TT 51: Focus Session: Broken Time Reversal Symmetry in Multiband Superconductors

A broken time-reversal symmetry (BTRS) superconducting state is observed for several unconventional superconductors (SC) such as Sr_2RuO_4, SrPtAs, and UPt_3. This state can be described as a coherent chiral state of degenerate order parameter symmetries such as p_x +/- i p_y or $d_{x^2-y^2}$ +/- d_{xy} which form since they avoid the formation of node lines on the Fermi surface. The main experimental evidence for BTRS SC comes from the observation of a polar Kerr effect and the appearance of small static internal magnetic fields in muon spin relaxations measurements at zero external field below T_c. However, a clear experimental proof for a specific order parameter symmetry is difficult. Recently, a new strategy has been developed to identify these states in Sr_2RuO_4 by applying uniaxial strain which triggered many new experimental studies in this field. For multi-band iron-based superconductors a new route to chiral sc order parameters based on the frustrated competition of different sc phases has been proposed. This state is now found in the hole-doped $B_{1-x}K_xFe_2As_2$ system.

Organized by: Hans-Henning Klauss (TU Dresden), Ilya Eremin (RU Bochum), Dimitry V. Efremov (IFW Dresden)

Time: Thursday 9:30–13:00 Location: H2

Invited Talk TT 51.1 Thu 9:30 H2

Evaluation of chiral superconductivity in Sr_2RuO_4 — •Clifford Hicks — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Sr_2RuO_4 is among the very few superconductors that may have a chiral order parameter. Evidence for chirality comes from Kerr effect, muon spin rotation, and junction critical current measurements. One fundamental consequence of a chiral order parameter is that uniaxial stress, by lifting the tetragonal symmetry of the unpressurised lattice, should lift the degeneracy of the x and y components of the chiral order, resulting in a split transition. In this talk, I will discuss results of a set of measurements performed on uniaxially pressurised Sr_2RuO_4: scanning SQUID microscopy, heat capacity, and muon spin rotation. I will present an evaluation of chiral superconductivity in Sr_2RuO_4 taking these new results into account.

Invited Talk TT 51.2 Thu 10:00 H2

Magnetic excitations and their possible role in the superconducting pairing in Sr_2RuO_4 — •Markus Braden[1], Stefan Kunkemöller[1], Kevin Jenni[1], Paul Steffens[1,2], Yvan Sidis[3], Zhiqiang Q. Mao[4], Yoshiteru Maeno[5], and Igor Mazin[6] — [1]University of Cologne, Germany — [2]Institut Laue Langevin, France — [3]Laboratoire Léon Brillouin, France — [4]Tulane University, USA — [5]Kyoto University, Japan — [6]Naval Research Laboratory, USA

The mechanism of the unconventional superconductivity in Sr_2RuO_4 is subject of ongoing debate opposing the impact of antiferromagnetic (AFM) and ferromagnetic (FM) fluctuations. Indirect evidence for FM fluctuations can be deduced from the metallic FM $SrRuO_3$, while isovalent Ca_2RuO_4 is an AFM Mott insulator [1]. With the recent progress in inelastic neutron scattering, we could follow the AFM signal associated with quasi-one-dimensional bands across the superconducting transition down to very low energies. Even well below twice the superconducting gap, there is no change in the magnetic response in Sr_2RuO_4 [2], which seems incompatible with the picture of a large gap on these Fermi-surface sheets. The quantitative analysis of FM fluctuations in Sr_2RuO_4 was performed with polarized neutron scattering yielding good agreement with reports of specific heat, magnetic susceptibility and NMR. Incorporating this ferromagnetic response into the BCS gap equation, however, does not stabilize a triplet pairing [3].

[1] S. Kunkemöller et al., Phys. Rev. Lett. 115, 247201 (2015)
[2] S. Kunkemöller et al., Phys. Rev. Lett. 118, 147002 (2017)
[3] P. Steffens et al., arXiv1808.05855

Invited Talk TT 51.3 Thu 10:30 H2

Topologically protected Bogoliubov Fermi surfaces — •Daniel Agterberg[1], Philip Brydon[2], Henri Menke[2], and Carsten Timm[3] — [1]Department of Physics, University of Wisconsin - Milwaukee — [2]Department of Physics and MacDiarmid Institute for Advanced Materials and Nanotechnology, University of Otago — [3]Institute of Theoretical Physics, Technische Universität Dresden

It is commonly believed that, in the absence of disorder or an external magnetic field, there are two possible types of nodal superconducting excitation gaps: the gap has point nodes or it has line nodes. Here, we show that, for an even-parity nodal superconducting state which spontaneously breaks time-reversal symmetry, the low-energy excitation spectrum generally does not belong to either of these categories; instead, it has extended Bogoliubov Fermi surfaces. These Fermi surfaces are topologically protected from being gapped by a non-trivial Z_2 invariant. In this talk, I will discuss the physical origin, topological protection, and energetic stability of these Bogoliubov Fermi surfaces, using chiral superconductivity in $j = 3/2$ fermions as a representative example.

15 min. break.

Invited Talk TT 51.4 Thu 11:15 H2

Time-reversal symmetry breaking in Fe-based superconductors — •Andrey Chubukov — University of Minnesota, Minneapolis, MN USA

I will discuss different scenario for time-reversal symmetry breaking in the superconducting state of Fe-based high Tc superconductors. I will review earlier works on s+id and s+is states and discuss recent theoretical and experimental results suggesting possible realization of time-reversal symmetry breaking nematic superconducting state in FeSe.

Invited Talk TT 51.5 Thu 11:45 H2

Emerging superconductivity with broken time reversal symmetry inside a superconducting s-wave state — •Vadim Grinenko[1,2], Rajib Sarkar[1], Philipp Materne[1], Kunihiro Kihou[3], Chul-Ho Lee[3], Saicharan Aswartham[2], Igor Morozov[2,4], Bernd Buechner[2], Ruben Huehne[2], Nielsch Kornelius[2], Konstantin Nenkov[2], Dmitriy Efremov[2], Stefan-Ludwig Drechsler[2], Paul Chekhonin[1], Werner Skrotzki[1], Vasiliy Vadimov[5], Mihail Silaev[6], Pavel Volkov[7], Ilya Eremin[7], Hubertus Luetkens[8], and Hans-Henning Klauss[1] — [1]TU Dresden, Germany — [2]IFW Dresden, Germany — [3]AIST, Tsukuba, Japan — [4]Lomonosov Moscow State University, Russia — [5]Institute for Physics of Microstructures, Russia — [6]University of Jyvaskyla, Finland — [7]Ruhr-Universitat Bochum, Germany — [8]PSI, Switzerland

In general, magnetism and superconductivity are antagonistic to each other. However, there are several families of superconductors, in which superconductivity may coexist with magnetism, and only a few examples are known, when superconductivity itself induces a magnetism. Here, we report the finding of a narrow dome of a novel $s + is'$ superconducting (SC) phase with broken time-reversal symmetry (BTRS) inside the broad s-wave SC region of the centrosymmetric multiband superconductor $Ba_{1-x}K_xFe_2As_2$ ($0.7 \lesssim x \lesssim 0.8$). The BTRS dome appears very close to a Lifshitz transition. With this, we experimentally demonstrate the emergence of a novel quantum state at topological changes of the electronic system [1].

[1] Phys. Rev. B 95, 214511 (2017); arXiv: 1809.03610 (2018)

TT 51.6 Thu 12:15 H2

Muon spin relaxation studies of Sr_2RuO_4 under uniaxial stress — •Shreenanda Ghosh[1], Rajib Sarkar[1], Vadim Grinenko[1], Jean-Christophe Orain[2], Felix Brückner[1], Artem Nikitin[2], Joonbum Park[3], Mark Barber[3], Dmitry Sokolov[3], Naoki Kikugawa[4], Jake Bobowski[5], Yoshiteru Maeno[6], Hubertus Luetkens[2], Andrew Mackenzie[3], Clifford Hicks[3], and

Hans-Henning Klauss[1] — [1]Institute for Solid state and Materials Physics, TU Dresden, Gerrmany — [2]Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, Villigen, Switzerland — [3]Physics of Quantum Materials, Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]National Institute for Materials Science, Tsukuba, Japan — [5]University of British Columbia, Canada — [6]Kyoto University, Japan

To probe its superconducting order parameter, we have performed muon spin relaxation(μSR) measurements on samples of Sr_2RuO_4 placed under uniaxial stress. Previous studies on unstressed Sr_2RuO_4 have revealed enhanced relaxation in the superconducting state, which is interpreted as evidence for a chiral $p_x \pm ip_y$ order parameter. With this order parameter, uniaxial stress is expected to induce a splitting between T_c and the onset of chirality. μSR requires large samples, so to perform these measurements. We have developed piezoelectric-based apparatus [1] capable of applying forces of up to $\sim$ 700 N and using it we have increased T_c from 1.4 K up to 2.1 K. First set of results will be presented, from μSR experiments under different strain.

[1] C. Hicks et al., JPS Conf. Proc. **21**, 011040 (2018)

TT 51.7 Thu 12:30 H2

Unconventional pairing states based on first-principles — •Balazs Ujfalussy[1], Gabor Csire[1,2], and James Annett[2] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]University of Bristol, Bristol, United Kingdom

We have combined the relativistic spin-polarized version of Korringa-Kohn-Rostoker method for the solution of the Dirac-Bogoliubov-de Gennes equations with a semiphenomenological parametrization of the pairing interaction. We employ this method to both $LaNiGa_2$ and its non-centrosymmetric relative $LaNiC_2$ which show spontaneous magnetism in the superconducting state. Based on symmetry considerations it was already shown that the breaking of time-reversal symmetry is only compatible with non-unitary triplet pairing states in these crystals. Our method allows to study different on-site triplet equal-spin pairing models involving the first-principle band structure. We compare our predictions for the temperature dependence of the specific heat and it is found that it can be described by an interorbital equal-spin pairing on the nickel which breaks the time-reversal symmetry. It is shown that this pairing induces nodeless, two-gapped quasiparticle spectrum and finite magnetisation due to the redistribution of Cooper pairs in spin space. The method is also applied for Nb/Au/Fe system where we show that the existence of spin-polarized quantum well states can lead to FFLO-like oscillations of the order parameter in the normal metal.

TT 51.8 Thu 12:45 H2

Anomalous Nonlocal Conductance in Superconductor/Ferromagnets Hybrids with Chiral *p*-wave pairing symmetry — •Satoshi Ikegaya and Dirk Manske — Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany

Finding a smoking-gun signature of chiral Majorana edge states is an urgent issue in physics of Sr_2RuO_4, which is a promising candidate material of intrinsic chiral p-wave superconductors. Thus far, the zero-bias conductance peak in the tunneling transport has been experimentally observed. However, the zero-bias conductance peak is not a conclusive evidence for the chiral Majorana edge states because it can be induced by any type of topologically protected edge states.

In this work, we demonstrate that the chiral nature of Majorana edge states is drastically manifested in nonlocal conductance in a junction consisting of a chiral p-wave superconductor and two ferromagnetic leads. The nonlocal conductance in the present junction is insensitive to the distance between the two leads and is sensitive to the chirality of the pair potential. These two drastic features enable us to identify the moving direction of the chiral Majorana edge states in the single experimental setup only by changing the lead wire to which the bias voltage is applied. We propose a smoking-gun experiment for detecting the chiral Majorana edge states in the chiral p-wave superconductor.