TT 19: Correlated Electrons: Quantum-Critical Phenomena

Time: Tuesday 14:00–18:30 Location: H 3010

TT 19.1 Tue 14:00 H 3010

Non-Fermi liquid metal without quantum criticality — •Christian Pfleiderer[1], Peter Böni[1], Thomas Keller[2,3], Ulrich Rössler[4], and Achim Rosch[5] — [1]Physik-Department E21, Technische Universität München, D-85748 Garching, Germany — [2]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany — [3]Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II), Technische Universität München, D-85748 Garching, Germany — [4]Leibniz-Institut für Festkörper-und Werkstoffforschung (IFW) Dresden, P.O. Box 270116, D-01171 Dresden, Germany — [5]Institute of Theoretical Physics, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

A key question in condensed matter physics concerns whether pure three-dimensional metals can always be described as Fermi liquids. Using neutron Larmor diffraction to overcome the traditional resolution limit of diffraction experiments, we studied the lattice constants of the cubic itinerant-electron magnet manganese silicide (MnSi) at low temperatures and high pressures [1]. We were able to resolve the nature of the phase diagram of MnSi and to establish that a stable, extended non-Fermi liquid state emerges under applied pressure without quantum criticality. This suggests that new forms of quantum order may be expected even far from quantum phase transitions. [1] C. Pfleiderer, et al., Science **316**, 1871 (2007).

TT 19.2 Tue 14:15 H 3010

Universal ratios of the phase diagram of Pomeranchuk instability: application to $Sr_3Ru_2O_7$ — •hiroyuki yamase — Max-Planck-Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

We analyze a pure forward scattering model, which exhibits spontaneous d-wave type Fermi surface deformations, the so-called Pomeranchuk instability. The phase diagram is known to be determined by a single energy scale in the weak-coupling limit, and thus dimensionless ratios of different characteristic quantities are universal[1]. We extend such a weak-coupling analysis to the presence of a magnetic field, which is a minimal model for $Sr_3Ru_2O_7$, and compare obtained universal ratios with those provided by experiments[2].

[1] H. Yamase, V. Oganesyan, and W. Metzner, Phys. Rev. B **72**, 035114 (2005).

[2] H. Yamase, Phys. Rev. B **76**, 155117 (2007).

TT 19.3 Tue 14:30 H 3010

Instability of the Quantum-Critical Point of a 2D Weakly Ferromagnetic Fermi Liquid. — •Dmitri Efremov[1], Joseph Betouras[2], and Andrey Chubukov[3] — [1]TU Dresden — [2]University of St Andrews — [3]University of Wisconsin

We report the study of the stability of a 2D weakly ferromagnetic fermi liquid near to the quantum critical point in the Eliashberg approach. We find that correlations associated with the Landau damping generate a universal negative, nonanalytic $q^{3/2}$ contribution to the static magnetic longitudinal susceptibility $\chi_{zz}(q, 0)$ and to the transverse susceptibility $\chi_\perp(q, 0)$. It leads towards either incommensurate ordering or first order phase transition. The instability manifests itself also in the free energy. The correlations associated with the Landau damping generate nonanalytic terms in the free energy expansion.

TT 19.4 Tue 14:45 H 3010

Low Temperature Investigations of $YbRh_2Si_2$ doped with Ir and Co — •Tanja Westerkamp[1], Philipp Gegenwart[2], Cornelius Krellner[1], Christoph Geibel[1], and Frank Steglich[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]1. Physikalisches Institut, Georg-August-Universität, Göttingen, Germany

The tetragonal heavy fermion system $YbRh_2Si_2$ shows interesting properties due to its vicinity to an antiferromagnetic quantum critical point (QCP). At zero magnetic field the system becomes antiferromagnetic below $T_N = 70\,\mathrm{mK}$. The system can be tuned through a field-induced QCP at $B_c = 0.05\,\mathrm{T}$ into a Landau-Fermi liquid (LFL) state at $B > B_c$. This state is restricted to temperatures below a scale $T_{LFL}(B)$. Recently, an additional energy scale $T^*(B)$ was found that vanishes at the QCP and was related to the disintegration of the heavy quasiparticles.

We studied the effect of chemical pressure on the phase diagram, using high quality $Yb(Rh_{1-x}M_x)_2Si_2$ single crystals with M = Ir, Co. Here, we present recent results focusing on measurements of the magnetic susceptibility.

TT 19.5 Tue 15:00 H 3010

Anomalous critical behavior at the antiferromagnetic phase transition of $YbRh_2Si_2$ — •Cornelius Krellner[1], Stefanie Hartmann[1], Adam Pikul[1], Niels Oeschler[1], Christoph Geibel[1], Jochen Wosnitza[2], and Frank Steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]HLD, Forschungszentrum Dresden-Rossendorf, Dresden, Germany

Quantum phase transitions are one of the important topics in the understanding of condensed matter. These transitions are driven by quantum fluctuations in contrast to classical phase transitions which are accompanied by thermal fluctuations. Recently, the heavy-fermion system $YbRh_2Si_2$ was intensively studied, because it is a clean and stoichiometric metal situated on the magnetic side ($T_N = 72$ mK), but very close to a quantum critical point, which can be crossed by applying a tiny magnetic field. Therefore, this system presents both an antiferromagnetic phase transition driven by thermal fluctuations as well as pronounced quantum fluctuations due to the vicinity to the quantum phase transition. In this contribution, we show accurate measurements of the specific heat C around T_N on a single crystal of highest quality (RRR$\sim$ 150). We observe a very sharp peak at T_N with absolute values as high as $C/T = 8\,\mathrm{J/mol\,K^2}$. A detailed analysis of the critical exponent α around T_N reveals $\alpha = 0.37$ which differs significantly from those of the conventional universality classes in the Landau theory $\alpha < 0.11$. We will discuss in detail the analysis and possible mechanisms.

15 min. break

TT 19.6 Tue 15:30 H 3010

Magnetization study of stoichiometric and slightly Ir- Co-doped $YbRh_2Si_2$ — •Manuel Brando[1], Luis Pedrero[1], Cornelius Krellner[1], Philipp Gegenwart[2], Christoph Geibel[1], and Frank Steglich[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Georg-August Universität Göttingen, 37077 Göttingen, Germany

Recent results on the heavy fermion compound $YbRh_2Si_2$ point to the presence of multiple vanishing energy scales, $T_N(H)$, $T_{LFL}(H)$ and $T^*(H)$, at the magnetic-field-driven quantum critical point (QCP) [1]. These scales can directly be observed in thermodynamic, transport and magnetic measurements, among them the dc-magnetization M versus the magnetic field H. More precisely, M shows a kink at $T_N(H)$ and a distinct crossover feature at $T^*(H)$ which smears out with increasing temperature.

Slight doping with isoelectronic Co as well as with Ir on the Rh site leads to a volume change, which tunes the strength of the magnetic interaction; this shifts the $T_N(H)$ line in the $T - H$ phase diagram without introducing much disorder in the single crystals. However, little is known about the behavior of the $T^*(H)$ line in the doped compounds.

We present a systematic analysis of different isothermal M vs. H curves for the stoichiometric, Co- (7%) and Ir-doped (6%) samples down to 50 mK to observe whether the two energy scales are still approaching zero at the same point in the doped compounds.

[1] P. Gegenwart *et. al., Science **315**, 5814 (2007).*

TT 19.7 Tue 15:45 H 3010

Thermopower investigations of $YbRh_2Si_2$ in the vicinity of an antiferromagnetic quantum critical point — •Stefanie Hartmann, Niels Oeschler, Cornelius Krellner, Christoph Geibel, and Frank Steglich — Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany

The stoichiometric heavy-fermion compound $YbRh_2Si_2$ exhibits an antiferromagnetic (AFM) phase transition at an extremely low temperature of $T_N = 72$ mK. Upon applying a tiny magnetic field the AFM ordering is suppressed and the system is driven towards a quantum critical point (QCP). Furthermore, an additional energy scale at T^* indicating the crossover from local to itinerant character of the $4f$

electron vanishes at the QCP. Here, we report on measurements of the thermoelectric power S of high quality single crystals from 6 K down to 50 mK in fields up to 2 T. $S(T)$ was measured within the easy ab plane of the system, that exhibits a critical field of only 50 mT. In the critical region S/T diverges upon approaching the QCP, while it exhibits a constant value in the Fermi liquid regime at higher fields. The low temperature behavior of the thermopower in $YbRh_2Si_2$ is discussed in detail and compared to available theoretical predictions. Whether the T^* line observed in Hall effect and magnetostriction measurements can also be resolved in the thermopower is a matter of great interest.

TT 19.8 Tue 16:00 H 3010

Low temperature electric transport of $Yb(M_xRh_{1-x})_2Si_2$ M=Co,Ir — •Sven Friedemann, Niels Oeschler, Cornelius Krellner, Christoph Geibel, and Frank Steglich — Max Planck Institute for Chemical Physics of Solids, Noethnitzer Strasse 40, 01187 Dresden, Germany

The heavy-fermion metal $YbRh_2Si_2$ exhibits pronounced non-Fermi liquid behavior due to its vicinity to a quantum critical point (QCP). By applying small magnetic fields, $YbRh_2Si_2$ is driven from an antiferromagnetic (AFM) state to the QCP. At the critical field a second energy scale $T^\star$ vanishes that manifests itself as a crossover in transport and thermodynamic properties, e.g. magnetoresistance. Doping Co (Ir) on the Rh side acts as chemical pressure enhancing (decreasing) the AFM ordering temperature and the critical field of the ordered phase. We here report low temperature resistivity and magnetoresistance measurements on $x = 3,7\%$ Co and $x = 6\%$ Ir doped single crystals. The data are compared with that of the undoped system. Although the ordering temperature is observed to change as expected we find the features associated with $T^\star$ to be robust upon doping.

TT 19.9 Tue 16:15 H 3010

Thermal expansion and magnetostriction measurements on a $CeCu_{5.85}Au_{0.15}$ single crystal — •Stefanie Drobnik[1,2], Kai Grube[1], Roland Schäfer[1], Frédéric Hardy[1], Christoph Meingast[1], Oliver Stockert[3], and Hilbert von Löhneysen[1,2] — [1]Forschungszentrum Karlsruhe, Institut für Festkörperphysik, 76021 Karlsruhe, Germany — [2]Physikalisches Institut, Universität Karlsruhe, 76128 Karlsruhe, Germany — [3]MPI für chemische Physik fester Stoffe, 01187 Dresdenm, Germany

A well-studied magnetic quantum critical point (QCP) exists at the onset of antiferromagnetic order in the heavy-fermion system $CeCu_{6-x}Au_x$ with a critical gold concentration of $x_c \approx 0.1$. Due to the instability at the QCP the entropy S shows at finite temperatures a maximum as a function of x, volume, or pressure p. The maximum leads to a sign change of the thermal expansion coefficient, $\alpha = -(1/V)(\partial S/\partial p)$, and of the Grüneisen parameter Γ, the ratio of α and specific heat. This feature and the divergence of Γ at $T \to 0$ are important thermodynamic probes to detect and classify QCPs. We report low-temperature thermal expansion and magnetostriction measurements on a $CeCu_{5.85}Au_{0.15}$ single crystal with a Néel temperature of $T_N \approx 90\,\mathrm{mK}$. The thermal expansion was measured along all orthorhombic axes in a temperature range of $30\,\mathrm{mK} < T < 10\,\mathrm{K}$ in magnetic fields parallel to the c axis of up to 3 T. The results are compared with theoretical predictions and measurements on other heavy-fermion compounds close to a QCP.

TT 19.10 Tue 16:30 H 3010

Breakdown of a valence bond solid in a Heisenberg model with four-spin interaction on honeycomb layers — •Thomas C. Lang[1,2], Anders W. Sandvik[2], and Fakher F. Assaad[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg, Germany — [2]Department of Physics, Boston University, Boston, MA 02115, USA

We investigate the scenario of the breakdown of a valence bond solid (VBS) in an $S = 1/2$ quantum antiferromagnet with non-frustrating four-spin interaction on the single and bilayer hexagonal lattice. By means of quantum Monte Carlo in the valence bond basis we find a strong first-order VBS-Néel phase transition in the single layer. In the bilayer the Néel regime separates the VBS and a disordered (zero tilted) phase by a continuous quantum phase transition. A quantum critical point marking a direct VBS-VBS or VBS-disorder transition is absent. This behavior is attributed to the lattice symmetry which allows rigid valence bond configurations to survive while spin-fluctuations are enhanced.

15 min. break

TT 19.11 Tue 17:00 H 3010

Quantum Critical Spin Dynamics of a Cu(II) S=1/2 antiferromagnetic Heisenberg chain studied by ^{13}C-NMR spectroscopy — •H. Kühne[1], H.-H. Klauss[1], J. Litterst[2], S. Grossjohann[3], W. Brenig[3], A.P. Reyes[4], P.L. Kuhns[4], C.P. Landee[5], M.M. Turnbull[5], H.-J. Grafe[6], B. Büchner[6], and J. Haase[6] — [1]Institut für Festkörperphysik, TU Dresden — [2]Institut für Physik der Kondensierten Materie, TU Braunschweig — [3]Institut für Theoretische Physik, TU Braunschweig — [4]NHMFL, FSU, Tallahassee, USA — [5]DPC, Clark University, Worcester, USA — [6]Leibniz-Institut für Werkstoffforschung, Dresden

The antiferromagnetic S=1/2 Heisenberg chain (S=1/2 AFHC) is a model system for quantum many-body physics. It allows a direct comparison between exact theoretical results and experiment for ground state properties and excitations. $Cu(C_4H_4N_2)(NO_3)_2$ (CuPzN) is a very good experimental realization of the unperturbed S=1/2 AFHC [1,2]. In this compound we study the low energy spin dynamics by means of NMR. We measured the nuclear spin-lattice relaxation rate T_1^{-1} of ^{13}C as a function of temperature in a wide external magnetic field range from 2T to 28T, with an emphasis on the vicinity of the quantum critical point (QCP) at 14T. The experimental data are in good agreement with Quantum Monte Carlo calculations and clearly show critical behavior at low temperatures, i.e. a divergence of T_1^{-1} at 14T and the linear opening of an energy gap for magnetic excitations with higher external fields. [1] P. Hammar et al., PRB. 59, 1008 (1999). [2] M.B. Stone et al., PRL 91, 037205 (2003).

TT 19.12 Tue 17:15 H 3010

Quantum Critical Dynamics of the S=1/2 AFM Heisenberg Chain in Finite Magnetic Fields: a QMC Study — •Simon Grossjohann[1], Wolfram Brenig[1], Hannes Kühne[2], and Hans-Henning Klauss[2] — [1]Institut für Theoretische Physik, TU Braunschweig — [2]Institut für Festkörperphysik, TU Dresden

We investigate the field driven quantum critical dynamics of the antiferromagnetic S=1/2 Heisenberg chain using Quantum Monte-Carlo techniques (SSE) and analytic continuation by Maximum Entropy methods. Results for the transverse and longitudinal dynamical structure factor $S_{\alpha\beta}(q,\omega)$ will be presented for different temperatures T, with $0.1 \leq T/J \leq 1$ and various magnetic fields below and above saturation field h_c. In the vicinity of h_c, condensation of the elementary excitations of the fully polarized phase induce a diverging longitudinal NMR relaxation rate $1/T_1$. Such quantum critical slowing down has been observed in recent experiments on $Cu(C_4H_4N_2)(NO_3)_2$ and agrees very well with our theoretical findings. In addition our spectra will be shown to be consistent with sum rules for the static structure factor and static susceptibility.

TT 19.13 Tue 17:30 H 3010

Dynamical Scaling Properties of a Doped Quantum Heisenberg Antiferromagnet in Two Dimensions — •Marcello Silva Neto, Juergen Falb, and Alejandro Muramatsu — Institut für Theoretische Physik III, Pfaffenwaldring 57, 70550, Stuttgart, Germany

We study the dynamical scaling properties of an effective quantum field theory for the magnetic degrees of freedom of the $t-t'-t''-J$ model, which is believed to be the relevant model for the physics of cuprate superconductors. We find that, at the lowest doping, where the Fermi surface for the doped holes is composed of very small hole pockets at special points in the magnetic Brillouin zone, damping due to the scattering of magnons from particle-hole excitations is *absent* and the dynamical critical exponent is $z = 1$. As doping increases, however, a nonzero damping term is present. In this case, we find that: i) for the case of Landau damping (clean limit), such term does not modify the dynamical exponent which remains at $z = 1$ for a large portion of the phase diagram, in agreement with experiments; ii) for the case of diffusive damping (dirty limit), such term changes the dynamical exponent from $z = 1$ to $1 < z \leq 2$, and for even larger doping a crossover to a Fermi liquid regime is expected. We compare our findings to previous discussions available in the literature and we discuss the relevance of our results to the physics of high-Tc superconductors.

TT 19.14 Tue 17:45 H 3010

Critical Properties of an Effective Field Theory for 2D Doped Antiferromagnets — •Juergen Falb, Marcello Silva Neto, and Alejandro Muramatsu — Institut für Theoretische Physik, Universität Stuttgart, Pfaffenwaldring 57, 70550, Stuttgart, Deutschland

Starting from the $t - t' - t'' - J$ model for high-Tc cuprate superconductors we derive an anisotropic and gauge massive CP^1 effective field theory that describes the low energy magnetic properties at low doping, establishing a link between doped antiferromagnets on a bipartite lattice and frustrated quantum antiferromagnets [1]. We first discuss the generation of mass for the gauge field introduced by doping, and comment on the possible incommensurate phases associated to it. The massive gauge field opens the possibility of deconfined spinons in the symmetric phase. We find a region of stability for the microscopic parameters J, t' and t'' where the theory is valid. Through a renormalization group study of the theory in weak coupling we obtain its phase diagram. The connection between our results and previous works on the literature are also discussed.

[1] J. Falb and A. Muramatsu, arXiv:0705.1918, accepted for publication in Nucl. Phys. B.

TT 19.15 Tue 18:00 H 3010

Probing field-induced quantum criticality in molecule-based low-dimensional spin systems — •Bernd Wolf[1], Yeekin Tsui[1], Ulrich Tutsch[1], Katarina Removic-Langer[1], Andrej Prokofiev[1], Wolf Assmus[1], Roser Valenti[2], Stefan Wessel[3], Andreas Honecker[4], Matthias Wagner[5], and Michael Lang[1] — [1]Physikalisches Institut, JWG-Universität Frankfurt; SFB/TRR49 — [2]Institut für Theoretische Physik, JWG-Universität Frankfurt; SFB/TRR49 — [3]Institut für Theoretische Physik, Universität Stuttgart — [4]Institut für Theoretische Physik, Georg-August-Universität Göttingen — [5]Institut für Anorganische und Analytische Chemie JWG-Universität Frankfurt; SFB/TRR49

A quantum critical point (QCP) is found in systems where a phase transition at T = 0 is driven by an external control parameter. Although a QCP takes place at T = 0, inaccessible by experiment, it has a significant influence on the physical properties over a wide range of temperature. Here we concentrate on field-induced QCPs in low-dimensional molecule-based spin systems. The molecular approach enables us to generate materials with magnetic exchange coupling constants weak enough for laboratory fields to drive the system into a new ground state. We present data of the magnetocaloric effect across the saturation field of an antiferromagnetic S = 1/2 Heisenberg chain system. These results compare favourably with theoretical predictions. In additon, we report thermodynamic measurements on the field-induced magnetic transition in coupled S = 1/2 dimer systems.

TT 19.16 Tue 18:15 H 3010

Quantum critical scaling behavior of deconfined spinons — •Flavio Nogueira[1], Steinar Kragset[2], and Asle Sudbo[2] — [1]Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin — [2]Department of Physics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

We perform a renormalization group analysis of some important effective field theoretic models for deconfined spinons. We show that deconfined spinons are critical for an isotropic SU(N) Heisenberg antiferromagnet, if N is large enough. We argue that nonperturbatively this result should persist down to $N = 2$ and provide further evidence for the so called deconfined quantum criticality scenario. Deconfined spinons are also shown to be critical for the case describing a transition between quantum spin nematic and dimerized phases. On the other hand, the deconfined quantum criticality scenario is shown to fail for a class of easy-plane models. For the cases where deconfined quantum criticality occurs, we calculate the critical exponent η for the decay of the two-spin correlation function to first-order in $\epsilon = 4 - d$.