TT 24: Unconventional Superconductors

Time: Wednesday 9:30–13:00 Location: H31

Invited Talk TT 24.1 Wed 9:30 H31

Possible Origin of High-Field Reentrant Superconductivity in UTe_2 — •Toni Helm — Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Due to its potentially spin-triplet-superconducting ground state, UTe_2 (fondly called Ute) has triggered a wave of enthusiasm among condensed-matter researchers since the discovery of superconductivity below 1.6 K in this anisotropic heavy-fermion paramagnet. As the quality of single crystals improved, e.g., Tc was pushed to 2.1 K, some of the fog about Ute's mysterious properties has cleared. Nevertheless, the excitement has only become stronger as Ute exhibits signatures of multiple superconducting phases with distinct order parameters stabilized by different tuning parameters such as pressure, magnetic field, or field orientation. Particularly, strong magnetic fields applied to Ute appear to not only suppress superconductivity, as expected for a textbook superconductor, but also enhance and enable additional phases in a rare and very unconventional phase diagram.

In this talk, we will look at Ute's high-field properties and review recent results concerned with the field-induced superconducting phases in this special compound. In particular, we will focus on what is known so far about the reentrant superconductivity that sets in for specific field orientations at field values beyond approximately 40 T. Latest results from experiments in fields up to 70 T have certain implication to the possible origin of the extremely field-robust reentrant superconductivity in UTe_2.

[1] T. Helm et al., Nat. Commun. 15 (2024).

TT 24.2 Wed 10:00 H31

Fermi surface studies on UTe_2 — •F. Husstedt[1,2], B. V. Schwarze[1], J. P. Brison[3], G. Knebel[3], G. Lapertot[3], M. Kimata[4], D. Aoki[4], T. Helm[1], and J. Wosnitza[1,2] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, HZDR, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Centre CEA de Grenoble, France — [4]Institute for Materials Research, Tohoku University, Japan

To date, the presence of three-dimensional (3D) Fermi surfaces in the heavy-fermion superconductor UTe_2 is strongly debated. We had access to high-quality UTe_2 single crystals with $T_c = 2\,K$ to perform angle-dependent measurements of the magnetic torque, magnetotransport, and Hall effect. The observed quantum oscillations provide further insight into the electronic structure of UTe_2. We measured de Haas-van Alphen frequencies that show a very good agreement with previous reports. Consistent with two-dimensional Fermi-surface cylinders, we also observed a 100 T Shubnikov-de Haas (SdH) frequency for field oriented along the crystallographic a axis. We investigated the angular dependence of this frequency in the a-b plane as well as in the a-c plane to clarify if it may originate from a 3D Fermi surface. The temperature dependence of the 100 T SdH frequency reveals an effective mass much lower than the ones reported for the fundamental frequencies.

TT 24.3 Wed 10:15 H31

Investigating the strain dependence of the lower and upper superconducting critical fields in Sr_2RuO_4: A novel approach using elastocaloric effect measurements — •Aleksei Frolov[1], You-Sheng Li[1], Naoki Kikugawa[2], Andreas W. Rost[3], Andrew P. Mackenzie[1,3], and Michael Nicklas[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]National Institute for Materials Science, Japan. — [3]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Elastocaloric measurements under uniaxial stress are an extremely sensitive technique that provides rich thermodynamic information. This is especially true when studying materials, such as the unconventional superconductor Sr_2RuO_4 [1]. In particular, the investigation of the elastocaloric effect in an applied magnetic field is challenging and pioneering, but highly relevant.

We have performed high resolution elastocaloric measurements on Sr_2RuO_4 in a magnetic field along the [001] axis with uniaxial stress applied in the [100] direction at low temperatures. We have studied the strain dependence of the lower and upper superconducting critical fields. Both show a dome-like shape with a maximum close to the Van Hove strain. We discuss the advantages and limitations of the elastocaloric technique compared to conventional probes such as electrical resistivity and susceptibility, highlighting its contribution to the understanding of unconventional superconductivity in Sr_2RuO_4.

[1] Y. S. Li *et al.*, Nature 607, 276 (2022).

TT 24.4 Wed 10:30 H31

Why scanning tunneling spectroscopy of Sr_2RuO_4 sometimes does not see the superconducting gap — •Adrian Valadkhani[1], Jonas Profe[1], Andreas Kreisel[2], Peter Hirschfeld[3], and Roser Valenti[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Copenhagen, Copenhagen, Denmark — [3]University of Florida, Gainesville, USA

Scanning tunneling spectroscopy (STS) and scanning tunneling microscopy (STM) are perhaps the most promising ways to detect the superconducting gap size and structure in the canonical unconventional superconductor Sr_2RuO_4 directly. However, in many cases, researchers have reported being unable to detect the gap at all in STM conductance measurements, while in others they were able to find the gap. Recently, an investigation of this issue on various local topographic structures on a Sr-terminated surface found that superconducting spectra appeared only in the region of small nanoscale canyons, corresponding to the removal of one RuO surface layer. In this talk, we analyze the electronic structure of various possible surface structures using ab initio density functional theory (DFT), and argue that bulk conditions, favorable for superconductivity, can be achieved, when removal of the RuO layer suppresses the RuO4 octahedral rotation locally. Our findings are supported by a paper recently published using numerical methods beyond DFT-random phase approximation (RPA) and functional renormalization group (FRG). We further propose alternative terminations to the most frequently reported Sr termination where superconductivity surfaces should be observed.

TT 24.5 Wed 10:45 H31

Complex impedance scanning tunneling microscopy as a probe for unconventional superconductors — •Amber Mozes[1], Sanghun Lee[2], Tjerk Benschop[1], Koen Bastiaans[1], and Milan Allan[1,2] — [1]Leiden University, Leiden, The Netherlands — [2]LMU, Munich, Germany

In many unconventional superconductors, the superconducting state is spatially inhomogeneous, and macroscopic superconductivity is suppressed. To understand what causes this suppression of superconductivity, we are developing a probe to measure the local complex impedance. We combine scanning tunneling microscopy (STM) with microwave microscopy. This could, in principle, allow to locally probe the impedance response and relate this to inhomogeneity in free carrier density whenever macroscopic homogeneity is suppressed. More specifically, it would be possible to measure the kinetic inductance of a superconductor, governed by the Meissner effect, as well as local resistivity from non superconducting carriers. Implementation of complex impedance measurements in STM requires a microwave impedance matching circuit to enable simultaneous DC and AC readout of the tip-sample response. I will present our recently developed chip circuits that are in situ replaceable, enabling sample specific circuit design, with the aim to impedance match for superconducting sample properties.

TT 24.6 Wed 11:00 H31

Tunneling spectroscopy on superconducting thin films of non-centrosymmetric niobium rhenium — •Marcel Strohmeier[1], Carla Cirillo[2], Andriy Smolyanyuk[3], Karsten Held[3], Carmine Attanasio[4], Angelo Di Bernardo[1,4], and Elke Scheer[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]CNR-Spin, c/o University of Salerno, 84084 Fisciano (SA), Italy — [3]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [4]Department of Physics 'E.R. Caianiello', University of Salerno, 84084 Fisciano (SA), Italy

In recent years, non-centrosymmetric superconductors have attracted increasing attention as they reveal various properties of unconventional superconductivity. With the absence of inversion symmetry and an asymmetric Rashba-type spin-orbit coupling (SOC) a mixed spin-singlet and spin-triplet pairing state is predicted in these materials. In our talk, we focus on the non-centrosymmetric compound $Nb_{0.18}Re_{0.82}$, whose superconducting order parameter remains under debate. Its favorable combination of material properties such as structural disorder, strong SOC and relatively high critical current densities makes NbRe an promising candidate for applications in superconducting single-photon detection and gate-controlled supercurrent devices. We present low-temperature scanning tunneling microscopy measurements on polycrystalline NbRe fabricated by magnetron sputtering. Using high-energy resolution N-I-S spectroscopy, we probe the local density of states in thin films of varying thickness and crystallinity to gain insights into the intrinsic pairing symmetry of the superconductor.

15 min. break

Invited Talk TT 24.7 Wed 11:30 H31

Unconventional Superconductivity in Epitaxial $KTaO_3$-Based Heterostructures — •Denis Maryenko — RIKEN Center for Emergent Matter Science, Wako, Japan

Spin-orbit coupling (SOC) is a driving force behind the emergence of novel quantum phenomena. Among these, superconductivity is particularly exciting due to its potential to form unconventional superconducting states that challenge conventional theories. The perovskite $KTaO_3$, with its inherently strong SOC, has recently gained attention as a promising material platform for exploring these phenomena. However, achieving precise control over interfacial electronic states to realize a conductive layer in $KTaO_3$ remains a significant challenge.

In this work, we present out recent progress on epitaxially grown $KTaO_3$-based heterostructures, with a focus on the $LaTiO_3$-$KTaO_3$ (110) interface[1]. Our findings reveal a systematic emergence of superconductivity in these structures. We demonstrate that the superconducting state, signaling unconventional Cooper pairing, can be tuned by electric and magnetic fields. This study sheds light on the interplay between superconductivity and SOC in low-dimensional systems, contributing to the broader understanding of quantum materials with strong spin-orbit interaction.

[1] D. Maryenko et al., APL Materials 11, 61102 (2023).

TT 24.8 Wed 12:00 H31

Topological Fermi Arcs and Surface Superconductivity in $PtBi_2$ — •Julia Besproswanny[1], Sebastian Schimmel[1], Sven Hoffmann[1], Gregory Shipunov[2], Saicharan Aswartham[2], Joaquin Puig[3], Yanina Fasano[3], Danny Baumann[2], Ricardo Vocaturo[2], Jorge I. Facio[3], Oleg Jansen[2], Jeroen van den Brink[2], Bernd Büchner[2], and Christian Hess[1] — [1]University of Wuppertal, 42119 Wuppertal, Germany — [2]IFW Dresden, 01069 Dresden, Germany — [3]Centro Atómico Bariloche, Instituto Balseiro, 8400 Bariloche, Argentina

t-$PtBi_2$ is a topological Weyl semimetal, as evidenced by band structure and quasiparticle interference (QPI) investigations [1]. It also exhibits unconventional surface superconductivity [2,3], with ARPES revealing a superconducting energy gap only on the Fermi arc states [3]. Low-temperature scanning tunneling microscopy and spectroscopy (STM/STS) reveals locally varying sample-dependent superconductivity revealed by the energy gap. In some cases the scale of the gap suggests BCS critical temperatures as high as 70-130 K. We study the temperature and magnetic field dependence of the the energy gap, demonstrating its persistence up to 50 K. Furthermore, QPI measurements in the superconducting state indicate an interplay between topological Fermi arcs and superconductivity.

[1] S. Hoffmann et. al., Adv. Phys. Res. 2400150 (2024);
[2] S. Schimmel et. al., Nat. Commun. 15, 9895 (2024);
[3] A. Kuibarov et. al., Nature 626, 294(2024).

TT 24.9 Wed 12:15 H31

Unconventional Superconductivity in Trigonal $PtBi_2$: Ginzburg–Landau Theory — Harald Waje[1], Ion Cosma Fulga[2], Jeroen van den Brink[2,3], and •Carsten Timm[1,3] — [1]TU Dresden, 01062 Dresden, Germany — [2]Leibniz Institute for Solid State and Materials Research Dresden (IFW), 01069 Dresden, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Trigonal $PtBi_2$ is a Weyl semimetal that exhibits unconventional surface superconductivity carried by the Fermi arcs [1]. Recent results indicate that the superconducting gap might be nodal, i.e., exhibiting topologically protected Majorana cones. There are three possible superconducting order parameters, corresponding to the three irreducible representations A_1, A_2, and E of the noncentrosymmetric point group C_{3v}. The gap has s-wave ($l = 0$), i-wave ($l = 6$), or d-wave ($l = 2$) symmetry, respectively. We set up a Ginzburg–Landau theory for these order parameters, which also includes coupling to an applied magnetic field. Finally, we discuss some effects described by this theory, such as field-induced pair-density waves.

[1] A. Kuibarov *et al.*, Nature **626**, 294 (2024).

TT 24.10 Wed 12:30 H31

Symmetry-Preserving First-Order Superconductor-to-Superconductor Transition in Heavy-Fermion $CeRh_2As_2$ — •Fabian Jakubczyk[1,2], Julia Link[1,2], and Carsten Timm[1,2] — [1]TU Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Locally noncentrosymmetric materials are attracting significant attention due to the unique phenomena associated with sublattice degrees of freedom. The recently discovered heavy-fermion superconductor $CeRh_2As_2$ has emerged as a compelling example of this class, garnering widespread interest for its remarkable H-T phase diagram, which features field-induced multi-phase superconductivity with non-trivial angular dependencies and large critical fields, as well as antiferromagnetic order, and potential higher multipole orders. To investigate the complex interplay of the ordered phases in $CeRh_2As_2$ including the impact of a magnetic field, we develop a theoretical framework based on group-theoretical considerations, combined with Bogoliubov–de Gennes and Ginzburg–Landau methods. This approach enables us to propose probable symmetries of the superconducting states and elucidate their close relationship with magnetism in this material. Intriguingly, we find that the dominant first-order transition can be interpreted as a transition between coexistence phases of the same symmetry but with distinct admixtures of individual order parameters. Our approach accurately reproduces current experimental phase diagrams, both if the transition to a magnetic phase occurs below the superconducting critical temperature and if it occurs above.

TT 24.11 Wed 12:45 H31

Cause and Effect - Understanding the Fundamental Principles Determining the Gap Structure in Fluctuation Driven Superconductors — •Jonas Profe[1], Olivier Gingras[2], Antoine Georges[3,2,4,5], and Roser Valenti[1] — [1]Institut für Theoretische Physik, Goethe-Universität Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany — [2]Center for Computational Quantum Physics, Flatiron Institute, 162 Fifth Avenue, New York, New York 10010, USA — [3]College de France, 11 place Marcelin Berthelot, 75005 Paris, France — [4]Centre de Physique Theorique, Ecole Polytechnique, CNRS, Institut Polytechnique de Paris, 91128 Palaiseau Cedex, France — [5]DQMP, Universite de Geneve, 24 quai Ernest Ansermet, CH-1211 Geneve, Suisse

Describing and understanding unconventional superconductors is one of the major challenges of modern condensed matter physics. Here, central questions are, what determines which symmetry the superconducting order will have in a material and how can we engineer specific superconducting orders? In this talk, we disentangle how the effective pairing interaction and the electronic structure influence the resulting superconducting order for attractive interactions mediated by fluctuations. For this, we analytically dissect the linearized gap equation in order to extract as much information as possible. We then exemplify how one can utilize this understanding to design models showing specific ordering tendencies in both a single and a multi-orbital setting.