TT 2: Quantum-Critical Phenomena

Time: Monday 9:30–12:45 Location: H19

TT 2.1 Mon 9:30 H19

The 'via cuprata' from antiferromagnetic to ferromagnetic Heisenberg chains and Li_2ZrCuO_4 as a missing link near the quantum critical point — •S.-L. Drechsler[1], J. Richter[2], J. Malek[1,3], M. Schmitt[4], H. Rosner[4], N. Tristan[1], O. Volkova[5], A. Vasiliev[5], and B. Buechner[1] — [1]IFW-Dresden, PF 270116, D-01171 Dresden — [2]Universität Magdeburg — [3]Institute of Physics, ASCR, Praha, Czech Rep. — [4]MPI CPfS Dresden — [5]Lomonosov-University, Moscow, Russia

We consider 9 magnetic chain cuprates with ferromagnetic nearest neighbor exchange J_1 and antiferromagnetic next-nearest neighbor exchange J_2 from the vicinity of the quantum critical point (QCP) for $\alpha_c = -J_2/J_1 = 0.25$ up to 10. Approaching α_c the maximum position T_m of the magnetic susceptibility $\chi(T)$ tends to 0, whereas $\chi(T_m)$ monotonously increases. The recently synthesized Li_2ZrCuO_4, which contains spin-1/2 chains of edge-shared CuO_4 plaquettes, is close to α_c and shows therefore a strong field dependence of the thermodynamical properties. Fitting $\chi(T)$ and the specific heat, $\alpha \sim 0.3$ was found [1]. Here, we present also a microscopic consideration of the origin of the relative large $J_1 \approx$ -30meV within the framework of an appropriate five-band extended Hubbard model including the ferromagnetic direct exchange K_{pd} as well as the Hund's rule coupling on O sites. In addition, we found that the obtained sizeable interchain coupling dominates the saturation field due to the vicinity of the QCP.

[1] S.-L. Drechsler *et al.* Phys. Rev. Lett. **98** (2007), accepted.

TT 2.2 Mon 9:45 H19

Thermoelectric transport in the vicinity of a superconductor-metal quantum phase transition in nanowires — •Bernd Rosenow, Adrian Del Maestro, and Subir Sachdev — Department of Physics, Harvard University, Cambridge, MA 02138, USA

We consider the field theory for a zero temperature transition between superconducting and diffusive metallic states in very thin wires due to a cooper pair breaking mechanism, e.g. a magnetic field in the wire direction or disorder in an unconventional superconductor. The critical theory contains current reducing fluctuations in the guise of both quantum and thermally activated phase slips. In a large-N limit, we calculate the universal dependence of electrical and thermal conductivity on both pair breaking strength and temperature. We find that the conductivity has a non-monotonic temperature dependence on the metallic side of the transition and that the Wiedemann-Franz law is obeyed at low temperatures. In the quantum critical region, we study the dynamics of a two-component order paramter field via Monte Carlo simulation of a Langevin equation and compare with the large-N result.

TT 2.3 Mon 10:00 H19

Low-temperature magnetic properties of novel spin-dimer systems synthesized by bridging Cu(II) ions with modified hydroquinone ligands — •Y Tsui[1], U Tutsch[1], A Brühl[1], K Remović-Langer[1], V Pashchenko[1], B Wolf[1], M Lang[1], T Kretz[2], H-W Lerner[2], M Wagner[2], A Salguero[3], B Rahaman[4], T Saha-Dasgupta[4], and R Valentí[3] — [1]Physikalisches Institut, J.W. Goethe-Universität, Frankfurt, Germany. — [2]Institut für Anorganische Chemie, J.W. Goethe-Universität, Frankfurt, Germany. — [3]Institut für Theoretische Physik, J.W. Goethe-Universität, Frankfurt, Germany. — [4]S.N. Bose Centre, Kolkata, India.

We have recently synthesized novel spin-dimer systems by bridging Cu(II) ions with hydroquinone linkers. By chemically modifying the hydroquinone linkers, spin-dimer systems with different intradimer and interdimer interactions are realized. These compounds include isolated and coupled spin-dimer systems. We will discuss the magnetic properties of these systems at low temperatures. In particular, we will focus on one of the 3D coupled spin-dimer systems, $[C_{36}H_{48}Cu_2F_6N_8O_{12}S_2]$ (TK91). Thermodynamic and magnetic measurements on TK91 suggest that a field-induced phase transition takes place at very low temperatures ($T \lesssim 0.2$K) and at fields between ∼5.8 and ∼6.5T. Such a phase transition has been observed in other spin-dimer systems and was interpreted as the Bose-Einstein condensation (BEC) of magnons. The ability to tune the magnetic interactions in TK91 will make it possible to explore the BEC phenomenon in magnetic systems under various conditions.

TT 2.4 Mon 10:15 H19

Anomalous thermodynamics of spin-gap systems close to quantum phase transitions — •T. Lorenz[1], S. Stark[1], O. Heyer[1], H. Tanaka[2], and K. Krämer[3] — [1]II. Phys. Inst., University of Cologne, Germany — [2]Dep. of Phys., Tokyo Inst. of Tech., Japan — [3]Dep. of Chem. and Biochem., Univ. of Bern, Switzerland

Very rich and fascinating physical properties are predicted for various theoretical models of coupled spin-1/2 dimers. $TlCuCl_3$ and $(C_5H_{12}N)_2CuBr_4$ can be viewed as model systems for three- and one-dimensionally coupled spin-1/2 dimers, respectively [1]. Both have nonmagnetic singlet ground states, but moderate fields of about 6 Tesla are sufficient to close the spin-gap to the first excited triplet states. Due to the three-dimensional couplings larger fields induce a Néel order in $TlCuCl_3$, while in the spin-ladder material $(C_5H_{12}N)_2CuBr_4$ a crossover takes place to a state, which can be mapped on a Luttinger-liquid phase. In the zero-temperature limit these transitions represent examples of quantum phase transitions, whose control parameter may be easily tuned by variation of the magnetic field. We present a high-resolution study of the thermal expansion and magnetostriction on both compounds and compare our experimental results to the theoretically predicted behavior in the vicinity of a pressure-dependent quantum critical point [2].

This work was supported by the DFG through SFB 608.

[1] T. Lorenz et al., cond-mat/0609348 (2006), B.C. Watson et al., PRL 86, 5168 (2001). [2] L.J. Zhu et al., PRL 91, 066404 (2003), M. Garst and A. Rosch , PRB 72, 205129 (2005).

TT 2.5 Mon 10:30 H19

High pressure quantum phase transition in the weakly coupled spin cluster system $Cu_2Te_2O_5Br_2$ — •Hans-Henning Klauss[1], Christopher Mennerich[1], Hemke Maeter[1], Hannes Kühne[1], Peter Lemmens[1], Jochen Litterst[1], Hubertus Luetkens[2], Alex Amato[2], Rie Takagi[3], and Mats Johnsson[3] — [1]IPKM, TU Braunschweig, Braunschweig, Germany — [2]Paul-Scherrer-Institut, Villigen, Switzerland — [3]Dept. of Inorganic Chem., Stockholm Univ., Stockholm, Sweden

Tetragonal $Cu_2Te_2O_5Br_2$ contains clusters of four Cu^{2+} (S = 1/2) in a planar coordination. These tetrahedra form weakly coupled sheets within the crystallographic a-b plane. Therefore, this system is ideal to study the interplay between the spin frustration on a tetrahedron with localized low-energy excitations and collective magnetism induced by inter-tetrahedra couplings. In this material a strongly reduced magnetic transition temperature $T_N = 11.4$ K in comparison with a dominant magnetic exchange of 40 K is found.

We examined the quantum critical behaviour of polycrystalline $Cu_2Te_2O_5Br_2$ in ZF muSR experiments under external pressures. We observed a continuous decrease of the magnetic phase volume and of the sublattice magnetization, studied via the spontaneous muon spin precession frequency, with increasing pressure. The measurements at 6 kbar did not show any sign of static magnetic correlations down to 0.3 Kelvin. We conclude that this system shows a quantum critical point at 6 kbar where the magnetic ordered phase disappears and a spin liquid ground state is formed.

TT 2.6 Mon 10:45 H19

Quantum phase transitions and dimensional reduction in antiferromagnets with inter-layer frustration — •Oliver Rösch, Inga Fischer, and Matthias Vojta — Institut für Theoretische Physik, Universität zu Köln

We discuss phase transitions of quasi-two-dimensional antiferromagnets with a fully frustrated inter-layer interaction. Using symmetry arguments in a perturbation expansion for the order parameter theory and applying the bond-operator method beyond the harmonic approximation, we calculate the magnetic excitation spectrum in different parameter regimes. We consider various crossovers in the vicinity of the quantum critical points and the finite-temperature transitions. We also discuss the relation of our results to recent experiments on $BaCuSi_2O_6$ which indicated the possibilty of dimensional reduction through geometric frustration.

15 min. break

TT 2.7 Mon 11:15 H19

Interplay between chiral symmetry breaking and spinon confinement in Mott insulators — •Flavio Nogueira and Hagen Kleinert — Institut für Theoretische Physik, Freie Universität Berlin

It is well known that compact quantum electrodynamics in 2+1 dimensions (QED_3) is an effective theory Mott insulators near the so called resonating valence-bond (RVB) flux phase. We have recently demonstrated the stability of the spin liquid for a large enough number of spinon species [1]. However, the effect of chiral symmetry breaking (CSB), which leads to the appearence of spin density wave, was not considered. CSB is known to occur in noncompact QED_3. In this work we discuss the interplay between CSB and confinement in the compact case and point out the consequences for the stability of spin liquids for the physically relevant number of spinon species, N=2.

[1] F. S. Nogueira and H. Kleinert, Phys. Rev. Lett. **95**, 176406 (2005)

TT 2.8 Mon 11:30 H19

Spontaneous Fermi surface symmetry breaking in $Sr_3Ru_2O_7$ — •Hiroyuki Yamase and Andrey Katanin — Max-Planck-Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

The most salient features observed around a metamagnetic transition in $Sr_3Ru_2O_7$ are well captured in a simple model for spontaneous Fermi surface symmetry breaking under the Zeeman magnetic field, without invoking a putative quantum critical point. The Fermi surface symmetry breaking happens in both a majority and a minority band but with different magnitude of the order parameter, when either band is tuned close to van Hove filling by the magnetic field. The transition is second order for high temperature (T) and changes into first order for low T. The first order transition is accompanied by a metamagnetic transition. The uniform magnetic susceptibility and the specific heat divided by temperature show strong T dependence, especially $\log T$ divergence at van Hove filling. The Fermi surface instability then cuts off these non-Fermi liquid behaviors and gives rise to a specific heat jump and a cusp in the susceptibility at T_c.

TT 2.9 Mon 11:45 H19

Logarithmic Fermi-liquid breakdown in $Nb_{1.02}Fe_{1.98}$ — •Manuel Brando[1], Dennis Moroni-Klementowicz[2], Carsten Albrecht[2], William Duncan[2], Daniel Gruener[1], Guido Kreiner[1], Rafik Ballou[3], Bjorn Fak[4], and Malte Grosche[2] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Strasse 40, D-01187 Dresden, Germany — [2]Dept. of Physics, Royal Holloway, University of London, Egham TW20 0EX, UK — [3]Laboratoire Louis Néel, CNRS, B.P. 166, 38042 Grenoble Cedex 9, France — [4]Commissariat à l'Energie Atomique, Département de Recherche Fondamentale sur la Matière Condensée, SPSMS, 38054 Grenoble, France

We report measurements of the heat capacity C and of the resistivity ρ in stoichiometric and slightly Nb-rich $NbFe_2$ samples, including a single crystal with the composition $Nb_{1.02}Fe_{1.98}$, which on the phase diagram is located very close to the quantum critical point ($T_N \simeq 2.8$K). Both the resistivity and the heat capacity of the nearly quantum-critical single crystal display striking, robust non-Fermi liquid temperature dependences: while the heat capacity coefficient $\gamma = C/T$ diverges weakly as $C/T \sim \log T$ from 4K down to 0.1K, in line with theoretical predictions for 3-D *ferromagnetic* quantum criticality, the resistivity follows a $T^{3/2}$ power-law, familiar from the case of MnSi and naively predicted for the proximity of an *antiferromagnetic* quantum critical point.

TT 2.10 Mon 12:00 H19

High-temperature echo of the quantum phase transition in $CeCu_{6-x}Au_x$ — •M. Klein[1], A. Nuber[1], H. v. Löhneysen[2,3], and F. Reinert[1] — [1]Universität Würzburg, Experimentelle Physik II, Am Hubland, 97074 Würzburg — [2]Universität Karlsruhe, Physikalisches Institut, D-76128 Karlsruhe — [3]Forschungszentrum Karlsruhe, Institut für Festkörperphysik, D-76021 Karlsruhe

During the last years many experiments and theoretical investigations have been performed to explain the nature of quantum critical points (QCP) in heavy-fermion compounds. One important candidate of these compounds is $CeCu_{6-x}Au_x$ which goes from a paramagnetic metal to an antiferromagnetic metal as x increases. The QCP appears when the critical value of $x_c \sim 0.1$ is reached.

We have performed high-resolution photoemission experiments($\Delta E <$ 5 meV) on single crystals with different gold concentrations at temperatures in the range from $T = 15$ K to 60 K. Though these temperatures were much higher than the characteristic temperatures we see a significant jump in the spectral weight of the Kondo-resonance at x_c implying a sudden change in the correlation between localized 4f-electrons and conduction electrons. A comparison with NCA calculations allows a quantitative determination of the Kondo temperature and the crystal field energies. This finite temperature signatur is a further key to solve the question about the nature of the QCP in this system.

TT 2.11 Mon 12:15 H19

Multiple energy scales at a quantum critical point — •P. Gegenwart[1], T. Westerkamp[2], C. Krellner[2], Y. Tokiwa[3], S. Paschen[4], C. Geibel[2], F. Steglich[2], E. Abrahams[5], and Q. Si[6] — [1]I. Physikalisches Institut, Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]Max-Planck Institute for Chemical Physics of Solids, 01187 Dresden — [3]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — [4]Institute for Solid State Physics, Vienna University of Technology, 1004 Vienna, Austria — [5]Center for Materials Theory, Department of Physics and Astronomy, Rutgers University, Piscataway, New Jersey 08855, USA — [6]Department of Physics & Astronomy, Rice University, Houston, TX 77005, USA

We report thermodynamic and transport measurements at the magnetic-field-driven quantum critical point in the heavy fermion metal $YbRh_2Si_2$. The data define a new energy scale, which approaches zero as the quantum critical point (QCP) is reached. This scale is distinct from the crossover scale below which Fermi liquid behavior is established. The collapse of multiple energy scales provides evidence for a new type of quantum criticality, with critical excitations in addition to the slow fluctuations of the order parameter.

TT 2.12 Mon 12:30 H19

Electric transport at the quantum critical point in $YbRh_2Si_2$ — •Sven Friedemann[1], Niels Oeschler[1], Cornelius Krellner[1], Christoph Geibel[1], Silke Paschen[1,2], and Frank Steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, Noethnitzer Strasse 40, 01187 Dresden, Germany — [2]Vienna University of Technology, Karlsplatz 13, 1040 Wien, Austria

The heavy-fermion metal $YbRh_2Si_2$ exhibits pronounced non-Fermi liquid (NFL) behavior due to its vicinity to a quantum critical point (QCP). By applying small magnetic fields, $YbRh_2Si_2$ is driven from an antiferromagnetic state through the QCP towards the paramagnetic state. Currently, two scenarios for a system at this type of QCP are discussed: The spin-density-wave scenario at which heavy electrons are present on both sides of the QCP and the locally QCP at which the heavy electrons on the paramagnetic side disintegrate into localized magnetic moments and light conduction electrons on the magnetic side of the QCP. The field-dependent Hall effect as a measure of the Fermi volume is assumed to be the appropriate method to characterize the QCP in $YbRh_2Si_2$. As an extension to previous results [1] we present low temperature Hall-effect data of new high-quality samples which confirm a step in R_{H} for $T \rightarrow 0$ and thus support the local scenario. The T dependence of the height and the width of the crossover are discussed. Corresponding features are also observed in the magnetoresistance. Furthermore, the maximum of the Hall-effect at $T \approx 1\,$K is presumably due to the spin fluctuations in the NFL region.

([1] S. Paschen et al., Nature 432, 881 (2004))