TT 69: Focus Session: Superconductivity in the Vicinity of a Quantum Critical Point

Unconventional (i.e., nonphonon-mediated) superconductivity is often observed at the border of magnetic order. The suppression of the long-range order opens up a wide parameter regime where the physics may be controlled by an underlying quantum critical point (QCP). Presently, a central question in condensed matter concerns the interplay between quantum criticality and unconventional superconductivity in these strongly correlated electron systems. This session covers the central advances, reported in the last years, connecting quantum criticality and superconductivity in the major classes of unconventional superconductors.

Organization: Cornelius Krellner, Universität Frankfurt; Philipp Gegenwart, Universität Augsburg; Roser Valentí, Universität Frankfurt

Time: Thursday 15:00–18:15 Location: HSZ 03

Invited Talk TT 69.1 Thu 15:00 HSZ 03

The Antiferromagnet $YbRh_2Si_2$ - a New Heavy-Fermion Superconductor — •Frank Steglich — MPI CPfS Dresden, Germany — CCM, ZJU Hangzhou, China — IOP, CAS, Beijing, China

While unconventional superconductivity (SC) often occurs in the vicinity of quantum critical points (QCPs) in antiferromagnetic (AF) heavy-fermion metals, no SC has so far been observed near the QCP induced by a small magnetic field in $YbRh_2Si_2$. Here, we explore results of magnetic and calorimetric measurements on $YbRh_2Si_2$ down to $T = 1$ mK (E. Schuberth *et al.*, Science **351**, 485 (2016)). They reveal the onset of a hybrid nuclear-electronic type of AF order dominated by the Yb-derived nuclear spins at T_A slightly above 2 mK and the subsequent development of SC at $T_c = 2$ mK. The initial slope of the upper critical field curve, $B_{c2}(T)$, at T_c is found to be as large as $-B'_{c2} \simeq 25$ T/K. This indicates that the effective charge-carrier mass must be of the order of several 100 m_{el}, implying that the superconducting state is associated with the Yb-derived $4f$-electronic rather than nuclear spins. Therefore, the theoretical possibility of superheavy-fermion SC based upon an underlying nuclear Kondo effect can be ruled out. In conclusion, we ascribe the formation of Cooper pairs in $YbRh_2Si_2$ to the critical fluctuations associated with the unconventional, Mott-type, QCP of this antiferromagnet, which are revealed when the primary electronic order is diminished by the competing nuclear-dominated hybrid order. Our results demonstrate a new means to reach a field-induced QCP and provide further evidence that SC in the vicinity of AF QCPs is a general phenomenon.

Invited Talk TT 69.2 Thu 15:30 HSZ 03

Quantum Criticality in Cuprate and Iron Based Superconductors — •Antony Carrington — University of Bristol, U.K.

I will review experiments which show that $BaFe_2(As_{1-x}P_x)_2$ is perhaps the best example of a quantum critical superconductor with a high T_c. Quantum oscillation cyclotron mass, specific heat and magnetic penetration depth are all strongly enhanced over a narrow range of x. Interestingly this increase in mass does not influence either the lower or upper critical fields in the expected way.

I will also discuss the applicability of quantum criticality to the cuprates. By measuring quantum oscillations in $YBa_2Cu_4O_8$ under hydrostatic pressure we are able to show that the quasiparticle mass *decreases* as maximum T_c is approached. This result is opposite to the behaviour found when $YBa_2Cu_3O_{7-\delta}$ is tuned towards maximum T_c by oxygen doping. Our results suggest that the proximity of the CDW end point to the maximum in T_c with doping is coincidental and that therefore quantum fluctuations of the CDW order do not boost T_c in the cuprates.

Invited Talk TT 69.3 Thu 16:00 HSZ 03

Evolution of the Fermi Surface of the Nematic Superconductors $FeSe_{1-x}S_x$ — •Amalia Coldea — University of Oxford

I will present the evolution of the Fermi surfaces and electronic interactions across the nematic phase transition in single crystals of $FeSe_{1-x}S_x$ using Shubnikov-de Haas oscillations in high magnetic fields up to 45 tesla in the low temperature regime. The unusually small and strongly elongated Fermi surface of FeSe increases monotonically with chemical pressure, x, due to the suppression of the in-plane anisotropy except for the smallest orbit which suffers a Lifshitz-like transition once nematicity disappears. Even outside the nematic phase the Fermi surface continues to increase, in stark contrast to the reconstructed Fermi surface detected in FeSe under applied external pressure. I will present the unusual signatures of orbital-dependent quasiparticle mass renomalization suppressed for those orbits with dominant $d_{xz/yz}$ character, but unusually enhanced for those orbits with dominant dxy character. The lack of enhanced superconductivity outside the nematic phase in $FeSe_{1-x}S_x$ suggest that nematicity may not play the essential role in enhancing Tc in these systems.

15 min. break.

Invited Talk TT 69.4 Thu 16:45 HSZ 03

Superconductivity near Structural Instabilities — •Malte Grosche — Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK

Complex materials frequently display an interesting interplay between structural and electronic instabilities, which can often be studied effectively under applied pressure. This talk will present some recent examples, including (i) a structural quantum critical point and its consequences for superconductivity in the quasi-skutterudite system $(Sr/Ca)_3(Ir/Rh)_4Sn_{13}$ [1], (ii) unconventional superconductivity in YFe_2Ge_2 and its connection with superconductivity in the high-pressure collapsed tetragonal phase of alkaline-metal iron arsenides [2], and (iii) strong-coupling superconductivity in the incommensurate high-pressure host-guest structure of elemental bismuth.

[1] Goh et al., Phys. Rev. Lett. **114,** 097002 (2015)
[2] Chen et al., Phys. Rev. Lett. **116,** 127001 (2016)

Invited Talk TT 69.5 Thu 17:15 HSZ 03

An Empirical Approach to the 2 mK Transition in $YbRh_2Si_2$ — •Christoph Geibel, Manuel Brando, and Alexander Steppke — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

The Kondo lattice system $YbRh_2Si_2$ is located extremely close to a quantum critical point (QCP) separating the magnetic ordered from the paramagnetic ground state. This results in a number of very unusual properties whose origins are controversially discussed. Recently an abrupt drop in the magnetic susceptibility at 2 mK provided evidence for a combined nuclear-electronic magnetic and superconducting transition [1]. However, the scenario proposed in [1], being based on a Landau model with a large number of free parameters, met some skepticism. Here we analyze the specific properties of $YbRh_2Si_2$ in view of possible mechanisms for this 2 mK transition. After introducing how hyperfine interaction works for Yb, we single out some very peculiar properties of $YbRh_2Si_2$ which result in a specific and unique situation for the interplay between 4f and nuclear moments. Below a few mK the AFM state formed at 70 mK, because of its tiny ordered 4f moment, becomes inherently unstable against the formation of a state with a larger ordered moment. Our analysis strongly supports the existence of a combined nuclear-electronic transition in the mK range in $YbRh_2Si_2$, but indicates that the ordered 4f moment should increase at this transition, in contrast to the decrease proposed in [1].

[1] E. Schuberth et al., Science 351, 485 (2016)

TT 69.6 Thu 17:45 HSZ 03

THz response of $CeCoIn_5$ and evolution of effective mass in the non-Fermi liquid regime — Uwe S. Pracht[1], Martin Dressel[1], Jernej Mravlje[2], Peter Wölfle[3], Ryota Endo[4], Tatsuya Watashige[4], Yousuke Hanaoka[4], Masaaki Shimozawa[5], Takahito Terashima[4], Takasada Shibauchi[5], Yuji Matsuda[4], and •Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Germany — [2]Jozef Stefan Institute, Ljubljana, Slovenia — [3]Karlsruhe Institute of Technology, Karlsruhe, Germany — [4]Kyoto

University, Kyoto, Japan — [5]University of Tokyo, Chiba, Japan

$CeCoIn_5$ is a heavy-fermion superconductor that exhibits non-Fermi-liquid properties in the metallic state below 30 K that are interpreted in terms of quantum criticality. The strong evolution of the quasiparticle effective mass with temperature or energy, which is characteristic for heavy fermions, takes place in this normal-state regime, but is typically difficult to access experimentally. Optical spectroscopy on metals can reveal the temperature- and frequency-dependent effective mass and transport scattering rate in and beyond the quantum-critical regime.

Here we perform THz spectroscopy on $CeCoIn_5$ thin films in wide temperature (3 K to 150 K) and frequency (0.2 THz to 1.1 THz) regions that match in energy [1], and we employ an extended Drude analysis. We find strong frequency and temperature dependence of the scattering rate and the effective mass, and we discuss the implications for understanding the evolution of the heavy-fermion, non-Fermi-liquid state of $CeCoIn_5$.

[1] U.S. Pracht *et al.*, J. Magn. Magn. Mater. **400**, 31 (2016).

TT 69.7 Thu 18:00 HSZ 03

Approaching a Van Hove Singularity in Sr_2RuO_4 Using Uniaxial Stress — •Mark E. Barber[1,2], Alexandra S. Gibbs[1,3], Yoshiteru Maeno[4], Clifford W. Hicks[2], 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]ISIS Facility, Rutherford Appleton Laboratory, Chilton, Didcot OX11 OQX, United Kingdom — [4]Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan

Sr_2RuO_4 is an unconventional superconductor with a well characterised Fermi liquid normal state. It is known that one of its three conduction bands lies in close proximity to a Van Hove singularity and we show that by the application of uniaxial pressure the Fermi level can be made to traverse the Van Hove singularity. For the first time we can tune through this topological Liftshitz transition using a clean and continuous tuning parameter. We observe more than a factor of 2.3 enhancement of T_c and quantum critical behaviour in the normal state properties.