TT 60: Correlated Electrons: f-Electron Systems

Time: Thursday 9:30–13:15 Location: HSZ 201

TT 60.1 Thu 9:30 HSZ 201

Fermi-surface evolution in the $Nd_xCe_{1-x}CoIn_5$ doping series — •J. Klotz[1,2], E. Green[1], K. Götze[1], C. Petrovic[3], I. Sheikhin[4], J.-H. Park[5], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Institut für Festkörperphysik, TU Dresden, Germany — [3]Brookhaven National Laboratory, Brookhaven, USA — [4]Laboratoire National des Champs Magnétiques Intenses, Grenoble, France — [5]National High Magnetic Field Laboratory, Tallahassee, USA

$CeCoIn_5$ is one of the prime examples for heavy-fermion (HF) superconductivity [1]. However, superconductivity vanishes upon Nd doping on the Ce site [2]. Since there are several theory studies suggesting a relation of the Fermi-surface (FS) geometry and superconductivity, e. g. [3], the knowledge of the Fermi surface is of vital importance. Here, we present quantum-oscillation data of $Nd_xCe_{1-x}CoIn_5$ obtained using a rotatable torque magnetometer in fields up to 35 T and temperatures down to 50 mK. In combination with band-structure calculations, our data reveal only a subtle change in the cylindrical FS sheet of $CeCoIn_5$, but a strong change in the effective-mass renormalization.

[1] C. Petrovic, P. G. Pagliuso *et al.* J. Phys.: Condens. Matter **13**, L337 (2001).
[2] R. Hu, Y. Lee *et al.* Phys. Rev. B **77**, 165129 (2008).
[3] T. Moriya, Y. Takahashi, and K. Ueda, J. Phys. Soc. Jpn. **59**, 2905 (1990).

TT 60.2 Thu 9:45 HSZ 201

Investigation of the energy scales in SmB_6 by scanning tunneling microscopy — •Lin Jiao[1], Sahana Rössler[1], Dae-Jeong Kim[2], Liu Hao Tjeng[1], Zachary Fisk[2], Frank Steglich[1], and Steffen Wirth[1] — [1]Max-Planck-Institute for Chemical Physics of Solids, Dresden, Germany — [2]Department of Physics, University of California, Irvine, California, USA

SmB_6 has been proposed as a topological Kondo insulator, which possesses topologically protected nontrivial surface states inside the bulk hybridization gap. By conducting scanning tunneling microscopy and spectroscopy, we are able to perform local measurements on well identified non-reconstructed (001) surfaces. Above ∼7 K and up to 80 K, the electronic states in SmB_6 are governed by the Kondo effect of the bulk [1]. At temperatures as low as 0.35 K, we observed several well-resolved states within the hybridization gap (±20 meV) of SmB_6 for the first time [2]. These states possess sharp peak-like features with a strong temperature dependence below 7 K, which indicates an additional energy scale at the surface of SmB_6, in line with a suppression of the Kondo effect at the surface. These high resolution data offer the opportunity to directly compare our spectroscopy with band structure calculations, and analyze their surface or bulk origin, which may help reconciling many contradicting assertions in this material.

[1] S. Rößler *et al.*, Proc. Natl. Acad. Sci. USA 111, 4798 (2014)
[2] L. Jiao *et al.*, Nat. Commun. 7, 13762 (2016)

TT 60.3 Thu 10:00 HSZ 201

Subsurface electronic structure of the mixed-valent SmB_6 — •Chul-Hee Min[1], Peter Lutz[1], Katharina Treiber[1], Thiago R.F. Peixoto[1], Hendrik Bentmann[1], Boyoun Kang[2], Beongki Cho[2], and Friedrich Reinert[1] — [1]Universität Würzburg, EP7, Würzburg, Germany — [2]School of Materials Science and Engineering, Gwangju Institute of Science and Technology (GIST), Gwangju, Korea

Strongly correlated topological insulators are expected to show drastically distinct phenomena near the surface region [1,2] because the hybridization strength V_{cf} of bulk and surface can be different [3]. We present an investigation on the probing depth dependence of $4f$ states and $3d$ core-levels in samarium hexaboride (SmB_6) to identify the unique subsurface electronic properties. From both angle- and photon energy-dependent studies, we estimate the thickness of the subsurface layer, which shows different Sm valence from the bulk one. Based on our estimation, we discuss about the surface, subsurface and bulk contributions in the $4f$ spectra. Our results indicate that at least two-component are present in the soft x-ray $4f$ spectra, which brings the size of the bulk gap of SmB_6 into question.

[1] Y. Xu, et al., Phys. Rev. Lett. 116, 246403 (2016).
[2] O. Erten, et al. Phys. Rev. Lett. 116, 046403 (2016).
[3] J. Allen, Phil. Mag. 96, 3227 (2016).

TT 60.4 Thu 10:15 HSZ 201

Excitons in topological Kondo insulators - theory of thermodynamic and transport anomalies in SmB_6 — •Johannes Knolle and Nigel R. Cooper — TCM Cavendish Laboratory, Univer- sity of Cambridge, UK

Kondo insulating materials lie outside the usual dichotomy of weakly versus correlated - band versus Mott - insulators. They are metallic at high temperatures but resemble band insulators at low temperatures because of the opening of an interaction induced band gap. The first discovered Kondo insulator (KI) SmB_6 has been predicted to form a topological KI (TKI) which mimics a topological insulator at low temperatures. However, since its discovery thermodynamic and transport anomalies have been observed that have defied a theoretical explanation. Enigmatic signatures of collective modes inside the charge gap are seen in specific heat, thermal transport and quantum oscillation experiments in strong magnetic fields. Here, we show that TKIs are susceptible to the formation of excitons and magneto-excitons. These charge neutral composite particles can account for long-standing anomalies in SmB_6 which is crucial for the identification of bulk topological signatures.

TT 60.5 Thu 10:30 HSZ 201

Magnetic field dependence of spin excitations in CeB_6 — P. Y. Portnichenko[1], S. V. Demishev[2], A. V. Semeno[2], H. Ohta[3], A. S. Cameron[1], M. A. Surmach[1], H. Jang[4,5], A. V. Dukhnenko[6], N. Yu. Shitsevalova[6], V. B. Filipov[6], A. Schneidewind[7], J. Ollivier[8], A. Podlesnyak[9], and •D. S. Inosov[1] — [1]TU Dresden, Germany — [2]General Physics Institute, Moscow — [3]Kobe University, Japan — [4]MPI für Festkörperphysik, Stuttgart — [5]National Accelerator Lab, Stanford, USA — [6]Inst. for Problems of Material Sciences, Kiev, Ukraine — [7]Forschungszentrum Jülich, Germany — [8]ILL, Grenoble, France — [9]SNS, Oak Ridge, USA

We employ inelastic neutron scattering (INS) to study the field dependence of spin fluctuations in CeB_6. The exciton shows no field splitting in marked contrast to $CeCoIn_5$. Instead, we observe a second field-induced magnon whose energy increases with field. At the ferromagnetic zone center, however, we find only a single mode with a nonmonotonic field dependence. At low fields, it is initially suppressed to zero together with the antiferromagnetic order parameter, but then reappears at higher fields inside the hidden-order phase, following the energy of an electron spin resonance (ESR). This is a unique example of a ferromagnetic resonance in a heavy-fermion metal seen by both ESR and INS consistently over a broad range of magnetic fields.

TT 60.6 Thu 10:45 HSZ 201

The quartet ground state in CeB_6: an inelastic x-ray scattering study — •Martin Sundermann[1,2], Kai Chen[1], Hasan Yavaş[3], Zachary Fisk[4], Maurits Haverkort[2,5], Liu Hao Tjeng[2], and Andrea Severing[1,2] — [1]University of Cologne, Institute of Physics II, 50937 Cologne, Germany — [2]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [3]PETRA III, Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, 22607 Hamburg, Germany — [4]Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA — [5]*present address*: Institute for Theoretical Physics, Heidelberg University, 69120 Heidelberg, Germany

We investigated the ground state symmetry of the cubic hidden order compound CeB_6 by means of core level non-resonant inelastic x-ray scattering (NIXS). The information is obtained from the directional dependence of the scattering function that arises from higher than dipole transitions. Our new method confirms that the paramagnetic ground state is well described using a localized crystal-field model assuming a Γ_8 quartet ground state.

TT 60.7 Thu 11:00 HSZ 201

Hard axis ordering in ferromagnetic YbNiSn — •Dmitry Sokolov[1,2], Andrew Huxley[2], and Franz Demmel[3] — [1]MPI, CPfS, Dresden, Germany — [2]The University of Edinburgh, UK — [3]ISIS Facility, Rutherford Appleton Laboratory, Chilton, UK

We report on magnetic field induced critical points in ferromagnetic heavy fermion YbNiSn. We show via direct measurements of the static and dynamic magnetic susceptibility and also via bulk measurements that the ferromagnetism can be suppressed to zero temperature by a modest magnetic field of 1.7 T. Our neutron diffraction find a canted ferromagnetism in YbNiSn, in which the orientation of the ordered moment can be flipped by the magnetic field of 1 T. Above the field of 1 T the ordered moment attains a much higher value indicating a true easy axis. Our inelastic neutron scattering measurements find a gapped spin wave excitation, which softens at the field induced moment-reorientation transition at 1 T. As the magnetic field approaches 1.7 T transition into a fully polarized state the excitation loses its intensity and disappears. We discuss the origin of the hard-axis ordering and the soft mode in this material.

15 min. break.

TT 60.8 Thu 11:30 HSZ 201

Direct bulk sensitive probe of $5f$ symmetry in URu_2Si_2 — Martin Sundermann[1], Maurits W Haverkort[2,4], Mark Golden[3], Yinkai Huang[3], Anne de Visser[3], Peter Thalmeier[2], Liu Hao Tjeng[2], and •Andrea Severing[1] — [1]University of Cologne, Institute of Physics II, 50937 Cologne, Germany — [2]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [3]Van der Waals-Zeeman Institute, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands — [4]present address: Institute for Theoretical Physics, Heidelberg University, 69120 Heidelberg, Germany

The order parameter of the second-order phase transition into a hidden order phase in URu_2Si_2 is still a mystery, despite 30 years of research. However, it is understood that the symmetry of the order parameter must be related to the symmetry of the low lying local electronic f-states. Here we present results of a novel spectroscopy, namely core-level non-resonant inelastic x-ray scattering (NIXS). This method allows for the measurement of local high-multipole excitations and it is bulk sensitive. The observed anisotropy of the scattering function unambiguously shows that the $5f$ ground state wave function is composed mainly of the Γ_1 with majority $J_z = |4\rangle + |-4\rangle$ and/or Γ_2 singlet states. The incomplete dichroism indicates the superposition of quantum states necessary for constructing the *HO* state with the breaking of the fourfold symmetry.

TT 60.9 Thu 11:45 HSZ 201

Field induced Lifshitz transition in UPt_2Si_2: Fermi surface under extreme conditions — Dirk Schulze Grachtrup[1], •Nico Steinki[1], Stefan Süllow[1], Zübeyir Cakir[2], Gertrud Zwicknagl[2], Yuriy Krupko[3], Marcelo Jaime[4], and John A. Mydosh[5] — [1]Institut für Physik der Kondensierten Materie, TU Braunschweig, D-38106 Braunschweig, Germany — [2]Institut für Mathematische Physik, TU Braunschweig, D-38106 Braunschweig, Germany — [3]Laboratoire National des Champs Magnétiques Intenses (LNCMI-EMFL), CNRS, UGA, 38042 Grenoble, France — [4]National High Magnetic Field Laboratory, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — [5]Kamerlingh Onnes Laboratory, Leiden University, 2300RA Leiden, The Netherlands

We have measured Hall effect, magnetotransport and magnetostriction on the field induced phases of single crystalline UPt_2Si_2 in magnetic fields up to 60 T at temperatures down to 50 mK. For the magnetic field applied along the c axis we observe strong changes in the Hall effect at the phase boundaries. From a comparison to band structure calculations utilizing the concept of a dual nature of the uranium $5f$ electrons, we find evidence for field induced topological changes of the Fermi surface due to at least one Lifshitz transition. Furthermore, we find a unique history dependence of the magnetotransport and magnetostriction data, indicating that the Lifshitz type transition is of a discontinuous nature, as predicted for interacting electron systems.

TT 60.10 Thu 12:00 HSZ 201

Microwave response of $CeCu_2Si_2$ — •Markus Thiemann[1], Martin Dressel[1], Silvia Seiro[2], Christoph Geibel[2], Nicholas Lee-Hone[3], David Broun[3,4], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Germany — [2]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [3]Department of Physics, Simon Fraser University, Burnaby, Canada — [4]Canadian Institute for Advanced Research, Toronto, Canada

$CeCu_2Si_2$ is a heavy fermion compound, exhibiting a onset of superconductivity ($T_c \approx 0.6$K) at a quantum critical point. Although superconductivity in this compound was discoverd over 30 years ago, its origin and the symmetry of the order parameter still remain unclear. While it was long believed that the order parameter had a d-symmetry, supported by neutron scattering experiments and NQR, recent specific heat measurements indicate fully gapped multigap superconductivity. Since the relevant energy scales of this compound are in the μeV regime, microwave measurements are an adequate technique to reveal intrinsic electronic properties of this system.

We performed microwave resonator measurements in a frequency and temperature range from 2.5GHz to 20GHz and 0.1K to 10K. This enabled us to determine the complex optical conductivity in the metallic as well as the superconducting state. In the metallic state, above 0.6K we see signs of the heavy fermion state arising, pushing the scattering rate towards our spectral range. In the superconducting state the absense of a coherence peak and the temperature dependence of the superfluid density point towards unconventional superconductivity.

TT 60.11 Thu 12:15 HSZ 201

Ising-type Magnetic Anisotropy in $CePd_2As_2$ — •M. O. Ajeesh[1], T. Shang[2], W. B. Jiang[2], W. Xie[2], R. D. dos Reis[1], M. Smidman[2], C. Geibel[1], H. Q. Yuan[2], and M. Nicklas[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Center for Correlated Matter and Department of Physics, Zhejiang University, Hangzhou, China

We studied the magnetic, thermal, and electrical transport properties of $CePd_2As_2$. X-ray diffraction confirmed the tetragonal $ThCr_2Si_2$-type structure and the high-quality of the single crystals. Magnetization and magnetic susceptibility data taken along the different crystallographic directions evidence a huge crystal electric field (CEF) induced Ising-type magneto-crystalline anisotropy with a large c-axis moment and a small in-plane moment at low temperature. Accordingly, we observe a uniaxial antiferromagnetic (AFM) ordering at a transition temperature of $T_N \approx 15$K with the crystallographic c-direction being the magnetic easy axis. The magnetic entropy gain up to T_N reaches almost Rln2 indicating localized $4f$-electron magnetism without significant Kondo-type interactions. Below T_N, the application of a magnetic field along the c-axis induces a metamagnetic transition from the AFM to a field-polarized phase at $B_C \approx 1$T, exhibiting a text-book example of a spin-flip transition as anticipated for an Ising-type AFM. A detailed crystal electric field analysis based on the magnetic-susceptibility data indicates an almost pure $|\pm 5/2\rangle$ CEF ground-state doublet with the dominantly $|\pm 3/2\rangle$ and the $|\pm 1/2\rangle$ doublets at 290K and 330K, respectively.

TT 60.12 Thu 12:30 HSZ 201

Stress - Temperature Phase Diagram of Antiferromagnetic order in $CeAuSb_2$ Under Uniaxial Pressure — •Joonbum Park[1,2], Hideaki Sakai[3], Andrew P. Mackenzie[1,4], and Clifford W. Hicks[1] — [1]Max Planck Institute for Chemical Physics of Solids, Noethnitzer Strasse 40, 01187 Dresden, Germany — [2]Max Planck POSTECH Center for Complex Phase Materials, Max Planck POSTECH/Korea Research Initiative (MPK), Gyeongbuk 376-73, Korea — [3]Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan — [4]Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St. Andrews, St. Andrews KY16 9SS, United Kingdom

We present results of the electrical transport measurements under uniaxial pressure on the antiferromagnet $CeAuSb_2$. In the unstrained system, the resistivity along [100] shows a sharp drop at the Néel temperature ($T_N \approx 6.5$ K), suggesting a first order transition. With compression along [100] by ≈ 0.3 %, the transition splits into two continuous transitions, at temperatures T_1 and T_2. T_1 is fully suppressed at a compression of ≈ 0.6 %, and in pressure ramps at low temperature this transition is a sharp cusp with hysteresis, indicating a first-order transition. T_2, on the other hand, rises continuously with increasing compression, reaching 9 K at 1.2 % compression. At present, the nature of the strain-induced phase between T_1 and T_2 is not clear.

TT 60.13 Thu 12:45 HSZ 201

Incommensurate short-range multipolar order parameter of phase II in $Ce_3Pd_{20}Si_6$ — •Pavlo Y. Portnichenko[1], Silke Paschen[2], Andrey Prokofiev[2], Matthias Vojta[3], Alistair S. Cameron[1], Jean-Michel Mignot[4], Alexandre Ivanov[5], and Dmytro S. Inosov[1] — [1]IFP, TU Dresden, Germany — [2]Vienna Univ. of Technology, Austria — [3]ITP, TU Dresden, Germany — [4]LLB, France — [5]ILL, France

The clathrate compound $Ce_3Pd_{20}Si_6$ is a heavy-fermion metal that exhibits magnetically hidden order at low temperatures. Reputedly, this exotic type of magnetic ground state, known as "phase II", could be associated with the ordering of Ce $4f$ quadrupolar moments. In contrast to conventional (dipolar) order, it has vanishing Bragg intensity in zero magnetic field and, as a result, has escaped direct observation by neutron scattering until now. Here we report the observation of diffuse magnetic neutron scattering induced by an application of magnetic field along either the $[1\bar{1}0]$ or the [001] direction within phase II. The broad elastic magnetic signal that surrounds the (111) structural Bragg peak can be attributed to a short-range G-type antiferromagnetic arrangement of field-induced dipoles modulated by the underlying multipolar order on the simple-cubic sublattice of Ce ions occupying the 8*c* Wyckoff site. In addition, for magnetic fields applied along the [001] direction, the diffuse magnetic peaks in $Ce_3Pd_{20}Si_6$ become incommensurate, suggesting a more complex modulated structure of the underlying multipolar order that can be continuously tuned by a magnetic field.

TT 60.14 Thu 13:00 HSZ 201

Frustrated local moment magnetism in a metallic system: $Ce_6Ni_6P_{17}$ — •Diego Franco and Christoph Geibel — Max-Planck-Institut für Chemische Physik Fester Stoffe

Frustrated metallic systems are potentially of strong interest because the interaction between magnetic and itinerant degrees of freedom is expected to result in unusual properties. However the number of appropriate systems is extremely scarce. Because of its structure the polyphosphide $Ce_6Ni_6P_{17}$ is an attractive candidate. Ce atoms are located on the corners of octahedra, which form a body centered cubic lattice. Thus one might expect frustration within the octahedra and frustration because of the body centered arrangement of the octahedra [1]. A preliminary study provided some evidence for frustration, but presented only limited experimental results [1]. We synthesized polycrystalline samples and present magnetization, specific heat and resistivity data. Our results confirm $Ce_6Ni_6P_{17}$ to be a metallic, frustrated local moment system. Kondo interaction are negligible resulting in well-defined 4f local moments. Specific heat C(T)/T data evidence magnetic order at merely $T_N = 0.97$ K, with only a small anomaly at T_N compensated by a huge tail in C(T)/T extending far above T_N. The magnetic fluctuations indicated by this large tail in C(T)/T are also seen as a broad maximum in $\chi(T)$ at $T > T_N$. Thus $Ce_6Ni_6P_{17}$ is a very promising candidate for studying magnetic frustration in a metallic system.

[1] N. Takeda et al., J. Phys. : Conf. Series 391 (2012) 012071