TT 21: Focus Session: Nematicity, Magnetism and Superconductivity in FeSe and Related Compounds

Iron based superconductors form the largest family of unconventional superconductors known to us. Among these, the FeSe systems present a curious phenomenology: almost all members related to this family exhibit $T_c \sim$ 35-45 K, and even reaching 60-70 K in the case of single unit cell thick FeSe grown on $SrTiO_3$ (STO). Furthermore, bulk FeSe demonstrates a peculiar phase diagram with variety of transitions including nematic (structural), magnetic and the superconducting one. The nature of the phase competition between superconductivity and other phases is qualitatively different from what is seen in other iron based systems and likely tied to the strong mixing between s- and d-wave Cooper pairing. The aim of this focus session is to bring together the leading experimental and theoretical experts, and thus to directly address some of the most pressing controversies in this field.

Organization: Ilya Eremin, Universität Bochum; Jörg Schmalian, KIT

Time: Tuesday 9:30–12:15 Location: HSZ 03

Invited Talk TT 21.1 Tue 9:30 HSZ 03

BCS-BEC Crossover, Preformed Pairs and Highly Spin-Polarized Superconducting Phase in FeSe — •Yuji Matsuda — Kyoto University, Kyoto, Japan

There is growing evidence that superconducting semimetal FeSe (T_c=8K) is deep in the crossover regime between weak coupling Bardeen-Cooper-Schrieffer (BCS) and strong-coupling Bose-Einstein-condensate (BEC) limits. Therefore FeSe offers a unique and fascinating platform to study the crossover physics. Here we discuss several unique features which may provide new insights into fundamental aspects of the crossover. First is the observation of giant superconducting fluctuations by far exceeding the standard Gaussian theory and a possible pseugogap formation above T_c. Second is the electronic structure. FeSe is a compensated semimetal, and hence it is essentially multiband superconductor, which makes the crossover physics in FeSe distinguished from that in ultracold atomic gases. Third concerns the fate of the superfluid when the spin populations are strongly imbalanced. In FeSe in the crossover regime, the Zeeman effect is especially effective in shrinking the Fermi volume associated with the spin minority. We show the emergence of a distinct field-induced superconducting phase, which has an unprecedentedly large spin-imbalance.

Invited Talk TT 21.2 Tue 10:00 HSZ 03

Discovery of Orbital-Selective Cooper Pairing in FeSe — •J. C. Séamus Davis[1], Peter Sprau[2], Andrey Kostin[2], Andreas Kreisel[3], Anna Böhmer[4], Paul Canfield[4], S. Mukherjee[5], Peter Hirschfeld[6], and Brian Andersen[7] — [1]Department of Physics, Cornell University, Ithaca, NY 14853, USA. — [2]Brookhaven National Laboratory, Upton, NY 11973, USA. — [3]Universität Leipzig, D-04103 Leipzig, Germany — [4]Ames Laboratory, U.S. Department of Energy, Ames, IA 50011, USA — [5]Binghamton University - SUNY, Binghamton, USA. — [6]University of Florida, Gainesville, Florida32611, USA — [7]University of Copenhagen, DK 2100 Copenhagen, Denmark

FeSe is the focus of intense research interest as the basis for achieving the highest critical temperatures of any iron-based superconductor. However, its Cooper pairing mechanism has not been determined because an accurate knowledge of the momentum-space structure of superconducting energy gaps on the different electron-bands does not exist. Here we use Bogoliubov quasiparticle interference (BQPI) imaging to determine the coherent Fermi surface geometry of multiple bands, and to measure their superconducting energy gaps. We show directly that both gaps are extremely anisotropic but nodeless, and of opposite sign. This complex configuration of energy gaps which was unanticipated by existing pairing theories for FeSe, reveals a unique form of superconductivity based on orbital-selective Cooper pairing of electrons from the dyz orbitals of iron atoms.

Invited Talk TT 21.3 Tue 10:30 HSZ 03

Frustrated Magnetism and Electron-Electron Interactions in FeSe — •Roser Valenti — Goethe University Frankfurt, Germany

The temperature-pressure phase diagram of bulk FeSe continues to fascinate a large fraction of researchers working on unconventional superconductivity. In this talk, we will discuss this phase diagram from a first principles prespective. We will show that the magnetic interactions in chalcogenides, as opposed to pnictides, demonstrate unusual frustration, which suppresses magnetic, but not nematic order, favors orbital order in the nematic phase and can naturally explain the nonmonotonic pressure dependence of the superconducting critical temperature. Furthermore we will argue on the importance of electron-electron interactions in FeSe and compare our results based on a combined first principles with many-body methods study with available recent experimental results.

15 min. break.

Invited Talk TT 21.4 Tue 11:15 HSZ 03

Orbital-Selective Pairing and Gap Structures of Iron-Based Superconductors — •Brian Andersen — Juliane Maries Vej 30, 2100 Copenhagen, Denmark

Recent experiments in the superconducting phase of iron-based superconductors have mapped out the detailed momentum dependence of the superconducting gap structure. We discuss the influence on spin-fluctuation pairing theory of orbital selective strong correlation effects in Fe-based superconductors, particularly Fe chalcogenide systems. We propose that a key ingredient for an improved itinerant pairing theory is orbital selectivity, i.e. incorporating less coherent quasiparticles occupying specific orbital states into the pairing theory. This modifies the usual spin-fluctuation pairing via suppression of pair scattering processes involving those incoherent states and results in orbital selective Cooper pairing of electrons in the remaining states. We show that this paradigm yields remarkably good agreement with the experimentally observed anisotropic gap structures in both bulk and monolayer FeSe, as well as LiFeAs, indicating that orbital selective Cooper pairing plays a key role in the more strongly correlated iron-based superconductors.

Invited Talk TT 21.5 Tue 11:45 HSZ 03

New Experimental Results Concerning the Nematic State in Fe-based Superconductors — •Christoph Meingast — Institute for Solid State Physics, Karlsruhe Institute of Technology, Germany.

The nature of the nematic state in FeSe and Ba-122 systems is studied using a variety of experimental probes. In particular, we use a new technique, in which a considerable uniaxial strain is applied to the crystals by glueing them to a substrate with a large anisotropic thermal expansion, to measure the in-plane anisotropy of the uniform magnetic susceptibility and the resistivity under large strains [1]. We discuss the scaling of these quantities for both Ba-122 and FeSe. Further, we study the shear-modulus response of the C4-reentrant phase in Na - doped Ba-122 using a three-point bending technique. Surprisingly, we still find a sizeable nematic susceptibility in this phase, which further increases upon entering the superconducting state, in strong contrast to the behavior of optimally doped crystals. This is likely related to the strong competition between superconductivity with the double-Q state, as our previous studies have shown [2,3]. Finally, we study the coupling between nematicity and superconductivity of FeSe crystals using thermal expansion, magnetostriction and heat capacity. Surprisingly, the orthorhombic distortion is enhanced by superconductivity in S-substituted FeSe [4]. Heat capacity data point to a nodal superconducting gap structure.

[1] M. He et al., arXiv:1610.05575.
[2] A. E. Boehmer et al., Nat. Commun. 6, 7611 (2015).
[3] L. Wang et al., PRB 93, 014514 (2016)
[4] L. Wang et al., physica status solidi (b) 1-6 (2016), 10.1002/pssb.201600153.