TT 53: Correlated Electrons: Heavy Fermions

Time: Thursday 9:30–13:00 Location: H19

TT 53.1 Thu 9:30 H19

Formation of the coherent heavy fermion liquid at the 'hidden order' transition in URu_2Si_2 — Shouvik Chatterjee[1], •Jan Trinckauf[2], Torben Hänke[2], Daniel E. Shai[1], John W. Harter[1], Travis J. Williams[3], Graeme M. Luke[3], Kyle M. Shen[1,4], and Jochen Geck[2] — [1]Laboratory of Atomic and Solid State Physics, Department of Physics, Cornell University, Ithaca, New York 14853, USA — [2]Leibniz Institute for Solid State and Materials Research IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [3]Dept. of Physics and Astronomy, McMaster University, 1280 Main St. West, Hamilton, Ontario L8S 4M1, Canada — [4]Kavli Institute at Cornell for Nanoscale Science, Ithaca, New York 14853, USA

We present angle-resolved photoemission (ARPES) spectra of the heavy-fermion superconductor URu_2Si_2. Detailed measurements as a function of both excitation photon energy and temperature allow us to disentangle a variety of spectral features, revealing the evolution of the low energy electronic structure at the hidden order transition. We directly observe that precisely at THO, localized and fluctuating electronic states rapidly hybridize with light conduction states, forming a well-defined heavy band coincident with a dramatic reduction in the scattering rate. We thereby demonstrate that in URu_2Si_2, the formation of the coherent heavy fermion liquid occurs via a thermodynamic phase transition into the HO phase. This behavior is in stark contrast with the gradual crossover expected in Kondo lattice systems, suggesting the possibility of multiple pathways towards the creation of heavy fermionic states.

TT 53.2 Thu 9:45 H19

High field Hall measurements on UPt_2Si_2 at very low temperatures — •Dirk Schulze Grachtrup[1], Ilya Sheikin[2], Stefan Süllow[1], and John A. Mydosh[3] — [1]Institut für Physik der Kondensierten Materie, Braunschweig, Germany — [2]Grenoble High Magnetic Field Laboratory, Grenoble, France — [3]Kammerlingh Onnes Laboratory, Leiden, The Netherlands

Tetragonal UPt_2Si_2 is a moderately mass enhanced antiferromagnet with a transition temperature $T_N = 32$ K in zero magnetic field. Moreover, in magnetization and resistivity measurements in high magnetic fields multiple features indicating new field induced phases have been observed. These features, together with signs of Fermi surface effects point to a significant role of the Fermi surface in UPt_2Si_2 [1].

Here, we present new magnetoresistivity and Hall effect data on UPt_2Si_2 at temperatures 50 mK to 2 K in magnetic fields up to 34 T. For the a axis this field range only covers the AFM phase. Instead, for the c axis, we observe a broad maximum in the magnetoresistivity in the field range ~ 25 to ~ 33 T indicating the transition into one of the high field phases. Additionally, the magnetoresistivity is hysteretic at all temperatures, with multiple steps appearing at temperatures below ~ 530 mK. Moreover, in the Hall signal we observe a significant change with an increase of the Hall coefficient by about 40% in the field range 23 - 26 T, this independent of temperature. These findings are discussed in the context of the proposed magnetic phase diagrams and the possibility of the occurence of a Lifshitz transition.

[1] D. Schulze Grachtrup *et al.*, Phys. Rev. B **85**, 054410 (2012)

TT 53.3 Thu 10:00 H19

Quasiparticles and Fermi surface of UPt_2Si_2 — •Zübeyir Cakir and Gertrud Zwicknagl — Institut für Mathematische Physik, TU Braunschweig, Braunschweig, Germany

U intermetallic compounds exhibit highly complex phase diagrams at low temperatures with unusual and often enigmatic orders. The high sensitivity with respect to variations in external parameters like pressure or magnetic field reflect the strong correlations within the U 5f shell. The present contribution focusses on the tetragonal compound UPt_2Si_2. We calculate the quasi-particle dispersion comparing the results for itinerant and (partially) localized U 5f electrons. The role of the local geometry is emphasized.

TT 53.4 Thu 10:15 H19

The magnetic phase diagram of $CeAu_2Ge_2$ — •Felix Eilers[1], Diego Zocco[1], Chien-Lung Huang[1,2], Veronika Fritsch[2], Kai Grube[1], and Hilbert v. Löhneysen[1,2] — [1]Karlsruher Institut für Technologie, Institut für Festkörperphysik — [2]Karlsruher Institut für Technologie, Physikalisches Institut, Karlsruhe, Germany

$CeAu_2Ge_2$ hosts one of the lighter heavy-fermion systems located far on the magnetic side of the Doniach phase diagram. Being a strongly uniaxial antiferromagnet, its metamagnetic transition is of the spin-flip type. Recent neutron diffraction measurements [1] indicate several commensurate and incommensurate magnetic structures in the magnetically ordered state. In order to map out a detailed phase diagram we measured magnetostriction and thermal expansion on a $CeAu_2Ge_2$ single crystal. We found several phase transitions. The crystal under study has a Néel temperature of 9 K and a critical magnetic field around 3.4 T for $B \parallel c$ [2]. The uppermost transition changes from continuous to discontinuous at temperatures below approximately 6 K. At temperatures below 0.5 K the phase-transition lines fan out and exhibit increased hysteresis. The Néel temperature of $CeAu_2Ge_2$ changes very little with hydrostatic pressure [3]. Using the Ehrenfest relation and the Clausius-Clapeyron relation we extracted the uniaxial pressure dependencies of the Néel temperature and the critical magnetic field.

[1] D. K. Singh et al., Physical Review B 86, 060405(R) (2012)
[2] V. Fritsch et al., Physical Review B 84, 104446 (2011)
[3] C. L. Huang et al., Physical Review B, in print (2012)

TT 53.5 Thu 10:30 H19

Strong enhancement of the thermopower of $YbRh_2Si_2$ by La substitution — •Ulrike Stockert[1], Heike Pfau[1], Cornelius Krellner[1,2], Steffen Wirth[1], Christoph Geibel[1], and Frank Steglich[1] — [1]MPI for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Present address: Physikalisches Institut Goethe-University Frankfurt, 60438 Frankfurt (Main)

$YbRh_2Si_2$ orders antiferromagnetically below $T_N = 70$ mK and $B_c \approx 60$ mT $\perp c$. In addition, a crossover from a small Fermi surface (FS) at low fields to a large FS incorporating the $4f$ electrons at high fields takes place at $T^*(B)$. Rather large values are found for the absolute thermopower divided by temperature $|S/T|$. The different regions of the phase diagram are characterized by specific T and B dependencies, e.g. a broadened step-like increase of $|S/T|$ upon crossing $T^*(B)$.

Substitution of 2 % La on the Yb site of $YbRh_2Si_2$ results in a suppression of T_N to below 20 mK, while $T^*(B)$ is not altered. Moreover, additional scattering centers are introduced. This leads to a lowering of the thermal conductivity in $Yb_{0.98}La_{0.02}Rh_2Si_2$. By contrast, $|S/T|$ is strongly enhanced below 1 K, but falls rapidly below the value for $YbRh_2Si_2$ already in moderate magnetic fields. In order to evaluate the origin of this unexpected behavior we studied in detail the field-dependence of the low-T thermopower of $Yb_{0.98}La_{0.02}Rh_2Si_2$. Our results suggest, that the enhancement of the absolute thermopower upon La substitution and the strong field dependence are related to modifications of the band structure upon doping into the $4f$ sublattice.

TT 53.6 Thu 10:45 H19

Magnetic phases in $Yb(Rh_{0.42}Co_{0.58})_2Si_2$ — •A. Hannaske[1], O. Stockert[1], C. Klingner[1], C. Krellner[1,2], S. Matas[3], M.-H. Lemee-Cailleau[4], L. Pedrero[1], M. Brando[1], C. Geibel[1], and F. Steglich[1] — [1]Max-Planck-Institut CPfS, Dresden, Germany — [2]Goethe-Universität Frankfurt, Frankfurt a. M., Germany — [3]Helmholtz-Zentrum Berlin, Berlin, Germany — [4]Institut Laue-Langevin, Grenoble, France

The heavy fermion compound $YbRh_2Si_2$, which orders antiferromagnetically below $T_N = 70$ mK, has attracted particular interest due to its anomalous properties such as pronounced non-Fermi-liquid behaviour, the divergence of the magnetic Grüneisen ratio as well as strong ferromagnetic fluctuations when approaching the quantum critical point. For a better understanding of this unique behaviour we started to investigate the microscopic magnetic structure in $Yb(Rh_{1-x}Co_x)_2Si_2$. For $x = 1$ and 0.68 we found an incommensurate propagation vector $\tau_1 \approx (0.25\ 0.08\ 1)$ below T_N followed by a change to a commensurate structure at a lower T_L with $\tau_2 = (0.25\ 0.25\ 1)$. Around $x \approx 0.5$, which is close to a minimum in the $(x - T)$-phase diagram, a change of the magnetic structure takes place. This change was investigated by a comprehensive study of magnetisation and neutron diffraction in magnetic fields on $Yb(Rh_{0.42}Co_{0.58})_2Si_2$. While below $T_L \approx 700$ mK the same commensurate propagation vector was found as for the higher Co concentrations, ferromagnetic behaviour was observed for $T_L < T < 820$ mK, which might be connected to the

magnetic order for Co concentrations $x < 0.58$.

TT 53.7 Thu 11:00 H19

Electronic Structure of $LuRh_2Si_2$ - reference to $YbRh_2Si_2$ — •Pascal Reiss[1], Swee K. Goh[1], F. Malte Grosche[1], Zachary Fisk[2], Michael Sutherland[1], Patrick M.C. Rourke[3], Gertrud Zwicknagl[4], and Sven Friedemann[1] — [1]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, CB3 0HE Cambridge, United Kingdom — [2]Department of Physics and Astronomy, University of California, Irvine, CA 92697-4575, USA — [3]National Research Council Canada, 1200 Montreal Road, Ottawa, Ontario, K1A 0R6, Canada — [4]Institute for Mathematical Physics, TU Braunschweig, Mendelssohnstraße 3, 38106 Braunschweig, Germany

The intermetallic compound $LuRh_2Si_2$ is of interest as a non-magnetic reference compound to the heavy fermion material $YbRh_2Si_2$. $YbRh_2Si_2$ features an intensively studied quantum critical point (QCP) when small magnetic fields suppress the Neel temperature to zero. Signatures in transport and thermodynamic properties suggest a reconstruction of the Fermi Surface from a small configuration with localised f-electrons in the antiferromagnetic phase to a large configuration with itinerant f-electrons in the paramagnetic phase. Hence isostructural $LuRh_2Si_2$ with its completely filled f-shell and identical lattice parameters is a perfect reference compound for the small Fermi surface configuration. Here we present band structure calculations of $LuRh_2Si_2$ and compare predicted and observed Shubnikov-de Haas frequencies under different angles in dependence of the relative z/c position of the Si atoms.

15 min. break

TT 53.8 Thu 11:30 H19

Eu valence and Fermi-surface development in EuX_2Si_2 (X = Co, Rh, Ir) systems — •K. Götze[1,5], S. Seiro[2], C. Geibel[2], H. Rosner[2], V. Petzold[2], A. Polyakov[1], J. Wosnitza[1], I. Sheikin[3], and A. Suslov[4] — [1]Hochfeld-Magnetlabor Dresden, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]MPI for Chemical Physics of Solids, Germany — [3]LNCMI-Grenoble, France — [4]National High Magnetic Field Laboratory, Tallahassee, USA — [5]TU Dresden, Institut für Festkörperphysik, Germany

The valence-fluctuating Eu systems EuX_2Si_2, with X being the transition metal Co, Ir, or Rh, show different types of ground states, strongly depending on X. The instability of the Eu 4f shell underlies this phenomenon and leads among other effects to different valence states ranging from Eu^{2+} over mixed valence and intermediate valence behavior to Eu^{3+} [1]. Investigations on the structure and the magnetic behavior of $EuCo_2Si_2$, $EuIr_2Si_2$, and $EuRh_2Si_2$ have revealed their Eu valence. Further experiments on specific heat and resistivity gave insights to magnetic ordering, electronic correlations, and possible valence fluctuations. We report about a systematic de Haas-van Alphen study on the Fermi-surface development of the EuX_2Si_2 compounds in magnetic fields up to 35 T. High-quality single crystals were available for the first time. We will focus on the Fermi-surface topology obtained by angle dependent measurements and discuss a comparison to band-structure calculations.

This work was partly supported by EuroMagNET, EU contract 228043 and DFG within GRK1621.

[1] Z. Hossain et al., Journal of Alloys and Compounds 323-324 (2001).

TT 53.9 Thu 11:45 H19

Optical study of archetypical valence-fluctuating Eu systems — V. Guritanu[1], S. Seiro[1], •J. Sichelschmidt[1], N. Caroca-Canales[1], T. Iizuka[2], S. Kimura[2], C. Geibel[1], and F. Steglich[1] — [1]MPI Chemische Physik fester Stoffe, Dresden, Germany — [2]UVSOR Facility, Institute for Molecular Science, Okazaki, Japan

We have investigated the optical conductivity of the prominent valence-fluctuating compounds $EuIr_2Si_2$ and $EuNi_2P_2$ in the infrared energy range to get new insights into the electronic properties of valence-fluctuating systems. For both compounds, we observe upon cooling the formation of a renormalized Drude response, a partial suppression of the optical conductivity below 100 meV and the appearance of a midinfrared peak at 0.15 eV for $EuIr_2Si_2$ and at 0.13 eV for $EuNi_2P_2$. Most remarkably, our results show a strong similarity with the optical spectra reported for many Ce- or Yb-based heavy-fermion metals and intermediate valence systems, although the phase diagrams and the temperature dependence of the valence differ strongly between Eu- and Ce-/Yb-systems. This suggests that the hybridization between $4f$- and conduction electrons, which is responsible for the properties of Ce- and Yb-systems, plays an important role in valence-fluctuating Eu systems.

TT 53.10 Thu 12:00 H19

Non-Fermi liquid picture and superconductivity in heavy fermion systems — •Steffen Sykora[1] and Klaus W. Becker[2] — [1]IFW Dresden, D- 01171 Dresden, Germany — [2]Department of Physics, TU Dresden, D-01069 Dresden, Germany

We study the $S = 1/2$ Kondo lattice model which is widely used to describe heavy fermion behavior. In conventional treatments of the model a hybridization of conduction and localized f electrons is introduced by decoupling the Kondo interaction. However, such an approximation has the detrimental effect that a breaking of a local gauge symmetry is imposed which implicates that the local f occupation n_i^f is no longer conserved. To avoid such an artifact, we treat the model in an alternative approach based on the Projective Renormalization Method (PRM). Thereby, within the conduction electron spectral function we identify the lattice Kondo resonance as an almost flat incoherent excitation near the Fermi surface which is composed of conduction electron creation operators combined with localized spin fluctuations. This leads to a new concept of the Kondo resonance without having to resort to a symmetry breaking and Fermi liquid theory. Based on this new picture we develop a microscopic theory for superconductivity in heavy fermion systems. Thereby we study the momentum-dependence of the superconducting order parameter for singlet as well as triplet pairing. We show that in particular the triplet pairing components are strongly affected by the incoherent excitations found to be responsible for the Kondo resonance.

TT 53.11 Thu 12:15 H19

$YbPt_2Sn$ and $YbPt_2In$: Unusual weak magnetic exchange in two different structure types — •Thomas Gruner, Dongjin Jang, Alexander Steppke, Manuel Brando, and Christoph Geibel — MPI Chemical Physics of Solids, 01187, Dresden, Germany

We have synthesized the two new compounds $YbPt_2Sn$ (YPS) and $YbPt_2In$ (YPI) and investigated their structural and magnetic properties. Powder diffraction patterns show YPS to crystallize in the same hexagonal $ZrPt_2Al$ structure type as previously known RPt_2Sn and RPt_2In (R = Y, Gd - Tm) compounds, while at 300 K YPI was found to form in the cubic Heusler phase as $ScPt_2In$. Despite very different structure types both compounds show very similar, but peculiar magnetic properties. Analysis of susceptibility χ(T), magnetization M(H), specific heat C(T) and resistivity ρ(T) indicate a stable trivalent Yb^{3+} state, without any sign for a significant Kondo interaction. Nevertheless, C(T) data evidence a very low magnetic ordering temperature, of only 240 mK and 180 mK for YPS and YPI, respectively, connected with a very weak intersite magnetic exchange. This very weak exchange makes these compounds candidates for magnetic cooling. Possible origins for and implications of this weak exchange shall be discussed.

The transition from the $ZrPt_2Al$ structure type to the cubic laves phase upon decreasing the size of the R-element has been previously reported for the RPd_2Sn and RPd_2In series. Our results allow to generalize this observation to a whole series of RT_2X compounds and indicate that this transition is mainly induced by a size effect and not related to a particular valence electron count.

TT 53.12 Thu 12:30 H19

Magnetic field dependence of multiple order parameters in CeB_6 — •G. Friemel[1], H. Jang[1], A. Schneidewind[2], Y. Li[1], A. V. Dukhhenko[3], N. Y. Shitsevalova[3], N. E. Sluchanko[4], A. Ivanov[5], V. B. Filipov[3], B. Keimer[1], and D. S. Inosov[1] — [1]MPI für Festkörperforschung, Stuttgart, Germany — [2]FRM-II, Garching, Germany — [3]Institute for Problems of Material Sciences, Kiev, Ukraine — [4]General Physics Institute, Moscow, Russia — [5]Institut Laue-Langevin, Grenoble, France

The heavy fermion (HF) antiferromagnet CeB_6 is known for exhibiting an antiferroquadrupolar (AFQ) order below $T_Q = 3.2$ K at $\mathbf{Q} = R(1/2, 1/2, 1/2)$, which was confirmed by resonant x-Ray and polarized neutron diffraction. Furthermore, the compound orders antiferromagnetically (AFM) in a double-$\mathbf{k}$ pattern below $T_N = 2.3$ K, which was so far neglected in the discussion of this compound. Only recently we could observe a spin exciton mode formation in the AFM state at $\hbar\omega = 0.5$ meV by inelastic neutron scattering, which can be understood as a feedback effect of the AFM order on the itinerant spin dynamics. By applying magnetic field the AFM order becomes quickly suppressed

at $B_c = 1\,\mathrm{T}$, whereas the intensity at $R(1/2, 1/2, 1/2)$ stays constant up to $B_Q = 1.7\,\mathrm{T}$, suggesting that it belongs to an unknown phase different from AFM and AFQ, with the latter setting in at $B > B_Q$. The exciton mode energy surprisingly becomes enhanced in field, parallel to the emergence of multiple other modes reaching into the AFQ state. These latter modes show a strong field dependence in energy, but are absent in the zero field AFQ phase above T_N.

TT 53.13 Thu 12:45 H19

Spin excitons in the unconventional superconducting and hidden order state of strongly correlated electrons — •Alireza Akbari and Peter Thalmeier — Max Planck Institute for the Chemical Physics of Solids, 01187 Dresden, Germany

The formation of collective spin excitons below the single particle continuum is observed in numerous unconventional superconductors. $CeCoIn_5$ is the most well established case for heavy fermion compounds. It is also the first example where the magnetic field splitting of magnetic excitons is observed for fields within the tetragonal plane. Contrary to expectations it is revealed as a doublet excitation. We explain the splitting as the result of a strongly anisotropic spin response described within the context of an Anderson lattice type model. Recently it was shown that collective spin excitations also appear within the hidden order phase of non- superconducting CeB_6. It is a signature of the itinerant nature of spin response as opposed to the commonly used localized 4f approach in this compound. We show that the salient features of the spin exciton can be explained in an itinerant quasiparticle model supplemented by hidden and antiferromagnetic order.

[1] A. Akbari and P. Thalmeier, Phys. Rev. B 86, 134516 (2012)
[2] A. Akbari and P. Thalmeier, Phys. Rev. Lett. 108, 146403 (2012)