TT 28: Correlated Electrons: Quantum-Critical Phenomena - Experiment

Time: Tuesday 10:00–13:00 Location: H21

TT 28.1 Tue 10:00 H21

Quantum multicriticality in $Sr_3Ru_2O_7$ — •Dan Sun[1], Andreas Rost[2], Robin Perry[3], Manuel Brando[1], and Andrew Mackenzie[1,4] — [1]Max-Planck Institute for Chemical Physics of Solids, Noethnitzerstr. 40, Dresden, 01187, Germany — [2]Max-Planck Institute for Solid State Research, Heisenbergstraße 1, Stuttgart, 70569, Germany — [3]University College London, Gower Street, London, WC1E 6BT, United Kingdom — [4]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, United Kingdom

The low temperature phase diagram of the layered perovskite metal $Sr_3Ru_2O_7$ is of considerable interest because of the interplay between phase formation and quantum criticality [1,2]. We have performed high resolution specific heat and magnetocaloric measurements down to temperatures as low as 65 mK, uncovering evidence that a feature at 7.5 T previously thought to be a crossover is a quantum critical point resulting from the suppression towards T=0 of an extremely low energy scale. Additionally, we report for the first time the observation of thermodynamic signatures associated with the appearance of incommensurate magnetic order recently reported in neutron scattering measurements [3].

[1] S. Grigera et al. Science **306**, 1154 (2004)
[2] R. Borzi et al. Science **315**, 214 (2007)
[3] C. Lester et al. Nature Materials **14**, 373 (2015)

TT 28.2 Tue 10:15 H21

Effect of Uniaxial Strain on the Quantum Critical Phase of $Sr_3Ru_2O_7$ — •Mark E. Barber[1,2], Daniel O. Brodsky[1,2], Clifford W. Hicks[2], Robin Perry[3], and Andrew P. Mackenzie[1,2] — [1]Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St. Andrews, St. Andrews KY16 9SS, United Kingdom — [2]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, Dresden 01187, Germany — [3]School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, United Kingdom

$Sr_3Ru_2O_7$ has a metamagnetic quantum critical endpoint, which in highly pure samples is masked by a novel phase. This phase is isotropic in the absence of symmetry-breaking fields, but weak in-plane magnetic fields are well-known to induce strong resistive anisotropy, leading to speculation that the phase intrinsically breaks the tetragonal symmetry of the lattice. We have used uniaxial strain to break the symmetry of the lattice and have found a dramatic response: compression by 0.1%, for example, induces a resistive anisotropy of ~ 2.5. I will discuss these results in the context of the underlying symmetry of the anomalous phase.

TT 28.3 Tue 10:30 H21

Optical Conductivity of Layered Ruthenates: The Role of Spin-Orbit Coupling and Coulomb Anistropy — •Esmaeel Sarvestani, Guoren Zhang, Evgeny Gorelov, and Eva Pavarini — Institute for Advanced Simulation, Forschungszentrum Juelich, D-52425 Juelich, Germany

We use the combination of density functional theory and dynamical mean-field theory (LDA+DMFT) to calculate the optical conductivity of the layered ruthenates Sr_2RuO_4 and $Sr_3Ru_2O_7$. The calculations are performed via linear response theory and Kubo's formalism. For Sr_2RuO_4 two sets of interaction parameters, (U,J)=(2.3,0.4)eV and (3.1,0.7)eV, both commonly employed for ruthenates, are used. We show that including the spin-orbit coupling improves the agreement with experimental data. Finally, we analyze the effects of low-symmetry Coulomb interaction.

TT 28.4 Tue 10:45 H21

Quantum oscillation measurements of β-LuAlB$_4$ — Pascal Reiss[1], •Jordan Baglo[1], Xiaoye Chen[1], HongEn Tan[1], Michael Sutherland[1], Sven Friedemann[2], Swee K. Goh[3], Kentaro Kuga[4], Hisatomo Harima[5], Satoru Nakatsuji[4], and F. Malte Grosche[1] — [1]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom — [2]HH Wills Laboratory, University of Bristol, Bristol, United Kingdom — [3]Chinese University of Hong Kong, Shatin, N.T., Hong Kong — [4]Institute for Solid State Physics, University of Tokyo, Kashiwa, Japan — [5]Department of Physics, Graduate School of Science, Kobe University, Kobe, Japan

The Yb-based heavy fermion superconductor β-YbAlB$_4$ displays a quantum critical point without tuning by applied pressure, magnetic field, or doping, which has been attributed to an unusual renormalised band structure [1]. Quantum oscillation measurements of the Fermi surface in β-YbAlB$_4$ have so far proved inconclusive, motivating us to undertake a detailed study of the isostructural reference compound β-LuAlB$_4$, which in contrast to the Yb compound is characterised by a filled $4f$ shell. We present comprehensive results from rotation and mass studies in β-LuAlB$_4$, which broadly agree with band structure calculations and display moderate mass enhancements contrasting with the much larger enhancements seen in β-YbAlB$_4$ – further emphasising the important contribution of f electrons to the itinerant electron physics of β-YbAlB$_4$.

[1] A. Ramires *et al.*, PRL **109**, 176404 (2012).

TT 28.5 Tue 11:00 H21

High Pressure Quantum Oscillation Studies in the Metallised Mott Insulator NiS_2 — •Hui Chang[1], Jordan Baglo[1], Alix McCollam[2], Inge Leermakers[2], Sven Friedemann[3], Xiaoye Chen[1], Pascal Reiss[1], HongEn Tan[1], Monika Gamza[4], William Coniglio[5], Stanley Tozer[5], and Malte Grosche[1] — [1]Cavendish Laboratory, University of Cambridge, UK. — [2]High Field Magnet Laboratory, Nijmegen, The Netherlands. — [3]HH Wills Laboratory, University of Bristol, UK. — [4]Jeremiah Horrocks Institute, University of Central Lancashire, UK. — [5]NHMFL, Tallahassee, Florida, USA.

The transition from a metallic to a Mott insulating state is a longstanding theme of fundamental interest in condensed matter research. One of the most basic questions concerns the evolution of the Fermi surface and carrier mass in the correlated metallic state near the Mott transition. Quantum oscillation measurements present a direct probe of the Fermi surface, and pressure rather than doping should be used as the tuning parameter in this case. We investigate this question in the Mott insulator NiS_2, which becomes metallic at a modest pressure of 30kbar. Using the tunnel diode oscillator technique in conjunction with high pressure anvil cells, we have observed quantum oscillations at pressures between 38kbar and 46kbar in magnetic fields up to 31T. This enables us to resolve key elements of the Fermi surface of high pressure NiS_2 and to obtain estimates of the effective carrier mass, which is strongly enhanced over band structure values. Moreover, we discuss the evolution of the Fermi surface, carrier effective mass and relaxation time on approaching the Mott transition.

TT 28.6 Tue 11:15 H21

Fermi surface of NiS_2 — •Pascal Reiss[1], Hui Chang[1], Jordan Baglo[1], Sven Friedemann[2], and F Malte Grosche[1] — [1]Cavendish Laboratory, University of Cambridge, United Kingdom — [2]HH Wills Physics Laboratory, University of Bristol, United Kingdom

Upon application of hydrostatic pressure of roughly 30 kbar, NiS_2 is found to display a transition from a Mott insulating state with a weak ferromagnetic ordering into a metallic state with an antiferromagnetic ordering. In this talk, we will present the results of band structure calculations based on DFT which aim to describe the high-pressure state. In particular, we will study the size and the topology of the Fermi surface in dependence of both the magnetic ordering and the intra-site Coulomb repulsion U. The predicted extremal orbits and band masses are compared with recently performed quantum oscillation measurements. This enables us to better understand the nature of the Mott insulator transition in NiS_2.

15 min. break

TT 28.7 Tue 11:45 H21

ACRT technique for the single crystal growth of the heavy fermion compound $YbRh_2Si_2$ — •Sebastian Witt, Kristin Kliemt, Constantin Butzke, and Cornelius Krellner — Goethe University Frankfurt, 60438 Frankfurt am Main, Germany

In the heavy fermion compound $YbRh_2Si_2$ the antiferromagnetic ordering below 70 mK close to a quantum criticial point is well-studied. Beneath the magnetic ordering a new phase transition was found recently at 2 mK. [1] It is necessary to prepare large and high-quality single crystals for studying the nature of this new phase transition.

Besides the optimization of the single crystal growth it is important to investigate single crystals with different isotopes at this phase transition.

Here, we report the crystal growth of $YbRh_2Si_2$ with the accelerated crucible rotation technique (ACRT). ACRT shows for other compounds, e.g. YAG (yttrium aluminum garnet, $Y_3Al_5O_{12}$), that this technique can reduce flux impurities and enhance the yield of larger crystals. We also report the attempt to receive metallic isotopes of ytterbium with metallothermic reduction. Crystals with different isotopes of silicon and ytterbium can be used for NMR measurements to investigate the underlying phenomena of quantum criticality in more detail.

[1] Schuberth et al., J. Phys.: Conf. Ser. 150 (2009) 042178.

TT 28.8 Tue 12:00 H21

$YbNi_4P_2$: Single crystal growth by the Czochralski method and high-field magnetization measurements — •Kristin Kliemt[1], Tobias Förster[2], Manuel Brando[3], and Cornelius Krellner[1] — [1]Goethe-University, Frankfurt, Germany — [2]HLD, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]MPI for Chemical Physics of Solids, Dresden, Germany

We have investigated a new generation of $YbNi_4P_2$ single crystals that were grown from a levitating melt by the Czochralski method. With T_C= 0.17 K, this ferromagnetic material has the lowest Curie temperature ever observed among stoichiometric compounds [1]. A quantum critical point occurs in the substitution series $YbNi_4(P_{1-x}As_x)_2$ at $x \approx 0.1$ [2]. The hybridization between localized f-electrons and the conduction electrons leads to a Fermi-liquid ground state with narrow bands and strongly enhanced effective electronic masses (heavy fermion system, Kondo temperature 8 K). An external magnetic field can split the bands, deform the Fermi surface and simultaneously suppress the Kondo interaction. If such a deformation changes the topology, it is called a Lifshitz transition. Previous thermodynamic and electrical transport studies have found indications for Lifshitz transitions in this Kondo lattice system [3]. We report on results of high-field magnetization measurements at low temperature to further investigate the putative Lifshitz transitions in $YbNi_4P_2$.

[1] C. Krellner et al., NJP **13**, 103014 (2011)
[2] A. Steppke et al., Science **339**, 933 (2013)
[3] S. Friedemann, H. Pfau (unpublished)

TT 28.9 Tue 12:15 H21

Competing ground states in $LuFe_4Ge_2$ tuned by external pressure — •Mukkattu Omanakuttan Ajeesh, Katharina Weber, Ricardo dos Reis, Cristoph Geibel, and Michael Nicklas — Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, Dresden, Germany

Tuning competing ground-state properties using external pressure has attracted much attention in current condensed matter research. This is due to the fact that exotic phenomena and unconventional phases occur in regions of competing energy scales. Here, we present an investigation on $LuFe_4Ge_2$ by electrical resistivity experiments under external pressure in order to understand the interplay between competing ground states in a frustrated, itinerant magnetic system. At ambient pressure $LuFe_4Ge_2$ orders antiferromagnetically below 32 K. The antiferromagnetic (AFM) transition is connected with a structural transition. We have established the temperature – pressure phase diagram: pressure suppresses the original antiferromagnetically ordered state to zero temperature at around 1.7 GPa. Upon further increasing pressure a new pressure-induced phase emerges. This phase exhibits a qualitatively different magnetoresistance compared with the AFM phase suggesting a different type of ordering than at lower pressures. Furthermore, above 1.5 GPa we find a metamagnetic transition at higher magnetic fields. The onset of this phase shifts to lower fields with increasing pressure. Further studies to understand the nature of the new phases are on the way.

TT 28.10 Tue 12:30 H21

CePdAl - a frustrated Kondo lattice at a quantum critical point — •Veronika Fritsch[1,2], Akito Sakai[1], Zita Hüsges[3], Stefan Lucas[3], Wolfram Kittler[2], Christian Taubenheim[2], Kai Grube[2], Chien-Lung Huang[2,3], Philipp Gegenwart[1], Oliver Stockert[3], and Hilbert v. Löhneysen[2] — [1]EP 6, Electronic Correlations and Magnetism, University of Augsburg, Germany — [2]Karlsruhe Institute of Technology, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

CePdAl is one of the rare frustrated Kondo lattice systems that can be tuned across a quantum critical point (QCP) by means of chemical pressure, i. e., the substitution of Pd by Ni [1]. Magnetic frustration and Kondo effect are antithetic phenomena: The Kondo effect with the incipient delocalization of the magnetic moments, is not beneficial for the formation of a frustrated state. On the other hand, magnetic frustrated exchange interactions between the local moments can result in a breakdown of Kondo screening [2]. Furthermore, the fate of frustration is unclear when approaching the QCP, since there is no simple observable to quantify the degree of frustration. We present thermodynamic and neutron scattering experiments on $CePd_{1-x}Ni_xAl$ close to the critical concentration $x \approx 0.14$. Our experiments indicate that even at the QCP magnetic frustration is still present, opening the perspective to find new universality classes at such a quantum phase transition.

[1] V. Fritsch *et al.*, PRB **89**, 054416 (2014).
[2] T. Senthil *et al.* PRB **69**, 035111 (2004).

TT 28.11 Tue 12:45 H21

Enhancement of effective Grüneisen parameter near structural quantum critical point in $(Ca_{0.9}Sr_{0.1})_3Rh_4Sn_{13}$ — •Rudra Sekhar Manna[1], Swee K. Goh[2], Kazuyoshi Yoshimura[3], and Philipp Gegenwart[1] — [1]EP VI, EKM, Augsburg University, 86159 Augsburg, Germany — [2]Dept. of Physics, The Chinese University of Hong Kong, Hong Kong, China — [3]Dept. of Chemistry, Kyoto University, Kyoto 606-8502, Japan

The interplay between superconductivity and structural instabilities in quasi-skutterudite compounds is playing an important role in recent years. $Sr_3Rh_4Sn_{13}$ shows a second-order structural phase transition at 138 K which can be tuned to 0 K either by applying hydrostatic pressure or by chemical pressure in $(Ca_xSr_{1-x})_3Rh_4Sn_{13}$. A structural quantum phase transition occurs at a critical concentration x_c = 0.9. The specific heat for x_c = 0.9, measured in a magnetic field to suppress superconductivity indicates a pronounced enhancement of the phonon (T^3) contribution at low-temperature compared to the x = 0 sample, possibly related to the softening of an optical phonon mode [1, 2]. We have performed high-resolution thermal expansion and specific heat measurements on a lump of small $(Ca_{0.9}Sr_{0.1})_3Rh_4Sn_{13}$ crystals. Thermal expansion shows a huge enhancement of phonon contribution compared to x = 0 sample. Moreover, the effective Grüneisen parameter $\Gamma_{eff} = \beta \cdot V_{mol}/\kappa_T \cdot C$ displays a significant enhancement upon cooling, indicative of quantum criticality.

[1] S. K. Goh *et al.*, PRL **114**, 097002 (2015).
[2] W. C. Yu *et al.*, PRL **115**, 207003 (2015).