TT 22: Unconventional Superconductors

Time: Wednesday 15:00–19:15 Location: H10

Invited Talk TT 22.1 Wed 15:00 H10

Evidence for orbital loop current magnetism in Sr_2RuO_4 — R. Fittipaldi[1], R. Hartmann[2], M.T. Mercaldo[1], S. Komori[3], A. Bjørlig[4], W. Kyung[5], Y. Yasui[6], T. Miyoshi[6], L.A.B. Olde Olthof[3], C.M. Palomares Garcia[3], V. Granata[1], I. Keren[7], W. Higemoto[8], A. Suter[7], T. Prokscha[7], A. Romano[1], C. Noce[1], C. Kim[5], Y. Maeno[6], E. Scheer[2], B. Kalisky[4], J.W.A. Robinson[3], M. Cuoco[1], Z. Salman[7], A. Vecchione[1], and •A. Di Bernardo[2] — [1]CNR-SPIN, University of Salerno, Italy — [2]University of Konstanz, Germany — [3]University of Cambridge, UK — [4]Bar-Ilan University, Israel — [5]Seoul National University, South Korea — [6]Kyoto University, Japan — [7]Paul Scherrer Institute, Switzerland — [8]Japan Atomic Energy Agency

A deeper understanding of the normal-state properties of Sr_2RuO_4 is crucial also to determine its superconducting state symmetry. Using low-energy muon spin rotation spectroscopy, we have found evidence for a new form of magnetism on the surface of Sr_2RuO_4 in its normal state. We detect weak static dipolar fields with a relatively high onset temperature above 50 K. The magnetism observed is not conventional, and we demonstrate that it arises due to orbital loop currents at the reconstructed Sr_2RuO_4 surface. Our results [1] set a reference for the observation of orbital loop current magnetism in other materials and shed light onto a new mechanism that can affect the superconducting state of Sr_2RuO_4.

[1] R. Fittipaldi et al., Nat. Commun. 12, 5792 (2021)

TT 22.2 Wed 15:30 H10

Optimization of Sr_2RuO_4 thin films and devices based on single-crystals flakes — •Priyana Puliyappara Babu[1], Roman Hartmann[1], Sohaila Zaghloul Noby[1], Elke Scheer[1], Angelo Di Bernardo[1], Rosalba Fittipaldi[2], and Antonio Vecchione[2] — [1]University of Konstanz, 78457 Konstanz, Germany — [2]University of Salerno, 84084 Fisciano, Italy

Since its discovery in 1994, Sr_2RuO_4 has been the subject of intensive studies aiming at shedding light on the nature of its superconducting order parameter (OP). Despite earlier reports suggesting an unconventional nature of the Sr_2RuO_4 superconductivity, conflicting results have been recently reported and a definitive conclusion about the superconducting OP symmetry has not been yet achieved.

To address some of the open questions, it is crucial to fabricate superconducting devices based on high-quality superconducting thin films of Sr_2RuO_4. Thin films of Sr_2RuO_4 with very low density of defects, high residual resistivity ratio (> 30) and fully metallic down to low temperatures have been grown from single crystal target of $Sr_3Ru_2O_7$. The growth parameters that can be further optimized to get fully superconducting thin films have also been identified. In parallel, we are also fabricating superconducting devices based on Sr_2RuO_4 flakes produced by mechanical exfoliation of single crystals. Different fabrication routes involving lithography patterning followed by Inductively Coupled Plasma (ICP) etching and patterning with a helium ion microscope have been successfully employed to fabricate superconducting devices from Sr_2RuO_4 single-crystal flakes.

TT 22.3 Wed 15:45 H10

Angular dependence of superfluid density in Sr_2RuO_4 — •Javier Landaeta[1], Konstantin Semeniuk[1], Joost Aretz[1], Ismardo Bonalde[2], and Elena Hassinger[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Centro de Física, Instituto Venezolano de Investigaciones Científicas, Caracas 1020-A, Venezuela

Although being extensively studied for more than 25 years, the nature of the superconducting order parameter (SOP) of Sr_2RuO_4 is still debated. In recent years, experimental evidence revealed the possibility of two component SOPs. These results constrain the SOP to only a few allowed symmetries. To get insight on the nodal structure of the SOP, we carried out a comprehensive study of the temperature dependence of the superfluid density n_s at various angles. By measuring the superconducting lower critical field $H_{c1}(T)$ in a spherical sample with ac-susceptibility, we obtained the temperature dependence of $n_s = H_{c1}(T)/H_{c1}(0)$ down to $0.03\,T_c$. Our results show that $n_s(T)$ is identical for all the studied angles showing a low temperature power law of T^2, which rules out the possibility of horizontal line nodes in Sr_2RuO_4. These results impose strong constraints over the remaining allowed symmetries for SOPs.

TT 22.4 Wed 16:00 H10

Spin-fluctuation pairing and Hund's pairing in Sr_2RuO_4 — Mercè Roig[1], Astrid T. Rømer[1], Thomas A. Maier[2], •Andreas Kreisel[3], Peter J. Hirschfeld[4], and Brian M. Andersen[1] — [1]Niels Bohr Institute, University of Copenhagen — [2]Center for Nanophase Materials Sciences, Oak Ridge National Laboratory — [3]Institut für Theoretische Physik, Universität Leipzig — [4]Department of Physics, University of Florida

The unconventional superconductor Sr_2RuO_4 has been subject of enormous experimental investigations in the last two decades, but until now the form of its order parameter has not been explicitly determined. Given the exclusion of spin-triplet superconductivity by recent experiments, the time-reversal symmetry breaking linear combinations of s-, d- and g-wave one-dimensional (1D) irreducible representations are strong candidates. However, also a two-dimensional representation E_g, stabilized within the so-called Hund's coupling mean-field pairing scenario, has been proposed. In this work, we examine Hund's pairing on equal footing with spin-fluctuation pairing using a three dimensional electronic structure for Sr_2RuO_4 and a model that does not exhibit clear nesting features. For the latter, the superconducting state generated by the Hund's mechanism agrees well with that from the full fluctuation exchange vertex for large J/U ratios. On the other hand, for systems characterized by a peaked finite-momentum susceptibility, spin-fluctuation pairing generally dominates over Hund's pairing. We conclude that Hund's pairing states (and therefore also the E_g pairing) are unlikely to be realized in systems like Sr_2RuO_4.

TT 22.5 Wed 16:15 H10

Thermal conductivity of the two-phase superconductor $CeRh_2As_2$ — Seita Onishi[1], •Ulrike Stockert[1], Seunghyun Khim[1], Jacintha Banda[1], Manuel Brando[1], and Elena Hassinger[1,2] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]Physics Department, Technical University Munich, Germany

$CeRh_2As_2$ is an unconventional superconductor with $T_c = 0.26$ K. Two neighbouring superconducting phases are observed for a magnetic field H applied along the c-axis with an almost constant transition field $H^\star$ of about 4 T. In addition, antiferromagnetic order, quadrupole-density-wave order and the proximity of this material to a quantum-critical point have been reported: The coexistence of these phenomena with superconductivity is currently under discussion.

We present thermal conductivity, κ, and electrical resistivity, ρ, measured on single crystals of $CeRh_2As_2$ between 60 mK and 200 K and in magnetic fields ($H \parallel c$) up to 8 T. The extrapolation of our normal-state data to zero temperature is in line with the Wiedemann-Franz law. No clear anomaly is observed in the temperature dependence of κ at any of the reported phase transitions. Instead, $\kappa(T)$ shows a pronounced, field-dependent drop below T_c which is attributed to superconductivity. The field-dependence of the normalized thermal conductivity at 120 mK exhibits a change in slope around $H^\star$, similar to the specific heat coefficient γ. Measurements at higher fields and lower T are required to confirm that this is really due to the transition between the two superconducting phases.

TT 22.6 Wed 16:30 H10

Consequences of density-wave order in a staggered Rashba superconductor — •Anastasiia Skurativska[1,2], Manfred Sigrist[1], and Mark H Fischer[3] — [1]University of Zurich, Zurich, Switzerland — [2]Donostia International Physics Center, Donostia-San Sebastian, Spain — [3]Institute for Theoretical Physics, ETH Zurich, Zurich, Switzerland

Superconductors with local inversion-symmetry breaking can exhibit properties usually associated with non-centrosymmetric systems, such as local mixing of even and odd superconducting order parameters or unusual magnetic response. An example of a system with such local non-centrosymmetricity is a stack of layers with alternating Rashba spin-orbit coupling due to mirror symmetry breaking with respect to the individual layers. Motivated by recent experiments on the Ce-based superconductor $CeRh_2As_2$, which were interpreted as showing possible quadrupole-density-wave order, we investigate the effect of

density-wave order on the physics related to local inversion-symmetry breaking. In particular, we study how the partial gapping out of the Fermi surface changes the effect of local inversion-symmetry breaking.

TT 22.7 Wed 16:45 H10

Anisotropic vortex squeezing in Rashba superconductors: a manifestation of Lifshitz invariants — Lorenz Fuchs[1], •Denis Kochan[2], Christian Baumgartner[1], Simon Reinhardt[1], Sergei Gronin[3], Geoffrey Gardner[3], Tyler Tyler Lindemann[4], Michael Manfra[3], Christoph Strunk[1], and Nicola Paradiso[1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, 930 40 Regensburg, Germany — [2]Institut für Theoretische Physik, University of Regensburg, 930 40 Regensburg, Germany — [3]Microsoft Quantum Purdue, Purdue University, West Lafayette, Indiana 47907 USA — [4]Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana 47907 USA

Most of 2D superconductors are of type II, i.e., they are penetrated by quantized vortices when exposed to out-of-plane magnetic fields. In a presence of a supercurrent, a Lorentz-like force acts on the vortices, leading to drift and dissipation. The current-induced vortex motion is impeded by pinning at defects. Usually, the pinning strength decreases upon any type of pair-breaking interaction perturbs a system.

In the talk we will discuss surprising experimental evidences showing an unexpected enhancement of pinning in synthetic Rashba 2D superconductors when applying an in-plane magnetic field. When rotating the in-plane component of the field with respect to the driving current, the vortex inductance turns out to be highly anisotropic. We explain this phenomenon as a direct manifestation of Lifshitz invariant that is allowed in the Ginzburg-Landau free energy by symmetry when space-inversion and time-reversal symmetries are broken.

15 min. break

Invited Talk TT 22.8 Wed 17:15 H10

Role of the film geometry in the electronic reconstruction of infinite-layer nickelates on $SrTiO_3$(001) — •Benjamin Geisler — Fakultät für Physik, Universität Duisburg-Essen

The recent discovery of superconductivity in infinite-layer $NdNiO_2$ films on $SrTiO_3$(001) has sparked significant interest [1]. However, details of the physical mechanism behind this observation remained so far elusive, since in contrast to the thin films [2] bulk $NdNiO_2$ shows neither superconductivity nor the antiferromagnetic interactions characteristic of high-T_c cuprates.

First-principles simulations unravel the key role of the interface: Polarity mismatch drives a surprising electronic reconstruction that results in the emergence of a correlated two-dimensional electron gas (2DEG) in the $SrTiO_3$(001) substrate. The concomitant depletion of the self-doping Nd 5*d* states renders infinite-layer nickelates close to cuprate superconductors [3,4]. Recent work identifies an unexpected interface composition that completely quenches the 2DEG, but preserves the electronic reconstruction in the nickelate film [5]. This supports the notion of nickelate superconductivity as novel quantum phase, induced in film geometry by electronic reconstruction.

[1] D. Li *et al.*, Nature **572**, 624 (2019)
[2] H. Lu *et al.*, Science **373**, 213 (2021)
[3] B. Geisler and R. Pentcheva, PRB **102**, 020502(R) (2020)
[4] B. Geisler and R. Pentcheva, Phys. Rev. Res. **3**, 013261 (2021)
[5] B. H. Goodge, B. Geisler, K. Lee, M. Osada, B. Y. Wang, D. Li, H. Y. Hwang, R. Pentcheva, L. F. Kourkoutis, arXiv:2201.03613

TT 22.9 Wed 17:45 H10

Importance of electronic correlations in nickelates — •Paul Worm[1], Liang Si[1], Motoharu Kitatani[2], Ryotaro Arita[3,4], and Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [2]Department of Material Science, University of Hyogo, Ako, Hyogo 678-1297, Japan — [3]RIKEN Center for Emergent Matter Sciences (CEMS), Wako, Saitama, 351-0198, Japan — [4]Research Center for Advanced Science and Technology, University of Tokyo, Komaba, Tokyo, 153-8904, Japan

Motivated by the recent discovery of superconductivity in the pentalayer nickelate $Nd_6Ni_5O_{12}$ [1], we calculate its electronic structure and superconducting critical temperature. First we analyse the compound by means of state of the art density functional theory and dynamical mean field theory (DFT+DMFT) and find that electronic correlations remove the Nd pockets from the Fermi surface, which crucially changes the filling of the Ni $d_{x^2-y^2}$ band. An *effective* single-orbital Hamiltonian can be constructed for the five layers and we show that it's properties are stunningly similar to the infinite layer case. Subsequently we solve this *effective* model within the dynamical vertex approximation to determine the transition temperature. We further study the related bilayer nickelate and propose a suitable dopant to achieve a doping level where superconductivity is expected.

[1] Nature Materials 10.1038
[2] P. Worm et al., arXiv:2111.12697 (2021)
[3] K. Held et al., Front. Phys. 9:810394 (2021)

TT 22.10 Wed 18:00 H10

Collective Modes Contributions in Third-Harmonic Generation in Non-centrosymmetric Superconductors — •Simon Klein, Matteo Puviani, and Dirk Manske — Max Planck Institute for Solid State Research, Stuttgart, Germany

Recent interest for collective amplitude (Higgs) and phase (Leggett) excitations in single- and multi-band superconductors have led to various studies focused on third-harmonic generation (THG) experiments, both for singlet s- and d-wave gap structure. A resonance in the THG intensity appears, when matching the driving frequency to the energy of the corresponding investigated mode, leading to a phase jump at the resonance frequency. We extend these studies to superconductors without an inversion symmetry, which can be effectively described by a two-band model with an order parameter, consisting of spin singlet (even parity) and spin triplet (odd parity) components. We calculate the THG signal for the non-centrosymmetric compound CePt3Si, showing that it contains contributions from three distinguishable sources, namely the Higgs mode, the Leggett mode and quasiparticles. In the clean limit, only diamagnetic Raman-like processes contribute to the THG signal, whereas the quasiparticle contributions dominate the collective modes for all singlet-triplet ratios of the gap structure. In the dirty limit, we find a significant enhancement of the Higgs mode contributions to the THG signal, due to the inclusion of non-vanishing paramagnetic diagrams. We notice a significant change in the phase jump, which helps to differentiate between diamagnetic and paramagnetic results and thus between clean and dirty superconductors.

TT 22.11 Wed 18:15 H10

High-field superconductivity in UTe_2 — •Toni Helm[1,2], Motoi Kimata[3], Kenta Sudo[3], Julia Stirnat[1,5], Atsuhiko Miyata[1], Markus König[2], Tobias Förster[1], Jean-Pascal Hornung[1,5], Gerard Lapertot[4], Jean-Pascal Brison[4], Alexandre Pourret[4], Georg Knebel[4], Dai Aoki[3], and Jochen Wosnitza[1,5] — [1]Dresden High Magnetic Field Laboratory, HZDR, Germany — [2]MPI CPfS Dresden, Germany — [3]Tohoku University, Oarai, Ibaraki, Japan — [4]CEA, IRG-PHELIQs, Grenoble, France — [5]Technical University Dresden, Gremany

The potential spin-triplet superconductor UTe_2 with $T_c = 1.6$ K has attracted a lot of attention recently. The material is a highly anisotropic paramagnet that exhibits a metamagnetic transition at $H_M = 35$ T. In addition to its field-enhanced and pressure-induced superconducting ground state, high-field superconductivity (hfSC) was observed setting in for a particular field orientation just above H_M. We investigated magnetortransport and magnetic torque in pulsed magnetic fields up to 70 T for FIB-microfabricated samples of UTe_2. Our findings confirm the existence of the hfSC above 40 T for a narrow angular range around $\approx 30°$ tilt off the *b* axis. The upper critical field, H_{c2}, reaches almost 75 T and exhibits a temperature dependence that strongly deviates from the low-field SC phase. Excitingly, the Hall effect experiences a drastic suppression for field orientations exactly where the hfSC emerges. The anomalous angle-dependence in high field poses a challenge to the theoretical understanding of the electronic ground state of UTe_2.

TT 22.12 Wed 18:30 H10

Two bands Ising superconductivity from Coulomb interactions in monolayer $NbSe_2$ — Sebastian Hörhold, Juliane Graf, •Magdalena Marganska, and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, Germany

The nature of superconductivity in monolayer transition metal dichalcogenides is still object of debate. It has already been argued that repulsive Coulomb interactions, combined with the disjoint Fermi surfaces around the K,K' valleys and at the Γ point, can lead to superconducting instabilities in monolayer $NbSe_2$. Here, we demonstrate the two bands nature of superconductivity in $NbSe_2$. In our approach it arises from repulsive Coulomb interactions, long range (resulting in intravalley scattering) and short range (intervalley scattering), together

with Ising spin-orbit coupling. The two distinct superconducting gaps, one for the upper and one for the lower spin-orbit splitted band, both consist of a mixture of s-wave and f-wave components. Using a microscopic multiband BCS approach, we derive and self-consistently solve the gap equation, demonstrating the stability of nontrivial solutions in a realistic parameter range. The temperature dependence of the gaps and of the critical in-plane field are consistent with various sets of existing experimental data. Our results, although derived for $NbSe_2$, are however universal and apply to almost all systems with disjoint Fermi surfaces connected by two competing scattering processes.

TT 22.13 Wed 18:45 H10

Superconductivity in CrB_2 under pressure: Role of electron-phonon coupling and spin-fluctuations — •Sananda Biswas[1], Andreas Kreisel[2], Ronny Thomale[3], Roser Valentí[1], and Igor Mazin[4] — [1]Goethe Universität, Frankfurt, Germany — [2]Universität Leipzig, Leipzig, Germany — [3]Julius-Maximilians-Universität Würzburg, Würzburg, Germany — [4]George Mason University, Fairfax, VA, USA

Superconductivity has recently been discovered in CrB_2 under pressure with maximum reported T_c to be 7 K. Iso-structural to MgB_2, CrB_2 exhibits spin-density-wave (SDW) ground state at ambient pressure. In this talk, I will focus on the role of spin-fluctuations and electron-phonon coupling (EPC) in determining the T_c. We have performed ab-initio density functional perturbation theory to determine the EPC of this system and to study the spin-fluctuation, random-phase-approximation (RPA) has been employed.

TT 22.14 Wed 19:00 H10

p-wave superconductivity in Luttinger semimetals — •Julia M. Link[1] and Igor F. Herbut[2] — [1]TU Dresden, Dresden, Germany — [2]Simon Fraser University, Burnaby, Canada

We consider the three-dimensional spin-orbit-coupled Luttinger semimetal of "spin" 3/2 particles in presence of weak attractive interaction in the l=1 (p-wave) channel, and determine the low-temperature phase diagram for both particle- and hole-dopings [1]. The phase diagram depends crucially on the sign of the chemical potential, with two different states (with total angular momentum j=0 and j=3) competing on the hole-doped side, and three (one j=1 and two different j=2) states on the particle-doped side. The ground state condensates of Cooper pairs with the total angular momentum j=1,2,3 are selected by the quartic, and even sextic terms in the Ginzburg-Landau free energy. Interestingly, we find that all the p-wave ground states that appear in the phase diagram, while displaying different patterns of reduction of the rotational symmetry, preserve the time reversal symmetry. The resulting quasiparticle spectrum is either fully gapped or with point nodes, with nodal lines being absent.

[1] J. M. Link and I. F. Herbut, Phys. Rev. B 105, 134522 (2022)