TT 4: f-Electron Systems and Heavy Fermions I

Time: Monday 9:30–13:00 Location: HSZ 201

TT 4.1 Mon 9:30 HSZ 201

The potential of resonant x-ray scattering for the study of Kondo lattices — •Marein Rahn — Institute for Solid State and Materials Physics, Technical University of Dresden, 01062 Dresden, Germany

Kondo lattices represent a pivotal point of quantum matter - where local-itinerant correlations start being shaped by a material's lattice character and their consequences can no longer be reduced to local/mean-field models. Many traditional experimental probes cannot provide insights "beyond the mean field" because they themselves average this phenomenon over time and space. In this talk, I will showcase recent advances in momentum-resolved spectroscopies that can reveal the fine structure and dynamics of Kondo quasiparticles in unprecedented detail. Synchrotron-based techniques like resonant inelastic x-ray scattering provide a particularly interesting new perspective. Their experimental possibilities in f-electron systems have been hardly exploited, which should also be a strong motivation for progress in computational approaches.

TT 4.2 Mon 9:45 HSZ 201

Kondo screening and coherence on the Kagome lattice: Energy scales of the Kondo effect in the presence of at bands — •Christos Kourris and Matthias Vojta — Institut für Theoretische Physik, TU Dresden, Dresden, Germany

The formation of a heavy Fermi liquid in metals with local moments is characterized by multiple energy and temperature scales, most prominently the Kondo temperature and the coherence temperature, characterizing the onset of Kondo screening and the emergence of Fermi-liquid coherence, respectively. In the standard setting of a wide conduction band, both scales depend exponentially on the Kondo coupling. Here we discuss how the presence of flat, i.e., dispersionless, conduction bands modifies this situation. The Kagome Kondo-lattice model, due to its rich band structure, leads to a plethora of non-conventional Kondo behaviour emerging at different fillings. We utilize a parton mean-field approach to determine both the Kondo temperature and the coherence temperature as function of the conduction-band filling n_c, both numerically and analytically. For n_c values corresponding to the flat conduction band, we show that the exponential is replaced by linear and quadratic dependences for the Kondo and coherence temperature respectively, while a cubic power law emerges in the coherence temperature at n_c corresponding to the band edge between the flat and dispersive bands. We discuss implications of our results for pertinent experimental data.

TT 4.3 Mon 10:00 HSZ 201

Uniaxial strain tuning the signature of Kondo effect in the electrical resistance of heavy-fermion metals — •Soumendra Panja, Anton Jesche, Bin Shen, and Philipp Gegenwart — Experimental Physics VI, Center for Electronic Correlations and Magnetism, University of Augsburg, 86159 Augsburg, Germany

Physical properties of Kondo lattices are determined by the interplay of the Kondo effect and the RKKY interaction, which both depend sensitively on the antiferromagnetic exchange J between f- and conduction electrons. This competition is extremely sensitive to pressure, as evidenced by very large Gruneisen parameters found in these materials. We intend to tune the Kondo-maximum signature in the electrical resistance of such materials with tensile and compressive strain by utilizing a commercial piezo-strain device. In this talk, first results will be discussed under experimentally accessible strains.

TT 4.4 Mon 10:15 HSZ 201

Kondo breakdown transitions and phase-separation tendencies in valence-fluctuating heavy-fermion materials — •Pedro Monteiro Cônsoli and Matthias Vojta — Institut für Theoretische Physik, TU Dresden

The breakdown of the lattice Kondo effect in local-moment metals can lead to nontrivial forms of quantum criticality and a variety of non-Fermi-liquid phases. Given indications that Kondo-breakdown transitions involve criticality not only in the spin but also in the charge sector, we investigate the interplay of Kondo breakdown and strong valence fluctuations in generalized Anderson lattice models. We employ a parton mean-field theory to describe the transitions between deconfined fractionalized Fermi liquids and various confined phases. As a result, we find that rapid valence changes near Kondo breakdown can render the quantum transition first order. This leads to phase-separation tendencies which, upon inclusion of longer-range Coulomb interactions, will produce intrinsically inhomogeneous states near Kondo-breakdown transitions. We connect our findings to unsolved aspects of experimental data.

TT 4.5 Mon 10:30 HSZ 201

Quantum spin liquid in an RKKY-coupled two-impurity Kondo system — •Krzysztof P. Wójcik[1,2,3] and Johann Kroha[3] — [1]M. Curie-Skłodowska University, 20-031 Lublin, Poland — [2]Institute of Molecular Physics, PAS, 60-179 Poznań, Poland — [3]Physikalisches Institut, Universität Bonn, 53115 Bonn, Germany

We consider a 2-impurity Anderson model with spin-exchange coupling within the conduction-band sector of the Hamiltonian. Our numerical renormalization group calculations show that for strong intraband spin correlations their competition with the Kondo spin screening stabilizes a metallic spin-liquid phase of the localized spins, even without geometric frustration. It is characterized by nonuniversal impurity spectral density, fractionalization of the phase shift between the local and conduction-band parts, and large but not complete spin-spin correlations. For weak Kondo coupling the spin liquid and the Kondo singlet phase are separated by two quantum phase transitions and an intermediate RKKY spin-dimer phase, while beyond a critical coupling they are connected by a crossover. The results suggest how a quantum spin liquid may be realized in heavy-fermion systems near a spin-density wave instability.

TT 4.6 Mon 10:45 HSZ 201

Epitaxial $EuPd_2$ and $EuPd_3$ thin films — •Sebastian Kölsch and Michael Huth — Goethe Universität, Frankfurt (Main)

Europium-based binary compounds reveal a variety of interesting phenomena, which are attributed to strong electronic correlations and a competition between two different valence states of the europium ion, which lie close in energy [1]. As a result Eu forms intermetallic compounds usually either in a divalent (e.g. $EuPd_2$) or trivalent (e.g. $EuPd_3$) state, depending on the surrounding environment, whereas most other rare earth elements are always trivalent. Some ternary compounds even exhibit a change between both valence states, which may be tuned by temperature, pressure or high magnetic fields. As one of these rare candidates, $EuPd_2Si_2$ gained much interest due to a temperature driven valence transition from nearly Eu^{2+} above 200 K to Eu^{3+} below 50 K [2]. Recently we achieved for the first time the growth of epitaxial $EuPd_2Si_2$ thin films, where the valence transition was completly suppressed due to biaxial strain [3]. Epitaxial thin films thus offer the possibility to manipulate the strongly correlated Eu-based systems. Here we present the successful growth of $EuPd_2$ and $EuPd_3$ as epitaxial thin films and report on first results regardings their properties.

[1] Y. Onuki et al., Phil. Mag. 97, 36 (2017)
[2] K. Kliemt et al., Crys. Grow. & Des., 2022
[3] S. Kölsch et al., PRM 6, 2022

TT 4.7 Mon 11:00 HSZ 201

Single crystal growth of $EuPd_2Si_2$ under enhanced gas pressure — •Alexej Kraiker, Marius Peters, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt am Main, Germany

The study of collective phenomena raising from enhanced coupling between electrons and phonons is focussed on materials exhibiting phase transitions involving both, electronic and lattice-degrees of freedom. One system providing such a strongly coupled phase transition is $EuPd_2Si_2$ crystallizing in the $ThCr_2Si_2$ structure type. Because of the the high vapor pressure of Eu, high-quality single crystals of EuT_2X_2-compounds are very challenging to grow in larger size. One way to prevent Eu from evaporating out of the melt, is growing the crystals in argon overpressure. In this contribution, we present the crystal growth of $EuPd_2Si_2$ single crystals with a 20 bar and a 150 bar Czochralski-furnace. We show that the argon overpressure slows down the evaporation process of the Eu and leads to crystals with higher quality compared to Bridgman grown samples [1].

[1] K. Kliemt at al. Cryst. Growth Des. 2022, 9, 5399

15 min. break

TT 4.8 Mon 11:30 HSZ 201

Tuning the ground state of $EuPd_2(Si_{1-x}Ge_x)_2$ using He-gas pressure — •Bernd Wolf, Theresa Lundbeck, Marius Peters, Kristin Kliemt, Cornelius Krellner, and Michael Lang — Physikalisches Institut, Goethe University, 60438 Frankfurt/Main, Germany

The strongly correlated intermetallic compound $EuPd_2Si_2$ shows a strong valence-change crossover in a small temperature range. This valence change is accompanied by pronounced lattice effects together with significant changes in the magnetic properties. The material is located on the high-pressure side (crossover range) of the second-order critical endpoint (CEP) where novel collective phenomena which originate from a particularly strong coupling between electronic-, magnetic- and lattice degrees of freedom can be expected. We present magnetic susceptibility measurements data taken on high-quality single crystals of $EuPd_2(Si_{1-x}Ge_x)_2$ for nominal Ge-concentrations $0 \leq x_{nom} \leq 0.2$ in the temperature range 2 K $\leq$ T $\leq$ 300 K and He-gas pressure up to 0.5 GPa. For x = 0 at ambient pressure we observe a pronounced valence crossover centered around $T_V \sim 160$ K. As expected, T_V shifts to lower temperatures with increasing Ge-concentration, reaching $T_V \sim 90$ K for $x_{nom} = 0.1$, while still showing a non-magnetic ground state. For $x_{nom} = 0.2$ we observe long-range antiferromagnetic order setting in below $T_N = 47.3$ K. The important finding is that the application of a weak pressure as low as 0.2 GPa the long-range magnetic order can be suppressed giving way to a non-magnetic ground state with pronounced valence fluctuations.

TT 4.9 Mon 11:45 HSZ 201

Search for a critical endpoint in $Eu(Pd_{1-x}Au_x)_2Si_2$ single crystals — •Robert Möller, Marius Peters, Kristin Kliemt, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, Germany

In a general phase diagram for Eu compounds [1], the intermediate valent $EuPd_2Si_2$, $T_V \sim 150$ K, is located very close, but slightly at the high-pressure side of a second order critical endpoint [2]. The analysis of polycrystalline samples of $Eu(Pd_{1-x}Au_x)_2Si_2$ revealed that in this series a critical endpoint can be found which separates the region of continuous from first order transitions. It was shown that the valence state of the material can be tuned via Au substitution and that for x between 0.04 and 0.2 the transition becomes a first order phase transition [3]. Using single crystals grown with the Czochralski method, several characterisations were done to understand the main factors affecting the valence transition of $Eu(Pd_{1-x}Au_x)_2Si_2$.
[1] Y. Onuki et al., Phil. Mag. 97, 3399 (2017)
[2] B. Batlogg et al., in: Wachter, Boppart (eds.): Valence Instabilities, North-Holland publishing company (1982)
[3] C. U. Segre et al., Phys. Rev. Lett. 49, 1947 (1982)

TT 4.10 Mon 12:00 HSZ 201

Orbital selective coupling in $CeRh_3B_2$: co-existence of high Curie and high Kondo temperature — Andrea Amorese[1,2], Philipp Hansmann[3], Andrea Marino[2], Peter Körner[1], Thomas Willers[1], Andrew Walters[4], Kejin Zhou[4], Kurt Kummer[5], Nickolas B. Brooks[5], Hong-Ji Lin[6], Chien-Te Chen[6], Pascal Lejay[7], Maurits W. Haverkort[8], Liu Hao Tjeng[2], and •Andrea Severing[1] — [1]Institute of Physics II, University of Cologne, Germany — [2]MPI-CPfS, Dresden, Germany — [3]Department of Physics, University of Erlangen-Nürnberg, Germany — [4]Diamond Light Source, Didcot, UK — [5]ESRF, Grenoble, France — [6]NSRRC, Hsinchu, Taiwan — [7]Institut Neel, CNRS, Grenoble, France — [8]Institute for Theoretical Physics, Heidelberg University, Germany

$CeRh_3B_2$ combines seemingly exclusive properties of strong intermediate valence and high temperature ferromagnetism below 116K with strongly reduced magnetic moments. Utilizing recent advances in synchrotron techniques (XAS & RIXS) in combination with ab-initio density functional calculations, we find that the Rh states are irrelevant for the high temperature ferromagnetism and the Kondo effect, and that the crystal-field strength is not sufficiently strong to account for the Ce moment reduction. Instead our investigation reveals that different Ce 4f orbitals contribute differently to the magnetic coupling and the Kondo-type hybridization in $CeRh_3B_2$. The manifestation of such selective orbital coupling is a new aspect in the world of the strongly correlated 4f intermetallics.

TT 4.11 Mon 12:15 HSZ 201

Superconductivity beyond the Pauli limit in high-pressure $CeSb_2$ — •Oliver Squire, Stephen Hodgson, Jiasheng Chen, Vitaly Fedoseev, Christian de Podesta, Theodore Weinberger, Patricia Alireza, and Malte Grosche — Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK

The Kondo lattice system $CeSb_2$ has been recently found to undergo a structural transition under applied pressure. Here, we focus on the low-temperature properties in the new high-pressure structure which hosts an ultra-heavy fermion electronic state and antiferromagnetic order.

We have accessed the high-pressure structure of $CeSb_2$ using both piston-cylinder and anvil pressure cells at mK temperatures, and suppressed the magnetic order to a quantum critical point. In the vicinity of the quantum critical point, we have discovered a superconducting dome with $T_c = 250$ mK. The upper critical field exceeds the conventional Pauli limit by almost an order of magnitude and displays an unusual S-shaped temperature dependence. We will discuss the relationship between the upper critical field, the locally non-centrosymmetric crystal structure and the strong electronic mass enhancement in $CeSb_2$.

TT 4.12 Mon 12:30 HSZ 201

Structural and electronic instabilities in high pressure $CeSb_2$ — •Christian K. de Podesta[1], Theodore I. Weinberger[1], Oliver P. Squire[1], Stephen A. Hodgson[1], Jiasheng Chen[1], Rustem Khasanov[2], Christine Beavers[3], Patricia L. Alireza[1], and F. Malte Grosche[1] — [1]Uniersity of Cambridge, UK — [2]Paul Scherrer Institut, Switzerland — [3]Diamond Light Soure, UK

The Kondo-lattice material $CeSb_2$ undergoes a cascade of at least three magnetic transitions below 16 K and - unusually for a Ce system - settles on a ferromagnetic ground state. Whereas these transitions are initially hardly affected by applied pressure, they disappear abruptly above 18 kbar. We find that this disappearance is caused by a pressure induced structural change. The high pressure structure of $CeSb_2$ is profoundly different. It hosts a highly renormalised heavy fermion state which itself undergoes further magnetic transitions at very low temperature. Magnetic order within the high pressure structure extrapolates to zero at a pressure tuned quantum critical point, inducing a new superconducting phase with an anomalous field dependence[1].

We present the first detailed account of the high pressure crystal structure of $CeSb_2$ from X-ray diffraction, alongside a comprehensive study of the associated magnetic order, using μSR, AC-heat capacity and resistivity measurements. This provides the foundation on which to understand the anomalous superconducting properties which are thought to emerge from the quantum critical point.
[1] O. P. Squire et al., arXiv:2211.00975 (2022)

TT 4.13 Mon 12:45 HSZ 201

Observation of anomalous magneto-transport properties in $CeAl_2$ — •Christian Oberleitner, Christian Franz, Alexander Regnat, Jan Spallek, Michael Petrov, Georg Benka, Andreas Bauer, Marc Wilde, and Christian Pfleiderer — Physik-Department, Technische Universität München, D-85748 Garching, Germany

Rare-earth compounds historically have attracted great interest due to their diverse low-temperature properties comprising complex magnetic order, superconductivity, and heavy fermion behaviour. We report a study of the electrical transport properties of non-centrosymmetric $CeAl_2$ at low temperatures and large magnetic fields. For our study single crystals were grown by means of optical float-zoning, where Laue and powder x-ray diffraction as well as low residual resistivities confirm excellent sample quality. Measurements of the magnetization, specific heat, and torque magnetization were used to map out the magnetic phase diagram for different crystallographic orientations. In the regime of the antiferromagnetic order, which supports multi-k antiferromagnetic structures, the magnetoresistance and Hall effect are highly anomalous suggestive of an intricate interplay of anomalous and topological contributions.