magnetic moments lying in the fourth atomic layer below the surface;
v) Presentation of an efficient way for manipulating the spin and energy of 2D electrons at the Si-terminated surface by controlling the competition between spin-orbit and exchange magnetic interaction;
v) Demonstration of how strong spin-orbit coupling, lack of inversion symmetry and – as a novel ingredient – Kondo-related phenomena act together within a few atomic layers near the surface and how their mutual interaction affects the electronic and magnetic properties of such nanostructural objects.

Our experiments nicely demonstrate that the Si-T-Si-RE surface block of the RET_2Si_2 materials serves as a versatile playground for studying the fundamental properties of 4f magnetism and f-d interactions at reduced dimensionality. It can serve as a kind of construction kit with spin-orbit coupling, Kondo interaction, crystal-electric fields and magnetic exchange with different strengths as building blocks. Their mutual combination gives the opportunity to design systems for different scenarios and to study the physics of 2D electron states in the presence of these competing interactions. The obtained results create a solid platform for the time-resolved studies that are of particular importance for the physics and applications of magnetic materials. The most essential and interesting results were published in:

[1]. D. Yu. Usachov et al., Cubic Rashba Effect in the Surface Spin Structure of Rare-Earth Ternary Materials, Phys. Rev. Lett. 124, 237202 (2020).

[2]. S. Schulz et al., Emerging 2D-ferromagnetism and strong spin-orbit coupling at the surface of valence-fluctuating $EuIr_2Si_2$, npj Quantum Materials 4 26 (2019).

[3]. M. Güttler et al., Divalent $EuRh_2Si_2$ as a reference for the Luttinger theorem and antiferromagnetism in trivalent heavy-fermion $YbRh_2Si_2$, Nature Communications 10 796 (2019).

[4]. A. Generalov et al., Strong spin-orbit coupling in the noncentrosymmetric Kondo lattice, Phys. Rev. B 98 115157 (2018) (Editors' Suggestion).

[5]. A. Generalov et al., Spin orientation of two-dimensional electrons driven by temperature-tunable competition of spin-orbit and exchange magnetic interactions, Nano Letters 17 811 (2017).

[6]. S. Patil et al., ARPES view on surface and bulk hybridization phenomena in the antiferromagnetic Kondo lattice $CeRh_2Si_2$, Nature Communications 7 11029 (2016).

[7]. M. Güttler, Robust and tunable itinerant ferromagnetism at the silicon surface of the antiferromagnet $GdRh_2Si_2$, Scientific Reports 6 24254 (2016).

[8]. K. Kummer, et al., Temperature invariant Fermi surface in the Kondo lattice $YbRh_2Si_2$, Phys. Rev. X 5 011028 (2015).

[9]. A. Chikina et. al., Strong ferromagnetism at the surface of an antiferromagnet caused by buried magnetic moments, Nature Communications 5 3171 (2014).

[10]. M. Höppner et. al., Interplay of Dirac fermions and heavy quasiparticles in solids, Nature Communications 4 1646 (2013).

[11]. D.V. Vyalikh et. al., k-dependence of the crystal-field splittings of 4f states in rare-earth systems, Phys. Rev. Lett. 105, 237601 (2010).