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ABSTRACT BOOK

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ORAL PRESENTATION PROGRAM

Plenaries

Mo-PL1 / Some Unique Properties of Superconductivity in Cuprates

Karl-Alex Müller
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Abstract
Last year, the speaker published a review consisting of 56 panels with comments on the properties and their explanation regarding the superconductivity in layered, hole-doped copper oxides [1] .These comprised in substance many experiments probing the systems in real space and time, those yielding information in the energy wave-vector space being too indirect. In theory four groups contributed quantitatively, all based on the assumption that the carriers present have polaronic/vibronic character. The intent of the present presentation is to select from that review some of the observed unique properties, including their theoretical understanding.
These are: The phase diagram of the transition temperature versus hole doping n, containing the dome of the superconducting transition temperature Tc(n), the crossover temperature T*(n) > Tc(n), and the observed oxygen isotope effects 16O ® 18O along these two temperatures, which are quantitatively reproduced. The quasiparticles present are so-called Jahn–Teller intersite bipolarons, consisting of two Jahn–Teller polarons next to each other with antiparallel spins, i.e., S = 0, due to Mihailovic and Kabanov in 2000. From this, the dome of Tc(n) and the near linear behavior of T*(n) follow. Of relevance is the symmetry of the superconducting wavefunction at the surface and in the bulk: It is 100% d on the surface, but 1/4 to 1/3 s in the bulk of the CuO2 plane, and 100% s perpendicular to it! All this behavior is quantitatively accounted for with the vibronic theory of Bussmann-Holder and Keller. In it, a ground-state d-band (Cu) is coupled to an oxygen p band lying above it. Only a coupling with this higher oxygen band yields the observed high Tc(n). The vibronic theory also yields bipolarons as the ground state of these doped cuprates. In understanding the phenomena discussed, also the elastic forces present in the crystal are of relevance. Owing to them, the bipolarons are attracted to each other: they cluster in an anisotropic way to form metallic agglomerates or stripes. Therefore an intrinsic electric inhomogeneity is present, which is dynamic, as revealed by EPR and pulse-probe data. These clusters form and disappear in the insulating antiferromagnetic lattice in time.

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Mo-PL02 / High-temperature superconductivity: Some energetic considerations

Anthony J. Leggett
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Abstract
«High-temperature» superconductivity has by now been found in a variety of different systems:the cuprates,the ferropnictides,FeSe monolayers and,at least by a liberal definition,the organics and the Pu-based heavy-fermion compounds.I start by asking what it is that these systems have in common (two-dimensionality,low electron density,proximity to antiferromagnetism....) and,equally importantly,what they do _not_ have in common (e.g.normal-state band structure,order parameter symmetry...).I then discuss in general terms the energetics of the superconducting transition and,partly on the basis of the above comparisons,conjecture a scenario [1,2] in which it is driven by a saving of Coulomb energy in the regime of small (<~0.3 A^-1) wave vectors but high (~0.2-3.5 eV) energies.I discuss possible tests of this scenario in optical [2] and EELS experiments.

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Mo-PL3 / Superconductivity and CERN

Rolf Heuer
CERN, Switzelrand

Abstract
Superconductivity and High Energy Physics accelerators have been good companions for over 30 years. The prime example today is the Large Hadron Collider (LHC) at CERN. It is based on magnets operating at superfluid helium temperature and superconducting RF cavities and it is among the first large users of HTS. Last but not least, superconductivity is also present in the large superconducting magnets of the ATLAS and CMS experiments. All this allows particle physics to enter a new era of science. The LHC will provide a deeper understanding of the universe and the insights gained could change our view of the world. The talk will present some of the reasons for the excitement surrounding the LHC, which is expected to yield insights into the origin of mass, the nature of dark matter and into many other key questions.
This keynote will address the exciting physics prospects offered by the LHC and discuss in particular what the discovery of the Higgs boson tells us about Physics, Mankind and the Universe.

Tu-PL04 / Iron-based Superconductors : recent progress

Hideo Hosono
Tokyo Institute of Technology, Japan

Abstract
The dynamic formation of electron pair is prerequisite for emergence of superconductivity, while (anti) ferromagnetism emerges by long range static spin ordering. This is the reason why it is widely believed both compete with each other. Iron is a typical magnetic element with a large magnetic spin moment, and had been believed to the most harmful for emergence of superconductivity. However, the situation was totally changed since the discovery of an iron oxypnictide superconductors LaFeAsO1-xFx with Tc=26K in early 2008. This discovery sparked intense research activity on superconductivity in this system. As a consequence, more than 15,000 papers have been published to date along with several comprehensive review articles and monographs.
What is the impact of iron-based superconductors? There will be two answers, i.e., the first is the breaking of a widely accepted belief that "iron is antagonistic against superconductivity", which led to the opening of a versatile frontier in superconducting materials. It has become clear through intense research in the last 7.5 years that iron can be a good friend for high Tc-superconductors under certain conditions. The second is a rich variety in candidate materials and in pairing interaction. It has turned out that there are many material varieties in iron-based superconductors such as 7 parent materials,1111, 122, 111, 112, 245, 11 and thick-blocking layer bearing materials (where the number denotes the atomic ratio in constituting the compound for crystal structure of each compound). Each type has rather different electrical and magnetic properties including anti-ferromagnetic semimetal, Pauli para metal and antiferromagnetic Mott insulator.
Iron-based superconductors (IBSCs) have several unique properties such as robustness to impurity, high upper critical field and excellent grain boundary nature. These properties are advantageous for wire application. Recent progress in the performance of superconducting wires of IBSC is wide eyed, i.e., the maximal critical current has reached the level of commercial metal-based superconducting wires.
In this talk we review the current status of IBSC focusing on materials [. An emphasis is placed on heavily H-doped LnFeAsO1-xHx which gives a new insight into the origin of high Tc in bulk IBSCs. A Japanese expert team lead by Hosono performed extensive exploration for new superconductors over 4 years. The comprehensive review article including a list of ~600 unsuccessful materials is now published in an open access on line journal [2]. I would like to talk on this exploration as well.

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Tu-PL05 / x-ray scattering investigations of CDW correlations in high-Tc cuprates

Matthieu Le Tacon[1], Alex Frano[1], Santiago Blanco-Canosa[1], Matteo Minola[1], Toshinao Loew[1], Juan Porras[1], Martin Bluschke[1], Enrico Schierle[2], Eugene Weschke[2], Bernhard Keimer[1]
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Abstract
I will present an overview of the results obtained from various x-ray scattering experiments on high temperature superconducting cuprates in the last couple of years. I will first focus on Cu L-edge resonant scattering experiments that led us to uncover charge density wave (CDW) correlations competing with superconductivity in the YBCO family [1-3], for which a complete temperature and doping dependent phase diagram has been worked out [4]. These investigations have been extended to other families of cuprates (Bi2201[5], Bi2212[6] and Hg1201[7]) demonstrating the ubiquity and the universality of the phenomenon. Further information was gained from high resolution inelastic x-ray scattering. The observation of a quasi-elastic 'central peak' unraveled the static nature of the CDW correlations, attributed to the pining of CDW nanodomains on defects. Low energy phonons exhibit anomalously large superconductivity induced renormalizations close to the CDW ordering wave vector, providing new insights regarding the long-standing debate of the role of the electron-phonon interaction, a major factor influencing the competition between collective instabilities in correlated-electron materials [8]. Finally I will discuss new results obtained in a heterostructure comprising YBCO and metallic ferromagnet La2/3Ca1/3MnO3, where a stabilization of the CDW phase is concluded and discussed within the scope of tuning the equilibrium conditions of metastable phases via heterostructuring [9].

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We-Pl6 / Superconductivity in Fullerides

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Abstract
The understanding of high-temperature superconductivity in unconventional superconductors such as the cuprates remains a prominent open issue in condensed matter physics. Their electronic phase diagrams exhibit striking similarities—superconductivity emerges from an antiferromagnetic strongly correlated Mott insulating state upon tuning a parameter such as composition (doping control) and/or pressure (bandwidth control) accompanied by a dome-shaped dependence of the critical temperature, Tc, a common feature of other classes of correlated electron materials such as the heavy fermion intermetallic compounds. This electronic phase diagram is adopted by molecular superconductors such as both polymorphs of the cubic alkali fulleride, Cs3C60 [1-3], which are continuously tunable by pressure control of the bandwidth W via outer wave function overlap of the constituent molecules. The molecular electronic structure plays a key role in the Mott-Jahn-Teller insulator (MJTI) formed at large interfulleride separations, with the on-molecule dynamic Jahn-Teller (JT) effect distorting the C60(3–) units and quenching the t1u orbital degeneracy responsible for metallicity [4]. The relationship between the parent insulator, the normal metallic state above Tc, and the superconducting pairing mechanism is a key question in understanding all unconventional superconductors. The complexity associated with the comparable size of electron-electron and electron-phonon interactions and the electronic bandwidth in fullerides makes understanding of superconducting pairing challenging. Applying chemical pressure transforms the MJTI state of the fullerides first into an unconventional correlated JT metal (JTM) (where localized electrons coexist with metallicity and the on-molecule distortion persists), and then into a Fermi liquid with a less prominent molecular electronic signature [5]. This normal state crossover is mirrored in the evolution of the superconducting state, with the highest Tc found at the boundary between unconventional correlated and conventional weak-coupling BCS superconductivity, where the interplay between extended and molecular aspects of the electronic structure is optimized to create the dome [5].

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We-PL07 / Interface Enhanced High Temperature Superconductivity

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Abstract
We would first present the interface enhanced superconductivity with transition temperature above 65 K in the heterostructure of monolayer FeSe on SrTiO3 (STO) prepared by molecular beam epitaxy (MBE) [1, 2]. In the second part of the talk, by layer-by-layer imaging of the electronic structure of Bi-2212 superconductor with scanning tunneling microscopy (STM), we would discuss about the origin of the pseudogap and the possible pairing mechanism of Bi-2212 and its implication on the high temperature superconductivity of cuprates in general [3]. By revealing the similarities between FeSe/STO and Bi-2212 with atomic-scale information, we argue that the two systems may bear the same pairing mechanism in their high temperature superconductivity.

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We-S37-KN1 / Strain tuning of Sr2RuO4 and other materials

Andrew Mackenzie[1], Clifford Hicks[2], Alexander Steppke[2], Lishan Zhou[3], Daniel Brodsky[3], Mark Barber[3], Nabhanila Nandi[3], Heike Pfau[2], Yoshiteru Maeno[4], Shingo Yonezawa[4]
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Abstract
In this talk I will describe on-going work in our group on strain-tuning of Sr2RuO4, in which we are attempting to extend the range of compressive strains that we apply from the 0.25% reported in [1,2]. If uniaxial strains of 1% can be achieved, we believe that we can approach the van Hove singularity of the gamma band of Sr2RuO4. If time permits I will also report on preliminary work on cuprate superconductors and the unconventional non-superconducting low temperature phase of Sr3Ru2O7.

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Th-PL08 / Visualizing Signatures of Majorana Fermions in a Topological Superconductor

Ali Yazdani
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Abstract
Topological superconductors are a distinct form of matter that is predicted to host boundary Majorana fermions. The search for Majorana quasi-particles in condensed matter systems is motivated in part by their potential use as topological qubits to perform fault-tolerant computation, aided by their non-Abelian characteristics. Recently, we have proposed a new platform for the realization of Majorana fermions in condensed matter, based on chains of magnetic atoms on the surface of a superconductor. This platform lends itself to measurements with the scanning tunneling microscope (STM) that can be used to directly visualize the Majorana edge modes with both high energy and spatial resolution. Using rather unique STM instrumentation, we have succeeded in creating this platform and have observed the predicted signatures of localized Majorana edge modes. I will describe our Majorana platform, the experiments to date, and the outlook for further experiments.

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Th-PL09 / A cold grip on superfluidity and topology with atoms

Tilman Esslinger
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Abstract
The remarkable advances in cooling and manipulating atomic gases have opened up new avenues to explore fundamental ideas in quantum many-body physics, such as superconductivity or superfluidity. Control over parameters at a microscopic level makes it possible to tailor the properties of the experimental systems almost at will. In my talk I will review tools and concepts that influenced quantum gas experiments, such as optical lattices and superfluidity in strongly interacting Fermi gases. To illustrate the recent progress in creating topologically non-trivial systems, I will show how time-reversal symmetry can be broken in an optical lattice of honeycomb geometry. This enabled us to realize the topological Haldane model [1,2]. I will also report on a new generation of experiments in which the conduction of neutral atoms through single and multimode tubes is studied in both normal and superfluid regimes [3-6].

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Fr-PL10 / Light-induced superconducting-like phases at high temperatures

Andrea Cavalleri
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Abstract
The control of non-equilibrium phenomena in complex solids is a research frontier in condensed matter and in quantum many body research, encompassing new and highly surprising emergent phenomena. For example, recent experiments in cuprate superconductors have shown that selective excitation of certain lattice vibrations can create transient states with prototypical optical features of equilibrium superconductors even above the equilibrium transition temperature Tc. The underlying microscopic physics remains unexplained, with initial evidence that these properties are accompanied by ultrafast melting of competing orders and by lattice deformations that might be favorable to superconductivity. More recently, we have shown that coherent optical excitation of molecular vibrations can induce a non-equilibrium state with the optical properties of a superconductor even in the organic conductor K3C60, indicating that these effects are likely to be more general than previously envisaged. All these findings underscore the role of coherent light fields in inducing emergent order and open up tremendous challenges for our understanding of non-equilibrium condensed matter. These challenges are both theoretical and experimental, and they require the development of new time-resolved techniques that are not available yet.

Fr-Pl11 / Selected Views And Prospects In Materials And Mechanisms Of Superconductivity

George Sawatzky
University of British Colombia, Canada

Abstract
After almost 30 year of intense research regarding high transition temperature superconductors there is still no consensus regarding the basic mechanism(s) involved, knowledge of which could aid in the discovery of new superconducting materials with optimized properties. Concentrating mainly on the cuprates and Fe pnictides I will briefly discuss aspects like the importance of; single or multiple band approaches, electron phonon coupling, non-uniform polarizability going beyond the RPA approaches, multiplet effects and Hund's rule couplings in determining the effective Coulomb interactions. This with the hope of stimulating "out of the box" thinking or perhaps also reopening some apparently closed boxes where we may have the best chance yet of obtaining an understanding of current materials and pointing in directions of potential new discoveries including new artificial materials based on heterostructures and interfaces.

/ Superconductivity – from a 20th century discovery to a 21st century technology

J. Georg Bednorz
IBM Research, Switzerland

Abstract
A few years ago, the scientific community celebrated the centennial of the discovery of superconductivity and the 25th anniversary of the discovery of high-Tc superconductivity. Since the early days, applications of the phenomenon in resistance-free devices have been envisaged. On the one hand, however, the fundamental properties of the superconducting metals and alloys turned out to be a severe obstacle to a realization. On the other hand, large-scale applications were less attractive owing to the low temperatures at which the transition to the superconducting state occurred.
For decades, the field appeared to be mainly an attractive scientific topic, with the number of applications being very limited. A paradigm change, with a completely new concept in the search for new superconductors, led to the discovery of high- Tc superconductivity in a novel class of materials, and a new perspective for the creation of energy-efficient technology. But also these novel copper-oxide superconductors brought their own specific challenges for technology applications.
As a result of a worldwide science and engineering effort over the past two decades, major obstacles have been removed: Now, after one century, specific areas in applications for power generation, transportation and network reliability are gaining attraction, also fostered by the increased importance of renewable energy. Energy-efficient solutions for industrial processes are being provided by new and surprising concepts for the first commercial high-Tc superconductor products. Large-scale applications, which will need large quantities of superconducting wires, will however still have to overcome the usual problems of a new technology – but superconductivity will definitively become a key technology for the 21st century. And, recent discoveries demonstrate that from a scientific point of view, the field is far from being exhausted and fully explored.

/ Superconductors : the Magic and the Mystery

Louis Taillefer
University of Sherbrooke, Canada

Abstract
Superconductivity is a magical property of matter, whereby electrons enter spontaneously into a macroscopic quantum dance in which electricity flows perfectly. Were this state sustainable at room temperature, our technological world would be profoundly transformed. The most promising materials are the copper oxides that remain superconducting halfway to room temperature. But the long-standing mystery of what binds electrons into pairs to form superconductivity has prevented scientists from understanding how this maximal temperature might be raised.
In my lecture, I will discuss some of the magic of superconductors, properties harnessed to image brains in hospitals, whiz subatomic particles around at CERN, and levitate trains in Japan. I will also describe some recent advances in research that have shed new light on the mystery. A story of electrons and scientists, featuring very low temperatures, huge magnetic fields, pristine crystals, powerful microscopes, and the quantum world.

Mo-S01-KN1 / Mechanism and phenomenology of superconductivity in HTS cuprates

Jeffery Tallon
Robinson Research Institute, New Zealand

Abstract
We present the constraints on the pairing mechanism in cuprate high-Tc superconductors provided by the complex experimental phenomenology which is observed, particularly those constraints arising from thermodynamic studies. We clarify some controversial aspects of the reported phase behavior and show that, allowing for thermal phase and amplitude fluctuations the pairing is consistent with near weak-coupling limits. From the electron-boson interaction strength we further infer that the energy scale for the pairing boson is rather higher than that usually considered, in excess of 1 eV. From this we consider whether the pairing has magnetic or dielectric origins [1].

References
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Tu-S02-KN1 / Topological superconductivity: criterions, mechanisms and candidate materials

Liang Fu
Massachusetts Institute of Technology, United States of America

Abstract
Recent developments on topological phases of matter has given a new impetus to research on unconventional superconductors. The concept of topological superconductors with exotic excitations has emerged and attracted great interest. In this talk, I will describe a criterion for topological superconductors in terms of the odd-parity pairing symmetry, propose a novel mechanism for odd-parity pairing in the vicinity of inversion symmetry breaking, and discuss candidate materials for topological superconductivity.

Mo-S03-KN1 / Superconductivity in two-dimensional interfaces: Design principle for TRS-breaking and topological superconductivity

Joerg Schmalian, Mathias Scheurer
Karlsruhe Institute of Technology, Germany

Abstract
A range of systems exist where superconductivity occurs in a two-dimensional interface or sheets with broken inversion symmetry. Examples are oxide heterostructures, single layer FeSe and systems where superconductivity is induced by electrostatic carrier doping. In this talk we address two questions: 1. Under what conditions can such a superconducting state break time reversal symmetry? 2. Is there a link between the pairing mechanism and the topological properties of two-dimensional superconductors? We show that a necessary condition for time reversal symmetry breaking superconductivity is a three-fold rotation symmetry of the point group[1], such as a [111] terminated substrate or a hexagonal lattice. This can be used as a design principle for TRS superconductivity. In addition, we propose an unconventional pairing state for the electron fluid in two-dimensional oxide interfaces and establish a direct link to the emergence of nontrivial topological invariants.[2] Topological superconductivity and Majorana edge states can then be used to detect the microscopic origin for superconductivity.

References
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Mo-S04-KN1 / Progress in nanostructured coated conductor research and development

Xavier Obradors
ICMAB CSIC, Spain

Abstract
There is a worldwide huge effort in the R&D of high current superconducting wires for large scale power applications and magnets which encompasses many materials science and engineering challenges. Coated conductors is one of the most promising alternatives to reach the performance goals and to reduce the cost/performance ratio down to the levels required to make a reality these technological expectances. Within Europe, a large consortium of academic and industrial partners (EUROTAPES) collaborates to advance in these demanding challenges. In this presentation, several topics related to the recent progress in the different aspects covered by the project will be presented. On one hand, I will report on the efforts in increasing the robustness of the different coated conductor architectures (RABiT and ABAD) and, particularly, on the progress on using chemical solution approaches based on Ink Jet Printing to produce the multilayered structure. On the other hand, different approaches related to achieving nanostructured superconductors with enhanced flux pinning and high magnetic field performances will be also presented. This includes both, chemical solution deposition and PLD thin films and coated conductors.

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[1] Research funded from EU-FP7 NMP-LA-2012-280432 EUROTAPES project

Mo-S05-KN2 / Basic Properties of New (Li,Fe)OHFeSe Superconductors

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Abstract
We have studied the complete phase diagram of a newly synthesized superconducting system (Li1-xFex)OHFeSe (FeSe11111) with a similar structure to FeAs-based superconductors [1,2]. Our results indicate that iron selenide and arsenide superconductors share the same mechanism of electron pairings.
We then explored a novel hydrothermal ion-exchange technique and have successfully synthesized high-quality large-sized superconducting (Li0.84Fe0.16)OHFe0.98 Se single crystals with an optimal transition temperature (Tc=42 K) [3]. We find that its normal state properties are highly anisotropic and anomalous, suggesting the existence of two dimensional antiferromagnetic spin fluctuations in the FeSe layers.
Electronic structure investigated via ARPES [4] reveals that this single-phase bulk superconductor shows remarkably similar electronic behaviors to that of the superconducting single-layer FeSe/SrTiO3 film.
It is thus expectable that new iron selenide superconductors with higher transition temperature could be discovered in the future.

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Mo-S05-KN1 / Phase diagram and gated-tuned superconductor-insulator transition in (Li,Fe) OHFeSe

Xianhui Chen
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Abstract
In this talk, we report the synthesis of an air-stable material, (Li0.8Fe0.2)OHFeSe, which shows superconducting transition temperature up Tc to ~40 K, by means of a novel hydrothermal method. The crystal structure is unambiguously determined by a combination of X-ray and neutron powder diffraction and nuclear magnetic resonance. Moreover, antiferromagnetic order is found to coexist with superconductivity. This synthetic route opens a path for exploring superconductivity in other related systems, and confirms the appeal of iron selenides as a platform for understanding superconductivity in iron pnictides more broadly.
We observe a first-order transition from superconductor to AFM insulator with a strong charge doping induced by ionic gating in the thin flakes of single crystal (Li,Fe)OHFeSe. Tc is continuously enhanced with electron doping by ionic gating up to a maximum Tc of 43 K, and a striking superconductor-insulator transition occurs just at the verge of optimal doping with highest Tc. A novel phase diagram of temperature-gating voltage with the superconductor-insulator transition is mapped out, indicating that the transition from superconductor to AFM insulator is a common feature for unconventional superconductivity. These results help to uncover the underlying physics of iron-based superconductivity as well as the universal mechanism of high-Tc superconductivity.

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Mo-S06-KN1 / Interplay of d-symmetry Density Waves and d-symmetry Cooper Pairing in the Cuprate Pseudogap Regime

JC Seamus Davis
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Abstract
A central issue of cuprate high temperature superconductivity research is to understand the nature of the mysterious phase often referred to as the pseudogap and its relationship to the d-wave superconductivity. Using our recently developed technique of sub-lattice phase-resolved electronic structure visualization[1] within each CuO2 unit-cell, we discovered that the cuprate pseudogap state contains a d-symmetry form factor density wave [2]. Although long predicted, such an unconventional density-wave state has not previously been observed in any condensed matter system. Our simultaneous visualizations of both real-space and momentum-space electronic structure across the cuprate phase diagram then revealed that the transition of Fermi surface topology from "Fermi arc" to conventional Fermi surface occurs simultaneously with the disappearance of the d-symmetry FF density wave [3]. Taken together these results yield an atomic scale perspective on the antagonism between the d-symmetry Density Waves and d-symmetry Cooper Pairing in the pseudogap regime of underdoped cuprates.

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Mo-S07-KN1 / Developments in Understanding Superconductivity in Sr2RuO4

Catherine Kallin
McMaster University, Canada

Abstract
There is considerable experimental evidence in favor of chiral p-wave order in the superconducting state of Sr2RuO4, but discrepancies and gaps in our understanding remain and continue to drive new experiments and theoretical ideas. The most striking discrepancy is the lack of any observable signature of the charge currents expected to flow at the edge of a chiral p-wave superconductor, despite numerous experimental searches for such signatures.[1]
While the edge currents are not topologically protected, even in the absence of screening, they are closely connected to the topological chiral edge modes and generically large and robust for simple chiral p-wave models. However, the edge current can be substantially reduced, or even zero, if there are multiple zero-energy edge states.[2,3] There are a number of ways such multiple zeros can arise, including higher angular momenta pairing, such as chiral d- or f-wave, highly anisotropic chiral p-wave, or even surfaces with mesoscopic faceting.[2-4] We will discuss how these ideas might reconcile chiral p-wave pairing with the lack of observable edge currents, together with the positive signature for broken time-reversal symmetry seen in muon spin resonance (muSR).
A defining property of chiral order is broken time-reversal symmetry and for Sr2RuO4 this has been observed in both muSR experiments and polar Kerr experiments.[1] There are several theoretical proposals for understanding the Kerr effect in Sr2RuO4, predicting both an impurity effect due to skew-scattering and intrinsic effects associated either with collective modes in a 3-dimensional model or with the multiband nature of Sr2RuO4.[5] Further experiments might distinguish between these different proposals.
Other recent developments will be discussed as time permits, including half-quantum vortices, uniaxial strain and attempts to observe Majorana modes in Sr2RuO4. Our conclusion is that considerable progress and recent advances have been made on both experimental and theoretical fronts, but there are still important unresolved questions and there may well be more new physics to be discovered.

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Mo-S08-KN1 / Vortex confinement in nano-scale superconductors

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Abstract

When put in rotation, macroscopic quantum condensates develop a very peculiar collective response: Instead of rotating as a whole, they split in a huge number of small quantum tornados – vortices [1]. The vortex currents circulate owing to the gradient of the condensate wave function that accumulates exactly 2π phase difference around each vortex core - the eye of the cyclone - where the wave function vanishes. This general quantum phenomenon was observed in superconductors, superfluids, Bose-Einstein condensates of ultra-cold atoms [2]. Vortices may be seen as individual molecules: they repel each other and form a regular triangular lattice in bulk superconductors [1]. The confinement of quantum condensates to the scales comparable to their characteristic coherence length should modify the vortex lattice, leading to novel configurations.

Despite of 45 years of theoretical efforts, till recently there have not been relevant experiments on this topic. Importantly, since the pioneering work by Hess et al. [3] the Scanning Tunneling Spectroscopy (STS) at low temperatures is widely used to visualize the vortices in superconductors and to study their cores. Till now however, the STS was mainly performed on atomically flat (very smooth) surfaces, the STS on high-relief samples being an important experimental challenge. Owing our home-made UHV STM/STS working down to 0.3K in magnetic fields up to 10T we succeeded to visualize the vortex phases strongly confined in individual superconducting nano-crystals of Pb deposited in-situ onto Si(111)-7x7 [4], or even pinned at individual atomic steps of superconducting single atomic layers of Pb on Si(111) [5].

Starting from the simplest case of a single vortex confined in a superconducting box [6], in our talk we will show how the confinement influences the vortex lattice leading to novel ultra-dense vortex configurations, impossible in bulk superconductors, such as vortex lines, molecules and clusters. At even higher confinement the Giant Vortices - quantum tornados characterized by a multiple phase accumulation L x 2π, L = 2; 3; 4 - are experimentally revealed by STS; their unusual cores will be discussed.

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Mo-S09-KN1 / Orbital-driven nematicity in FeSe

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Abstract

A fundamental and unconventional characteristic of superconductivity in iron-based materials is that it occurs in the vicinity of two other instabilities. In addition to a tendency towards magnetic order, these Fe-based systems have a propensity for nematic ordering: a lowering of the rotational symmetry while time-reversal invariance is preserved. Setting the stage for superconductivity, it is heavily debated whether the nematic symmetry breaking is driven by lattice, orbital or spin degrees of freedom. Here, we report a very clear splitting of NMR resonance lines in FeSe at Tnem = 91 K, far above the superconducting Tc of 9.3 K. The splitting occurs for magnetic fields perpendicular to the Fe planes and has the temperature dependence of a Landau-type order parameter. The behavior of the spin–lattice relaxation rates above Tnem, which unequivocally establishes orbital degrees of freedom as driving the nematic order. We demonstrate that superconductivity competes with the emerging nematicity.

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Mo-S10-KN1 / Recent studies on unconventional superconductivity in $(TMTSF)_2X$

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Abstract
The organic superconductor (TMTSF)2X (TMTSF stands for tetramethyltetraselena-fulvalene, X stands for anions such as ClO4, PF6, etc.) [1] has been studied for more than 30 years because of its unique and simple quasi-one-dimensional electronic state, as well as possible unconventional superconductivity originating from underlying magnetic fluctuations. In particular, a number of key experiments are performed in the last 10 years, revealing unconventional nature of superconductivity in this material [2]. We have contributed such new trend by performing extensive transport and thermodynamic measurements under accurately controlled magnetic fields [3-5]: Our specific-heat study indicate d-wave-like spin-singlet state with lines of zeros on the superconducting gap. In addition, we have clarified unusual high-field regime with unusual in-plane field-anisotropy in the onset temperatures of resistance drop but with negligibly small entropy change. This high-field region may result from the realization of superconductivity with a real-space order-parameter modulation, namely an FFLO (Fulde-Ferrel-Larkin-Ovchinnikov) like state.
In this talk, we review recent experiments on the unconventional nature of superconductivity in (TMTSF)2X. In addition, we would like to present more recent results on the impurity-concentration dependence of thermodynamic properties of superconductivity.

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Tu-S11-KN1 / Axial charge order in the cuprates: broken symmetries, interplay with pair-density-wave, and the effect on superconductivity

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Abstract
I discuss incommensurate axial charge-density-wave (CDW) order in underdoped cuprates (the one with momenta (0,Q) or (Q,0)). I argue that this order not only breaks U(1) translational symmetry, but also breaks C4 lattice rotational symmetry and time-reversal and mirror symmetries.
I show that CDW order appears due to exchange of spin fluctuations before magnetic order develops. I further show that CDW order is almost degenerate with pair-density-wave order, and the two likely develop together. This gives rise to a number of interesting properties like, e.g., a generation of s-wave component of superconductivity. Finally, I analyze superconductivity near the onset of CDW order, first within phenomenological model of hot fermions attracting each other by exchanging soft charge fluctuations, and then within the underlying spin-fermion model. I argue that Tc induced by charge fluctuations may exceed Tc induced by spin fluctuations despite that charge order by itself originates from spin fluctuation exchange.

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Tu-S12-KN1 / Josephson Vortices in Iron-Pnictide Superconductors

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Abstract
In layered superconductors, such as the iron-pnictides or cuprates, sufficiently strong electronic anisotropy may lead to a suppression of the order parameter in between the superconducting layers. This spacial modulation of the order parameter influences the vortex matter, in extreme cases driving a transition from Abrikosov-type to Josephson-type vortices typically encountered in Josephson junctions. Tuning the interlayer suppression by comparing different structural classes of iron-pnictides allows to investigate the cross-over between these types of vortices.
We will show clear experimental evidence that the interlayer order parameter modulation in the anisotropic iron-arsenide superconductor (V2Sr4O6)Fe2As2 leads to intrinsic Josephson junctions within the crystal unit cell; thereby showing the first example of a multi-band intrinsic Josephson system. The intrinsic junctions are identified by periodic oscillations of the flux flow voltage upon increasing a well aligned in-plane magnetic field, which are observed over an extended temperature range. This periodic flux flow modulation is a hallmark signature of Josephson vortices confined junctions within the unit-cell, and is quantitatively explained by commensurability effects between the Josephson vortex lattice and the crystal structure. These observations suggest the iron-pnictide (V2Sr4O6)Fe2As2 to be an interesting candidate for novel phase-coherent quantum applications exploiting the multi-band nature of the material.
The more isotropic compound SmFeAs(O,F) presents an intriguing example of a weak inter-layer modulation of the order parameter that is too subtle to form true intrinsic Josephson junctions but strong enough to significantly influence the vortex structure. This impartial suppression leads to a new type of “hybrid vortex” matter, sharing characteristics of both Abrikosov- and Josephson-type vortices. We show the fingerprints of these novel vortices in an unusal field- and temperature dependence of vortex commensurability oscillations and compare the results to numerical Ginzburg-Landau simulations of vortices subjected to a weak special modulation of the order parameter.

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Tu-S13-KN1 / Two-dimensional Kondo Superlattices

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Abstract
Condensed matter systems that are both low-dimensional and strongly interacting often exhibit unusual electronic properties, with the high-Tc superconductivity in cuprates and iron pnictides as the most prominent example. A metallic state with the strongest electron correlation is realized in heavy fermion compounds, whose electronic structure is essentially 3D. Recently, by fabricating epitaxial superlattices built of alternating layers of Ce-based heavy-fermion and La- or Yb-based conventional nonmagnetic metals, we have succeeded in confining heavy fermions to two dimensions, resulting in slices of 2D Kondo lattice. In CeIn3/LaIn3 and CeRhIn5/YbRhIn5 superlattices, 2D heavy fermions display striking deviations from the standard Fermi liquid properties, and these are associated with the dimensional tuning of quantum criticality [1]. Superconductivity is observed in CeCoIn5/YbCoIn5 superlatttices even in the superlattice with only one-unit-cell-thick CeCoIn5 layers [3]. These superconducting superlattices with atomic layer thickness exhibit highly unusual behaviors, including striking enhancement [3] and highly unusual angular dependence of Hc2 [4,5]. We discuss these phenomena in terms of the entanglement of Pauli paramagnetism and Rashba interaction associated with the local inversion symmetry breaking at the heavy fermion interface. We also report spatially resolved NMR spectroscopy on CeCoIn5/YbCoIn5. The magnetic properties of Ce- and Yb- block layers and their interface were probed separately[6]. The heavy fermion superlattices offer a new playground for exploring exotic superconducting phases.

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Tu-S14-KN1 / Coherent manipulation of a Cooper pair in a superconducting atomic contact

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Abstract
The absorption of a photon by a superconductor is usually an incoherent process in which a Cooper pair is broken into a pair of independent quasiparticles. Here we show that in an atomic-size contact between two superconductors it is possible to coherently excite a pair from the ground state condensate into a discrete localized bound state. By coupling the contact to the electromagnetic field of a microwave resonator we perform time resolved experiments of this particular excitation. Lifetimes of several microseconds are measured for the excited state of the localized pair. Decoherence times of several tens nanoseconds are measured for coherent superpositions of states, which can increase up to a microsecond with an echo sequence. Single shot measurement of the quantum state of the pair is achieved when using a large number of photons in the resonator.

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Tu-S15-KN1 / Spontaneous symmetry breaking: from superconductivity to the Higgs boson and back again

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Abstract
Our ideas of spontaneous symmetry breaking originated from the work on superconductivity of Anderson, Nambu and others. These ideas were introduced into particle physics by Nambu and Goldstone, and then applied to gauge theories by Englert, Brout and Higgs. Salam and Weinberg introduced these ideas into Glashow's theory of the weak interactions, and the resulting theory is the basis for our understanding of the fundamental particle interactions. The culmination of this theory was the discovery at CERN in 2012 of the Higgs boson. Condensed-matter analogues of this particle have recently been found, e.g., by Endre et al and by Matsunaga et al., reconnecting spontaneous symmetry breaking with its superconducting roots.

Tu-S16-KN1 / Intra-Unit-Cell magnetic correlations near optimal doping in YBCO

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Abstract
A magnetic intra-unit-cell order was found to occur {\it at} the pseudo-gap temperature in four cuprates high-Tc superconducting families [1]. Using polarized neutron scattering on the diffractometer D7 at the Institut-Laue Langevin (Grenoble), we here report its persistence in $\rm YBa_2Cu_3O_{6.85}$ close to optimal doping [2]. However, momentum scans indicate that the magnetic order is short range at that doping and exhibits a finite-size planar magnetic correlation length of about $\xi\sim$ 75 \AA. Accordingly, the magnetic peak intensity is strongly reduced, but the integrated intensity remains similar to lower doping.
Using polarization analysis, we extract the moment components which display different temperature dependence suggesting that the origin of each magnetic component might be distinct. At high temperature, only the out-of-plane magnetic components correlate, revealing a strong Ising anistropy, as originally predicted in the loop current model. Below T*, a correlated in-plane response develops, giving rise the apparent tilt of the magnetic moment at low temperature[1,2]. The discovery of these two regimes put stringent constraints on the intrinsict nature of intra unit cell order, tightly bound to the pseudogap physics.

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Tu-S17-KN1 / Alternative London electrodynamics, hole superconductivity, and the origin of the Meissner effect

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Abstract
An electrodynamic theory of superconductors that allows for the presence of electrostatic fields in their interior was proposed initially by the London brothers in 1933 [1] but discarded shortly thereafter in favor of the one generally accepted to this date. I will argue that the original theory is closer to the truth. The theory of hole superconductivity [2] predicts that superconductors expel negative charge from their interior to the surface resulting in an outward-pointing electric field in the interior of superconductors and a spin current near the surface. The superconductor is a giant atom, with macroscopically inhomogeneous charge distribution and macroscopic zero-point motion. The electrostatic energy cost is paid by lowering of quantum kinetic energy. The microscopic Hamiltonian is a dynamic Hubbard model [3] describing the expansion of atomic orbitals upon double electronic occupancy. Electrodynamic equations in the charge [4] and spin sectors [5] and resulting predictions that can be tested experimentally will be discussed. It is argued that the theory is consistent with existing experiments, provides a unified explanation for high and low temperature superconductivity [6,7], and indicates that high temperature superconductivity results from holes conducting through closely spaced negatively charged anions [8]. Unlike the conventional theory, it provides a dynamical explanation of the Meissner effect [9,10].

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Tu-S18-KN1 / Long range proximity effects and supercurrents in ferromagnets induced by odd-frequency triplets

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Abstract
It is by now clear that, by generating odd-frequency triplet Cooper pairs, it is possible to have supercurrents flow through ferromagnets over lengths which are similar to those in normal metals. Such supercurrents bear the promise of being spin-polarized, which should be of use in devices for superconducting electronics ('superspintronics'). This has not yet materialized, but there is progress in understanding how spin-active interfaces can be engineered to generate such triplets, in particular by inserting an F*/N sandwich (N a normal metal and F* a different ferromagnet) between the S- and the F-layer. This has been aided by renewed interest in the behavior of so-called pseudo-spinvalve structures (also of type S/F*/N/F). In these devices triplet generation can be studied through the proximity effect in a magnetic field without the additional difficulty of having two identical banks as in experiments involving supercurrents. An overview will be given of the current experimental situation, with emphasis on the difference between the behavior found with conventional ferromagnets such as Co, and halfmetallic ferromagnets, in particular CrO2. In the latter, the effects (and in particular the proximity length) are significantly larger, presumably due to the strong reduction of spin flip scattering [1,2].

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Tu-S19-KN1 / Coherence in Ce-based Heavy Fermion Superconductivity

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Abstract
The loss of normal state electrical resistivity at low temperatures in heavy Fermions below a characteristic coherence temperature coincides with the establishment of a Fermi surface which includes the f-electrons. Empirically, the coherence temperature correlates with condensation into the ground state f-electron crystal field level. Superconductivity in Ce-based heavy Fermions appears as an instability of the coherent ground state, and we discuss the relationship between this superconductivity and the development of electronic coherence at low temperature.

Tu-S19-KN2 / Quantum criticality and superconductivity on the border of magnetic and dielectric quantum phase transitions

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Abstract
Superconductivity has frequently been observed on the border of magnetic quantum phase transitions in sufficiently carefully controlled samples. Here we compare and contrast these findings with related phenomena on the border of ferroelectric quantum phase transitions in the presence of carrier doping. In particular, we discuss quantum critical phenomena in ferroelectric materials in terms of models based on independently measured material-specific parameters. We present results of the measured pressure dependence of the superconducting transition temperature in electron-doped SrTiO3 and show an overall temperature-quantum tuning parameter phase diagram of this material. This shows that superconductivity occurs on the very edge of the ferroelectric quantum critical point in a way analogous to the behavior observed on the border of itinerant-electron magnetism. We outline a theory of superconductivity in which electrons are paired via polar optical phonons that exist close to dielectric transitions such as ferroelectricity or anti-ferroelectricity. The theory is able to account for the temperature-pressure-carrier doping phase diagram such as those seen in SrTiO3 and KTaO3 and can be used to anticipate superconductivity in new materials.

Tu-S20-KN1 / Snapshots of the retarded interaction of charge carriers with ultrafast fluctuations in cuprates

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Abstract
Recent advances in ultrafast optical spectroscopy unlocked the gate to the direct investigation of the electron dynamics in copper oxides on the timescale of the most fundamental interactions, such as the coupling with antiferromagnetic fluctations (e.g. h/2J). Here we simultaneously push the time resolution and the frequency range of transient reflectivity measurements up to the level of observing the build-up of the effective electron-boson interaction in doped bi-layer copper oxides (Bi2212). This extremely fast timescale (~16 fs) is in agreement with numerical calculations based on the t-J model and the repulsive Hubbard model, in which the relaxation of the photo-excited charges is achieved via inelastic scattering with short-range antiferromagnetic excitations.
Furthermore, we investigate the doping-dependence of the ultrafast dynamics of the charge-transfer excitation in the single-layer Bi2201 cuprate. We unveil an unexpected room-temperature discontinuity at the critical hole concentration pcr~0.17. This value corresponds to the doping at which the quantum critical point at T=0 is expected to occur.

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Tu-S21-KN1 / Spin fluctuations and charge order in electron-doped cuprates

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Abstract
Recently, charge order (CO) has been found in electron-doped cuprates (ref 1). As on the hole-doped side of the cuprate phase diagram, the exact role of this CO in the physics of the cuprates is being actively debated. The contrast between hole and electron doping in terms of the pseudogap, the doping dependence of the long range ordered antiferromagnetism, the doping range of spin fluctuations and charge order will be discussed in this talk. The main focus of this talk will be the recent experimental work on charge order in the electron-doped cuprates and the possible role of spin fluctuations in the low temperature transport properties and superconductivity (ref 2).

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Tu-S23-KN1 / Dynamic vortex Mott transition in a proximity array of superconducting islands

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Abstract
We report results of transport measurements on a square array of superconducting islands placed on a normal metal revealing vortex Mott insulator, predicted earlier by Nelson and Vinokur [1] and dynamic Mott insulator-to-metal transition driven by the applied current. We demonstrate dynamic scaling behaviour of differential resistivity near the Mott critical points as function of the applied current and magnetic field and establish that Mott dynamic transitions at integer and fractional filling factors belong in different universality classes. We demonstrate that critical exponents of the dynamic transition at the integer filling factors coincide with those for the thermodynamic Mott transition in electronic system [2] with the magnetic field substituting the pressure and the applied current taking the role of temperature. This suggests close correspondence between the thermodynamic and out-of-equilibrium phase transitions and indicates that dynamic vortex Mott transition belongs in the same liquid-gas transition universality class. Using quantum mechanics-statistical physics mapping we derive critical exponents for Mott transition and demonstrate their excellent agreement with the experimentally observed values. We demonstrate that the dynamics of the vortex Mott state is governed by thermally activated vortex motion establishing thus the real physical content of the quantum mechanics-statistical physics mapping where thermally activated dynamics of classical objects corresponds to tunnelling of quantum particles.

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Tu-S24-KN1 / Heat interference and thermal rectification in hybrid coherent caloritronic superconducting quantum circuits

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Abstract
The Josephson effect represents perhaps the prototype of macroscopic phase coherence and is at the basis of the most widespread interferometer, i.e., the superconducting quantum interference device (SQUID). Yet, in analogy to electric interference, Maki and Griffin predicted in 1965 that thermal current flowing through a temperature-biased Josephson tunnel junction is a stationary periodic function of the quantum phase difference between the superconductors. In this scenario, a temperature-biased SQUID would allow heat currents to interfere thus implementing the thermal version of the electric Josephson interferometer.
In this talk I shall initially report the first experimental realization of a heat interferometer [1]. We investigate heat exchange between two normal metal electrodes kept at different temperatures and tunnel-coupled to each other through a thermal `modulator' in the form of a DC-SQUID. Heat transport in the system is found to be phase dependent, in agreement with the original prediction. Next, I will present experimental results on the first quantum `diffractor' for thermal flux [2]. Specifically, thermal diffraction manifests itself with a peculiar modulation of the electron temperature in a small metallic electrode nearby-contacted to a Josephson junction when sweeping the magnetic flux Φ [2]. The observed temperature dependence exhibits a clear reminiscence with a Fraunhofer-like modulation pattern, as expected fingerprint for a quantum diffraction phenomenon. Our results confirm a recent prediction of quantum heat transport and, joined with double-junction heat interferometry demonstrated in [1], exemplify the complementary proof of the existence of phase-dependent thermal currents in Josephson-coupled superconductors.
I shall conclude by showing the first realization of an ultra-efficient low-temperature hybrid `heat current rectifier', thermal counterpart of the well-known electric diode. Our design is based on a tunnel junction between two different elements: a normal metal and a superconducting island. Electronic heat current asymmetry in the structure arises from large mismatch between the thermal properties of these two. We demonstrate temperature differences exceeding 60 mK between the forward and reverse thermal bias configurations [3]. This device offers a remarkably large heat rectification ratio up to about 140 and allows its prompt implementation in true solid-state thermal nanocircuits and general-purpose electronic applications requiring energy harvesting or thermal management and isolation at the nanoscale. This approach combined with well-known methods for phase-biasing superconducting circuits provides with a novel tool for mastering heat fluxes at the nanoscale.

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Tu-S25-KN1 / Collapse of the Pseudogap in Cuprate Superconductors : an electronic Raman scattering study

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Abstract
The pseudogap phase in cuprates remains hitherto a mysterious state of matter out of which the high-temperature superconductivity emerges. Discovered more than twenty five years ago [1], its indentification is still challenging although extensively studies have been carried out to elucidate its true nature [2,3].
In addition recent investigations in the underdoped side of the cuprate phase diagram have shown inside the pseudogap phase the existence of charge density wave order [4-6] which could be at the origin of the Fermi surface reconstruction in electron and hole pockets detected at high magnetic field by quantum oscillations[7,8] and transport measurements [9]. Instead of clarifying our understanding of cuprate phase diagram, these recent investigations have revealed its unexpected complexity.
In this context our purpose is to reveal by electronic Raman scattering, the signature of the normal state pseudogap and track its doping evolution through the cuprate phase diagram. Although intensively studied in the underdoped regime, relatively less is known about the normal state pseudogap on the overdoped side, where it weakens and eventually disappears at a critical doping pc.
Here, combining Raman spectroscopy on Bi-2212 over a large range of finely tuned doping with theoretical calculations, we determine pc=0.22 and we show that it coincides with a Lifshitz transition where the underlying hole-like active Fermi surface becomes electron-like [10].
Interestingly, the superconducting critical temperature Tc is unaffected by this transition and the energy scales of the spectral weight transfers respectively related to the pseudogap and superconducting phases are distinct. This demonstrates that the microscopic origins of the normal state pseudogap and the superconductivity are distinct. Only the former is tied to the change in the Fermi surface topology.

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We-S26-KN1 / Manifestation of the pseudogap in the ground state Fermi surface

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Abstract
Since the discovery of quantum oscillations corresponding to a small Fermi surface in the underdoped cuprate high temperature superconductors, an important question pertains to the role of the pseudogap in the creation of the small nodal Fermi surface. We use quantum oscillation measurements to show that the ground state Fermi surface comprises a nodal electron pocket unaccompanied by additional sections of Fermi surface. Our measurements reveal that the pseudogap is manifested as a fully developed gap that removes the antinodal density of states in the ground state Fermi surface.

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We-S27-KN1 / Constructing a unified understanding of iron based superconductors through the doping effects on electronic structures

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Abstract
Because of the diversities in their structures, electronic structures, and means of doping, Iron-based superconductors exhibit diversified phase diagrams. We systematically investigate the behaviors of dopants in a variety of iron-based superconductors with angle-resolved photoemission spectroscopy (ARPES). We find that dopants modify the carrier density, introduce quasiparticle scattering, and vary the bandwidth in extraordinary ways. Particularly, we find that instead of Fermi surface topology or carrier density, the bandwidth, which is closely related to electronic correlations, is likely the most universal electronic parameter to dominate superconductivity in various iron-pnictides and iron-chalcogenides. The bandwidths of the Fe 3d bands in these materials evolve systematically with either heterovalent or isovalent means of doping. With decreasing bandwidth, the ground state evolves from a normal metal to a superconductor, and eventually to an insulator or a magnetically ordered phase. This indicates that the iron-based superconductors can be unifiedly understood in the framework of bandwidth-control Mott physics, which is essentially reminiscent of the cuprate. Our results support local pairing scenarios based on short-range effective antiferromagnetic exchange couplings for iron-based superconductors.
This microscopic picture of doping facilitates a comprehensive and generic understanding of the rich phase diagrams of iron-based superconductors. Furthermore, it points out future directions to search for new iron-based superconductors with higher superconducting transition temperatures.

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We-S28-KN1 / Time-Reversal-Symmetry-Breaking In Unconventional Superconductors

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Abstract
It is common to describe unconventional superconductors as materials that display superconductivity but that do not conform to BCS or Migdal-Eliashberg theories. Indeed, BCS theory of conventional superconductivity describes pairing of spin-singlet time-reversed states, and is characterized by an order parameter which breaks U(1)-gauge symmetry leading to basic superconducting properties, such as the Meissner effect, persistent current and flux quantization. By contrast, unconventional superconductors exhibit additional broken symmetries, which often lead to distinct superconducting phases with unique properties. Using angular momentum (L) to distinguish unconventional superconductivity, we classify L=0, spin singlet superconductors as conventional, and L>0 superconductors as unconventional. Thus, key symmetries for this classification are time reversal and inversion.
Concentrating on time-reversal symmetry breaking (TRSB) superconductors, we use the zero-area loop Sagnac Interferometer (ZALSI) [1] to measure polar Kerr effect (PKE) as test for TRSB [2]. The ZALSI has the ability to detect non-reciprocal effects in transmission or reflection of circularly polarized light to a shot-noise sensitivity at low power, while by the symmetry of its construction, rejecting any reciprocal effects. Reviewing our earlier measurements on Sr2RuO4 [3] and on superconductor-ferromagnet proximity structures [4], we will show new results on UPt3, where TRSB is observed only in the lower-temperature B-phase of the superconducting state [5], URu2Si2 where the PKE detects a finite effect at Tc, but also point to a puzzling peak in the PKE at lower temperatures [6], and CeCoIn5 where no TRSB is observed. Preliminary results on PrOs4Sb12 will also be presented.
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We-S29-KN1 / Emergence of heavy-fermion superconductivity by the ordering of nuclear spins

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Abstract
Superconductivity at the border of magnetic ground states typifies the physics of collective fluctuations of a quantum critical point (QCP) which give rise to emergent phases [1]. Indeed, unconventional superconductivity often occurs in the vicinity of QCPs in antiferromagnetic (AF) heavy-fermion metals [2]. Nonetheless, no superconductivity has been observed near some of the canonical heavy-fermion QCPs, such as that induced by a magnetic field in YbRh2Si2 [3], raising the question about the generality of this paradigm. For this compound, here we explore the possibility of reaching the quantum critical regime by sufficiently weakening the AF order through its coupling to nuclear spins at very low temperatures, instead of applying a pair-breaking magnetic field. We report magnetic and calorimetric measurements on YbRh2Si2 down to T = 1mK. At TA ≳ 2 mK we identify a hybrid nuclear-electronic AF order dominated by the Yb-derived nuclear spins, in which superconductivity develops at Tc = 2 mK. The initial slope of the upper critical field curve, Bc2(T), at Tc is found to be very large: - Bc2' ≅ 25 T/K. It indicates that the effective charge-carrier mass must be of the order of several 100 me (me being the rest mass of the electron), implying that the superconducting state is associated with the Yb-derived 4f electrons. This heavy-fermion superconductivity may be called 'high Tc', in the sense that it is limited by an exceedingly high ordering temperature of nuclear spins (TA ≳ 2 mK as compared to common values of nK). We interpret the superconducting state as induced by the critical fluctuations associated with the QCP of this antiferromagnet, which are revealed when the primary electronic order is diminished by the competing nuclear order. Our results demonstrate a new means to reach the boundary of competing electronic ground states and provide evidence that inducing superconductivity by quantum criticality is a robust mechanism.
Work performed in collaboration with L. Steinke, S. Lausberg, A. Steppke, C. Krellner and C. Geibel.

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We-S30-KN1 / Recent progress on electronic nematic phase in iron pnictides

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Abstract
We use neutron resonance spin echo and Larmor diffraction to study the effect of uniaxial pressure on the tetragonal-to-orthorhombic structural (T_s) and antiferromagnetic phase transitions in electron doped iron pnictide BaFe$_{2-x}$Ni$_{x}$As$_{2}$. In underdoped BaFe$_{1.97}$Ni$_{0.03}$As$_{2}$ ($T_N=109$ K and $T_s=114$ K), an $\sim$15 MPa uniaxial pressure used to detwin the sample increases T_N to $\sim$118 K, smears out the structural transition, and induces an orthorhombic lattice distortion at all temperatures. By comparing temperature and doping dependence of the lattice distortion with the elastoresistance and nematic susceptibility obtained from transport and ultrasonic measurements, we conclude that the in-plane resistivity anisotropy found in electron underdoped iron pnictides arises from a strong coupling between the uniaxial pressure induced lattice distortion and electronic nematic state.

We-S31-KN1 / Non-Equilibrium momentum dependent dynamic of unconventional superconductors

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Abstract
Understanding how superconductivity emerges from other competing phases and how this balance evolves through the phase diagram is one of the biggest challenges in the field of high Tc superconductors. By using high resolution time- and angle- resolved photoemission spectroscopy (tr-ARPES) we are able to directly probe the effects of optical excitation on the electronic structure of cuprate superconductors, and study the resulting quasiparticles, superconducting gap, and Cooper pair formation dynamics near their natural time- scales. Direct measurements of these and other non-equilibrium spectral phenomena through the phase diagram further illustrate the power of this unique time- and momentum-resolved spectroscopy. These results reveal new windows into the nature of the pairing interaction in high Tc superconductors.

We-S32-KN1 / Quenching of magnetic excitations in YBa2Cu3O7/La2/3Sr1/3MnO3 superlattices revealed by resonant inelastic x-ray scattering

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Abstract

Transition metal oxide heterostructures are attracting great attention due to their extraordinary interface based materials properties not occurring in either of the constituents alone. Particularly fascinating systems are, e.g., ferromagnetic/superconducting heterostructures, which have a vast applications range in spintronics devices. Recent studies on YBa2Cu3O7/La2/3Ca1/3MnO3 superlattices have revealed rearrangement of the magnetic domain structure as well as indications of electronic orbital reconstruction at the interfaces [1, 2].

We have grown YBa2Cu3O7/La2/3Sr1/3MnO3 (YBCO/LSMO) superlattices by pulsed laser deposition. Our [YBCO5/LSMOx]4 superlattices with constant thickness of YBCO layers show a systematic depression of the superconducting transition temperature as a function of the thickness of the LSMO layers. We investigated these superlattices with resonant inelastic X-ray scattering (RIXS) at Cu L3-edge in order to probe both orbital and magnetic excitations of the YBCO layers as a function of the LSMO layer thickness. Employing angular and polarization dependence of the Cu L3-edge X-ray absorption spectroscopy and RIXS signals, we followed the electron charge transfer from LSMO to the YBCO layers. We observed suppression of superconductivity and an isotropic 3d9 orbital occupation of the Cu sites with contributions from both the YBCO planes and the chains for the sample with the thickest LSMO layers of 15 unit cells, [YBCO5/LSMO15]4.

This entails that both charge transfer of the electrons from LSMO to YBCO and reconstruction of the holes between the planes and the chains are invoked in the depression of the superconducting Tc. The associated quenching of the paramagnon excitations in the YBCO layers highlights that the ground state of the YBCO layers in these heterostructures is distinctively different from bulk YBCO [3].

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We-S33-KN1 / New Materials: Hunds metals in the 112 structure

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Abstract

Iron pnictides and chalcogenides should be thought as Hunds metals, a new class of strongly correlated electron systems, where the correlations are derived from the Hunds rule coupling J, rather than the Hubbard U. A generic properties of these materials, is the existence of orbital-spin separation, a property which reconciles the seemingly contradictory results of spectroscopies which probe the spin and charge degrees of freedom.

By now many families of iron pnictides have been synthesized. In this talk we will focus on the 112 family, which was predicted to have metallic space layers between the iron pnictide planes [1]. This family has been recently synthesized [2] and photoemission experiments have confirmed the theoretical prediction [3]. we will discuss the system specific physical properties which differentiates them from other pnictides, and what the lessons that they teach us.

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We-S34-KN1 / Non-equilibrium dynamics in superconductors and transition metal di-chalcogenides

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Abstract
Pump-probe laser spectroscopy, so far largely limited to the field of atomic and molecular physics, is gaining a surging interest in condensed matter physics. In this talk I will discuss two important achievements in a theoretical understanding of non-equilibrium dynamics that does not rest on any equilibrium assumptions.
One of its potentials is as a method for probing the so-called electron-phonon coupling—the dynamics of interaction between electrons and quantum modes of collective vibrations of the atomic nuclei in a solid-state material, crucial to the understanding of, for example, superconductivity among many phenomena. But, how to make sense of the "movies" obtained in this way remains a fundamental challenge. In this talk, I will discuss a significant step in the development of a concrete and general understanding of pump-probe spectroscopy studies of electron-phonon coupling. I will specifically show that this mains a viable route to directly uncover the Higgs mode in a superconductor.
While equilibrium band gap engineering has become a major theme since the first synthesis of monolayer graphene, it was only recently proposed that circularly polarized laser light could turn trivial equilibrium bands into topological non-equilibrium bands. I will discuss simulations that demonstrate the valley degeneracies can be lifted and tuned with circularly polarized light in transition metal di-chalcogenides, with the prospect of modulating band gaps and valleytronic-related dynamics.

We-S35-KN1 / Theory of high-Tc superconductivity: Beyond renormalized mean field theory and comparison to experiment

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Abstract
We have first generalized the renormalized mean-field theory approach to t-J model of high-Tc superconductivity by constructing the statistically consistent Gutzwiller approach (SGA) [1]. Some of the results compare favorably with experiment, other (e.g. doping dependence of the Fermi velocity) do not. In the second step, we have developed a systematic diagrammatic expansion for Gutzwiller wave function for both the Hubbard and t-J models [2]. The results provide a very good description of experimental results - the doping dependence of the superconducting (SC) gap magnitude and the Fermi velocity. Also, in the zero-order the SGA results are reproduced, whereas those in higher orders reproduce exactly the variational Monte Carlo (VMC) results. Additionally, the SC gap resembles a dx2-y2 wave symmetry only for the optimally doped and overdoped systems, being diminished in the antinodal regions for the for the underdroped case, in qualitative agreement with experiment. The new method opens up new perspectives, as it (i) works in the thermodynamic limit, (ii) is comparable in accuracy to VMC, and (iii) has numerical complexity comparable to that of SGA (the results are much easier to obtain than those in VMC approach). For a brief overview of the results see [3].
In the second part I discuss the onset of a spontaneous Fulde-Ferrell phase in a strongly correlated system [4], as well as analyse the appearance of Bose excitations in t-J and their relation to the pseudogap [5].

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We-S36-KN1 / Charge order, superconductivity and pseudogap physics in the cuprates

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Abstract
Recently, it has become more widely accepted that charge ordering is a universal property of hole doped high-temperature cuprate superconductors [1-12]. This talk gives an overview of the current experimental effort to reveal the nature of the charge density wave order. Special focus will be given to x-ray diffraction experiments. Implications for the Fermi surface reconstruction [2,13] and superconductivity will be discussed along with possible connections to pseudogap physics.

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We-S38-KN1 / Superconductivity in the vicinity of double helical magnetic order in CrAs and related materials

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Abstract
Transition-metal oxides or pnictides are rich in novel and intriguing electronic behaviours due to multiple quantum orders and competing phenomena. Among the different electronic states, the emergence of superconductivity in the vicinity of other quantum orders is at the heart of the exotic physics. Superconductivity has been observed in a majority of 3d transition-metal compounds except for the Cr- or Mn-based compounds. It is thus of high interest to explore possible superconductivity in these systems. Here, we report on the discovery of superconductivity on the verge of antiferromagnetic order in CrAs via the application of external pressure. Bulk superconductivity with Tc ~ 2K emerges at the critical pressure Pc~8 kbar, where the first-order antiferromagnetic transition at TN~265 K under ambient pressure is completely suppressed. The close proximity of superconductivity to an antiferromagnetic order suggests an unconventional
pairing mechanism for CrAs. The present finding opens a new avenue for searching novel superconductors in the Cr and other transition metal-based systems.

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We-S39-KN1 / Phase diagram of vortex matter and anisotropy in multiband superconductors

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Introduction:
Iron pnictides exhibit unique superconducting properties, such as anisotropic three – dimensional multiband superconductivity, coexistence of long – range magnetic order and superconductivity, unconventional s+/- pairing and both nodal and nodeless energy gap even within the same family of compounds which only differ in their doping level. Pronounced composition – dependent anisotropy of the superconducting gap plays key role in determined thermodynamic and transport properties. Not surprisingly, the behavior of these materials in the vortex state is also unconventional, showing extremely fast magnetic relaxation, highly doping – dependent magnetic irreversibility and anomalous Meissner effect.

Methods:
Given extreme sensitivity to doping, which also introduces scattering, controlled disorder is one of the important “clean” tuning parameters to probe both fundamental mechanisms, superconducting gap structure and vortex behavior without changing the electronic structure. We used 2.5 MeV relativistic electron irradiation at Ecole Polytechnique (SIRIUS facility, Ecole Polytechnique, France) to induce point – like disorder (vacancy – interstitial Frenkel pairs) at different concentrations and performed various in-situ and ex-situ measurements.

Results:
We measured direct and Hall – effect transport properties, anisotropic London and Campbell penetration depths, superconducting and magnetic transition temperatures, anisotropic upper critical field and irreversibility line, second magnetization peak, flux creep, as well as general evolution of temperature and field – dependent critical currents in a variety of iron based superconductors. A detailed discussion of the results in one of the most diverse and exhibiting extremely robust superconductivity pnictide family, Ba1-xKxFe2As2, as function of doping over the whole superconducting dome and amount of disorder will be presented. In particular, highly asymmetric response of pair – breaking scattering, magnetic irreversibility and superconducting gap structure as a function of x will be discussed.

Conclusions:
Overall, our findings fit so-called s+/- model of superconductivity in iron – based superconductors. However, some experimental results still lack theoretical interpretation.

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We-S40-KN1 / Charge order in cuprates: from hole to electron doping

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Abstract
Charge ordering has resurged as a prominent phenomenon in the physics of high-Tc cuprates. In this talk I will review our recent results from Bi2201 [1,2] and YBCO hole-doped cuprates [3,4], as well as electron doped NCCO [5]. With the early discovery of stripe-like order in La-based cuprates, this establishes charge ordering instabilities to be omnipresent in all cuprate families. I will discuss the connection between charge ordering and pseudogap phenomenology [2,5], similarities and asymmetries between hole and electron doping [2,5], and the native local symmetry of charge modulations [3,4].

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Th-S41-KN1 / Fluctuating Charge-density Waves in a Cuprate Superconductor

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Abstract
Cuprate materials hosting high-temperature superconductivity (HTS) also exhibit various forms of charge and spin ordering whose significance is not fully understood. So far, static charge-density waves (CDWs) have been detected by diffraction probes only at particular doping levels or in an applied external field. However, dynamic CDWs may also be present more broadly and their detection, characterization and relationship with HTS remain open problems. Here we present a method based on ultrafast spectroscopy to detect the presence and measure the lifetimes of CDW fluctuations in cuprates [1]. In an underdoped La1.9Sr0.1CuO4 film (Tc = 26 K), we observe collective excitations of CDW that persist up to 100 K. This dynamic CDW fluctuates with a characteristic lifetime of 2 ps at T = 5 K that decreases to 0.5 ps at T = 100 K. In contrast, in an optimally doped La1.84Sr0.16CuO4 film (Tc = 38.5 K), we detect no signatures of fluctuating CDWs at any temperature, favouring the competition scenario. This work forges a path for studying fluctuating order parameters in various superconductors and other materials.

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Th-S42-KN1 / A view from inside iron-based oxypnictides

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Abstract
Nuclear Magnetic Resonance (NMR) and Muon Spin Resonance (μSR) are among the most powerful tools to investigate the microscopic properties of iron-based superconductors (IBS) [1,2]. Owing to their local nature they allow one to suitably investigate intrinsic charge, magnetic and structural nanoscopic inhomogeneities, providing information hardly obtainable by means of other techniques [3]. In this talk, an overview on some of the main achievements obtained by NMR and μSR in LnFeAsO1-yFy (Ln1111 with Ln a lanthanide ion) IBS will be presented. It will be shown how the nuclear (muon) relaxation rates allow one to probe unconventional low-energy excitations, possibly associated with nematic fluctuations [4], and how the low-frequency spin fluctuations are affected by electron doping and/or by introducing localized impurities [5,6]. These two techniques permit to unravel the modifications of the magnetic and superconducting order parameters of Ln1111 IBS as the phase diagram is spanned either by charge doping, by an external pressure or by introducing magnetic and non-magnetic impurities. In particular, it will be highlighted that the muons are unique probes to study the nanoscopic coexistence between magnetism and superconductivity taking place at the crossover between the two ground-states [7,8,9,10].

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Th-S43-KN1 / The Astounding Physics of LaAlO3–SrTiO3 Interfaces

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Abstract
Superconductivity generated by interfaces is an exciting topic of research due to the fascinating underlying physics and also the potential of very high Tc's (see, e.g., [1]). Superconductivity, large spin-orbit coupling, and even magnetism are shown by two-dimensional, correlated electron systems that are generated at interfaces in oxide heterostructures. Embedded in epitaxial or related multilayers, such interfaces can be grown today in high quality. LaAlO3–SrTiO3 stacks are a prime example of such heterostructures.
In the presentation we will give an overview of the intrinsic mechanisms that generate and shape these superconducting interfaces and present astounding analogies to the properties of the high-Tc cuprates [2]. We will furthermore present tunneling spectroscopy experiments that reveal the pairing mechanism [3] and shed light on Cooper-pairs present in the charge-depleted, insulating phase of these electron-systems [4].

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Th-S44-KN1 / Optical spectroscopy of disordered superconductors

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Abstract
In the last few years an increasing experimental evidence has been accumulating that in materials like NbN, InOx and TiN a direct superconductor-to-insulator transition (SIT) occurs by increasing disorder. In addition, as the SIT is approached the superconducting state develops an emergent inhomogeneity of the electronic properties, that has been clearly identified in tunnelling experiments. Here I will review our theoretical progreses in the understanding of the nature of this glassy-like inhomogeneous superconductor, with particular attention to the identification of its signatures in the low-frequency optical spectroscopy.

Th-S45-KN1 / Theoretical design of topological superconductors in artificial structures

Naoto Nagaosa
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Abstract
Realization of topological superconductivity and associated Majorana fermions is one of the major challenges in current condensed matter physics. Up to now, several promising candidates have been proposed theoretically, and some experimental clues are also discovered. Here, I will talk on the theoretical design of topological superconductivity utilizing the artificial structures such as the superlattice and the composite system of magnet and superconductor [1-5]. Especially, the focus will be on the spin or pseudo-spin degrees of freedom in topological superconductors, which offer rich physics and also spintronics applications.
These works have been done in collaboration with Y. Tanaka, S. Nakosai, R. Wakatsuki, M. Ezawa, J. C. Budich, and B. Trauzettel.

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Th-S46-KN1 / A quantum bound on classical superconducting fluctuations in $La_{2-x}Sr_xCuO4$ and $YBa_2Cu_3O_7$

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Abstract
We present measurements of the fluctuation superconductivity on thin films of La2-xSrxCuO4 and YBa2Cu3O7 using time-domain THz spectroscopy. In general, such continuous phase transitions are typified by fluctuations with correlation length and time scales that diverge near their transition temperature. Dynamical measurements like THz spectroscopy are a sensitive probe of these fluctuations and can measure the characteristic time scale of the fluctuations 1/W. In this work our interest is not in the region of divergent correlations near Tc, but in following the correlations to higher temperature scales. Consistent with our previous work we find a relatively narrow range in temperature of 10-20 K above Tc where superconducting correlations can be resolved in the conductivity. In almost all samples, the characteristic fluctuation rate W at first increases sharply at temperatures above Tc, before at a temperature we denote as TQ it sharply crosses over to a behavior where it grows at a much smaller rate that is $proportional$ to temperature as alpha*kBT/ \hbar. Since the conversion from frequency to temperature requires an hbar, this is a purely quantum bound, the origin of which lies well outside the conventional paradigm of usual thermal fluctuations, of which a classical description is appropriate

Th-S47-KN1 / Anisotropy of magnetic correlations in FeAs based superconductors

Markus Braden[1], Florian Waßer[1], Navid Qureshi[1], Paul Steffens[3], Chul-Ho Lee[4], Kihou Kikou[4], Yvan Sidis[5], Astrid Schneidewind[6], Jitae Park[6], Sabine Wurmehl[7], Bernard Büchner[7]
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Abstract
Neutron scattering gives direct insight to the spin-space anisotropy of magnetic correlations. There is clear evidence that magnetic excitations in FeAs-based materials - antiferromagnetic and superconducting compounds - exhibit strong anisotropy with even split resonance modes. Polarized neutron scattering experiments in the FeAs 122 family have been performed for pure BaFe2As2 [1] as well as for Ni, K, Na and Co [2,4] doped compounds. The magnetic excitations in the SDW phase in BaFe2As2 exhibit sizeable anisotropy. In contrast to a simple easy-plane model of magnetic anisotropy it costs more energy to rotate the spins within the FeAs planes than perpendicular to them. This underlines the pronounced orthorhombic anisotropy in electronic properties in spite of the small structural distortions. All measurements on doped superconducting 122 samples yield significant anisotropies which resemble those in the SDW phase of the parent compound [4]. For 6% Co doping, there is evidence for a well-defined resonance excitation [2] sitting in energy below the broader isotropic mode. This additional mode appears in the c-polarized and in the longitudinal channels but not in the transverse in-plane one. Superconducting materials that are close to the SDW order and near optimum doping, exhibit thus two characteristics reminiscent of the AFM ordering: a finite l-dispersion [3] and pronounced spin-space anisotropy [2].
In slightly Na-underdoped BaFe2As2 polarized and unpolarized neutron diffraction reveals a spin reorientation from the normal alignment along the in-plane component of the propagation vector towards vertical alignment [5], which seems to be related with the anisotropies in purely superconducting samples. A possible orbital origin of the observed anisotropies will be discussed.

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Th-S48-KN1 / Grain boundaries in HTS materials – still a challenge to understand and to control

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Abstract
The huge efforts required to induce strong texture and minimize grain boundary (GB) density complicate manufacture and enforce a tape shape which is far from ideal for making high Jc conductors of arbitrary current-carrying capacity. Bi-2223 with a uniaxial [001] texture of ~15°and REBCO with a biaxial texture of 3-5° both require tape aspect ratios of 20-40:1 that show the strong intrinsic anisotropy of each compound. By contrast we have recently shown that Bi-2212 can be made as a very high Jc conductor [1] in a round wire form that is macroscopically isotropic, a significant and positive violation of the need for HTS conductors be strongly textured tapes. Close examination of optimized Bi-2212 shows that, most surprisingly, it too has a biaxial texture of ~15°, but in this case the texture is developed by growth from the melt in the final size wire [2]. High Jc is partly a function of ensuring a full density superconducting phase (as is also true in Bi-2223) but it also appears that the unexpected biaxial texture of Bi-2212 develops a low GB density biased to low misorientations. Strikingly round wire K-doped Ba122 can also develop rather high Jc even when the grain boundary density is high and texture is absent. Part of the route to higher Jc seems to involve defeating impurity segregations that recent atom probe analysis [3] shows to be present even in high Jc material, but part is probably also intrinsic. A recent study [4] of variably doped (Ca, O) YbBCO films with 6° and 7° [100] tilt grain boundaries shows that Ca doping can enhance Jc only at high T, a property associated with strong Ca de-segregation at the inter-dislocation channels which thus may have higher Tc than the grains on either side. I will review recent studies at the ASC of my colleagues and me on this vital topic for applications.

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Th-S49-KN1 / High-temperature superconductivity below one Micro-Kelvin

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Abstract
Ultracold Fermi gases near a Feshbach resonance allow one to realize a gaseous state with an effectively infinite coupling strength of a zero range, attractive two-body interaction. The critical temperature for the associated superfluid transition is close to 16 percent of the Fermi temperature. I will discuss the universal roperties of this system both in thermodynamics and in the excitation spectrum, which can be probed by momentum resolved RF-spectroscopy.

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Th-S50-KN1 / Weakly doped cuprates: Fractionalized Fermi liquids?

Matthias Vojta
TU Dresden, Germany

Abstract
High-temperature superconductivity in the copper oxides constitutes one of the most fascinating and challenging problems in modern condensed matter physics. I will address the physics of underdoped cuprates, starting from the weakly doped Mott insulator. In particular, I will focus on the concepts of selective Mott phases and fractionalized Fermi liquids (FL*), originally developed to describe non-Fermi liquid behavior in multi-band systems, and their possible relevance to the pseudogap regime of cuprates. Fractionalized Fermi liquids are non-Fermi-liquid metals without broken symmetries, where charge-e spin-1/2 quasiparticles coexist with a spin-liquid background. I will describe different routes to FL* phases in single-band models. Connections will be made to various types of symmetry-breaking order typically observed in underdoped cuprates.

Fr-S51-KN1 / Revised phase diagram of the cuprates

Neven Barišić
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Abstract
The superconducting state of the cuprates evolves upon cooling from an enigmatic metallic phase that is characterized near optimal hole doping by a planar resistivity with large magnitude and extended linear temperature dependence. Below optimal doping, at temperatures below T*, there exists an intermediate pseudogap phase with a partially gapped Fermi surface. These unusual properties have motivated proposals to consider unconventional electronic scattering mechanisms and even to abandon the Landau quasiparticle paradigm entirely.
$HgBa_2CuO_{4+\delta}$ (Hg1201) may be viewed a model cuprate system due to its relative structural simplicity, minimal disorder effects, and large optimal Tc of nearly 100 K [1]. We have found that the planar resistivity of Hg1201 exhibits quadratic temperature dependence, the behavior characteristic of a Fermi liquid, at temperatures below T** (T** <T*) [2]. This result motivated optical conductivity measurements that yielded the quadratic frequency dependence and the temperature-frequency scaling of the optical scattering rate expected for a Fermi liquid [3]. Furthermore, we demonstrated for Hg1201 (and for $YBa_2Cu_3O_{6+\delta}$) that the magnetoresistance obeys Kohler's rule at temperatures below T** [4]. By combining our dc resistivity results for Hg1201 with published data for three structurally more complex cuprates, we obtained the universal sheet resistance throughout most of the temperature-doping phase diagram and arrived at the unexpected conclusion that Fermi-liquid behavior extends to very low doping, close to the Mott-insulating state (2). In contrast to previous approaches that extended ideas developed for the strange metal phase (T > T*) to the pseudogap phase (T < T*), we will discuss the former in the context of the now well-documented pseudogap Fermi-liquid state [5].

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Fr-S52-KN1 / Conventional superconductivity at 203 K at high pressures in the sulfur hydride system

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Abstract
We found that sulfur hydride transforms at pressure ~90 GPa to metal and superconductor with Tc of 203 K at pressure 140 GPa (A.P. Drozdov et al arXiv:1506.08190). We proved occurrence of superconductivity by the sharp drop of the resistivity to zero; the decrease of Tc with magnetic field; the pronounce isotope shift of Tc in D_2S which evidences of a major role of phonons in the superconductivity; and the magnetic susceptibility measurements.

Fr-S53-KN1 / Superconductivity in gate-tunable high density two-dimensional electron systems

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Abstract
Superconductivity in heterogeneous interfaces has become one of the promising routes for creation of new states of matter in the past decade. Among these, electric field induced superconductivity by ionic gating is a unique platform of two-dimensional superconductivity, because of its versatility in terms of materials, stemming from oxides to organics and layered chalcogenides. For these phenomena, electric double layer transistor (EDLT), which has a device configuration equivalent to the field effect transistors, is extremely powerful, because EDLT is capable of producing and controlling the high density electron systems, which is sufficient for the occurrence of superconductivity. In this presentation, the following issues of electric filed induced superconductivity will be addressed; (1) Tunable carrier density, (2) Extremely thin, (3) Absence of inversion symmetry.
(1) Since the sheet carrier density is quasi-continuously tunable from 0 to the order of 10^{14} cm^{-2}, one is able to establish an electronic phase diagram of superconductivity, which will be compared with that of bulk superconductors.
(2) The thickness of superconductivity can be estimated as 2 – 10 nm, dependent on materials. These values are consistent with the theoretical estimation based on the Poisson- Schrödinger equation, and is much smaller than the in-plane coherence length. Such a thin but low resistance at normal state results in extremely weak pinning characteristic of 2D superconductors beyond the conventional dirty Boson model.
(3) Due to the electric filed, the inversion symmetry is inherently broken in EDLT. This feature manifests itself in the enhancement of Pauli limit of the upper critical field for the in-plane magnetic fields. In transition metal dichalcogenide with a substantial spin-orbit interactions, we were able to confirm the topological protection of Cooper pair due to its valley-dependent spin polarization.
This work has been made in collaboration with Y. Saito, J. T. Ye, Y. Kasahara, T. Nojima, M. S. Bahramy, Y. Yanase, Y. Nakamura, Y. Tokunaga, and Y. Kohama. This work has been supported by Grant-in-Aid for Scientific Research (S) (No. 25000003) from JSPS.

Fr-S54-KN1 / Holographic duality and the theory of superconductivity

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Abstract
In a highly surprising development it has become clear in recent years that a mathematical formalism originating in string theory has much to tell about the physics of the strongly interacting quantum matter realized in condensed matter systems [1]. This is the holographic duality (or "AdS/CFT correspondence") that makes possible to compute the properties of the quantum systems by mobilizing Einstein's theory of general relativity. I will present an overview of this development, focusing on results which are of potential relevance to high Tc superconductivity: the non-Fermi liquid strange metals of holography, the "Planckian dissipation" ruling the finite temperature transport properties, the holographic superconductors and -Fermi liquids, and the nature of the extreme types of quantum entanglement which are behind this new physics.

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Fr-S55-KN1 / A unified perspective on cuprates and layered organic superconductors

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Abstract
Band theory and BCS theory are arguably the most successful theories of condensed matter. Yet, both of them fail miserably for high-temperature superconductors and layered organic superconductors. In this talk, I compare experiment with theoretical results obtained from extensions of dynamical mean-field theory for the Hubbard model. In the two-dimensional normal state, at finite doping, a first-order transition between a metal and a pseudogap ends at a critical point. In the supercritical region, a Widom line and its precursor determine the crossovers seen experimentally in both types of materials. We demonstrate that much or the phase diagram, including superconductivity, is controlled by this first-order transition, a finite-doping signature of the Mott transition. The maximum Tc in this approach is not controlled by an antiferromagnetic quantum critical point. By contrast, in a frustrated model for heavy-fermions, it is.

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Invited speaker

Mo-S01-IT1 / Is magnetism relevant to cuprate superconductivity: lanthanides versus charge compensated 123

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Abstract
Many theories suggest that the mechanism for cuprate superconductivity is based on super-exchange interaction between electrons. The most obvious test of these theories is a measurement of the correlation between Tc and the super-exchange parameter J. Alteration of J is achieved by chemical modifications or external pressure. Measurements of J are done with muon s We-S35-KN1 pin rotation, two magnon Raman scattering, or resonant inelastic x-ray scattering. However, the experimental data is confusing. A recent Raman study by Mallet et al. [1] showed an anticorrelation between Tc and J in the set of RA□Cu□Oy compounds with A=(Ba, Sr) R=(La,..Lu,Y). On the other hand, experimental measurements [2] and theoretical calculations of J [3], on the charge compensated 123 material (CaxLa1-x)(Ba1.75-xLa0.25+x)Cu□Oy (CLBLCO) inferred an overall positive correlation between Tc and J [2]. Thus, the effect of J on Tc is not established experimentally. In this talk I will review the experimental situation and shed light on this controversy.

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Mo-S02-IT1 / Odd-frequency pairing and Andreev bound states

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Abstract
Symmetry properties of the pairing, i.e., the parity and spin-singlet/spin-triplet, determine the physical properties of the superconducting state. Recently it has been recognized that there is the important third symmetry of the pair amplitude, i.e., even or odd parity with respect to the frequency [1]. The conventional uniform superconducting states correspond to the even-frequency pairing, but the recent finding is that the odd-frequency pair amplitude arises in the spatially non-uniform situation quite ubiquitously [2]. Especially, this is the case in the Andreev bound state (ABS) appearing at the surface/interface of the sample. It has been revealed that there are many exotic properties relevant to odd-frequency pairing like anomalous proximity effect in spin-triplet superconductor junctions [3-4]. Here, we discuss a strong relationship between Majorana fermions and odd-frequency Cooper pairs which appear at a disordered normal (N) nanowire attached to a topologically nontrivial superconducting (S) one. The transport properties in superconducting nano wire junctions show universal behaviors irrespective of the degree of disorder: the quantized zero-bias differential conductance at in NS junction and the fractional current-phase relationship of the Josephson effect in SNS junction. These behaviors are exactly the same as those in the anomalous proximity effect of odd-parity spin-triplet superconductors. The odd-frequency pairs exist wherever the Majorana fermions stay [5].

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Mo-S03-IT1 / Interplay Between Magnetism and superconductivity in the Two-Dimensonal Electron Liquid at the Surface of SrTiO3

Marc Gabay, Oliver Hijano-Cubelos, Cyril Martins, Marcelo Rozenberg, Andrés Santander-Syro
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Abstract
Experimental reports of ferromagnetism in the two-dimensional electron liquid (2DEL) at the LaAlO3-SrTiO3 interface have ignited a surge of interest in the community. Four years later, the issue remains controversial, as the existence of magnetism appears to depend on the specifics of the growth process of the samples. The putative presence of moments raises fundamental questions regarding the mechanism(s) at play; indeed, evidence for 2D superconductivity in this 2DEL has been widely documented and this state is usually in competition with ferromagnetim. The respective energy scales are such that pairing should be supressed. Any attempt to gain insight into this puzzle requires one to understand whether the moments and the interactions between them are of intrinsic nature (i.e due to the carriers in the 2DEL) or of extrinsic character (i.e due for instance to oxygen vacancies). A 2DEL with similar bandstructure features was observed in ARPES measurements at the 001 surface of SrTiO3 cleaved in high vacuum. In that latter case the origin of the conducting sheet is ascribed to oxygen vacancies. Recent spin-polarized ARPES data on that same system suggested that the sub-bands of the 2DEL exhibit spin textures. We have investigated the interplay between oxygen vacancies and spin polarization of the bands in the 2DEL at the urface of SrTiO3 001, using two complementary approaches. One is based on DFT techniques for slabs of various sizes, and the other on the computation of tight-binding spectra for two types of clusters. When pairs of vacancies are introduced, the bandstructure shows good agreement with experimental data; including spin-orbit interactions in the relaxed structures yields spin textures and a small magnetic moment. The orbital character of the states and their spatial distribution is also determined. The picture that emerges from our study is that magnetism involves dz2 states while superconductivity takes place in the t2g manifold, implying an unconventional case of orbitally selective ordering.

Mo-S04-IT1 / The Call of High Energy Physics: LTS or HTS ?

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Abstract
High Energy Physics (HEP) is one of the main driver of the development of superconducting materials for large scale science. The pull on Nb-Ti in the years since its discovery, the mid 1960's till the construction of the LHC, was required to build a series of colliders of ever increasing energy and dimension. At present, after the end of the production for ITER, HEP is the main driver of industrial development of high Jc Nb3Sn. Indeed, Nb3Sn is the material that will be used to build the magnets for the High Luminosity LHC upgrade. But the focus on LTS is not exclusive. Indeed, HTS materials for magnet applications are receiving increasing attention, as they possess the characteristics necessary to "break" the barrier of 16 T that is perceived as the ultimate field that can be reached by LTS materials for HEP applications. Here we discuss the opportunities, optimum conditions and limits for the use of LTS and HTS materials in HEP magnets.

Mo-S05-IT1 / Enhancement of superconductivity by rare-earth elements and antimony double doping of 112-type $CaFeAs_2$

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Abstract
The 112-type CaFeAs2 is a novel iron-based superconductor, which we discovered very recently [1]. The compound crystallizes in a monoclinic structure and consists of alternately stacked superconducting FeAs and blocking CaAs layers. The La-doped compounds exhibited superconductivity at 35 K, while the Pr-doped compounds show superconductivity at 20 K. Recently, it was reported that the double doping of phosphorous or antimony with lanthanum drastically enhances superconducting transition temperature Tc in the 112 phase; Tc increased to 41 and 43 K as a result of 0.5% phosphorus and 1% antimony doping, respectively [2].
In this talk, we report the effects of the rare-earth emements (RE) and antimony double doping on the superconductivity of 112-type CaFeAs2. Single crystals were synthesized by a flux method. We found that a large amount of Sb doping further increases Tc of Ca1-xLaxFe(As1-ySby)2 up to 47 K, which corresponds to the second highest Tc after 1111-type iron-based superconductors [3]. Moreover, we observed superconductivity at 43, 43 and 43 K for the Sb double-doped compounds Ca1-xRExFe(As1-ySby)2 for RE = Ce, Pr and Nd, respectively. Notably, the Ce 112-phase did not show superconductivity without Sb doping. X-ray diffraction studies revealed that an increase in the b-axis parameter that tunes the As-Fe-As bond angle is important for enhancing the superconductivity of the 112-phase.

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Mo-S06-IT1 / Amperean pairing and the pseudo-gap state of cuprate superconductors

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Abstract
The enigmatic pseudogap phase in underdoped cuprate high T_c superconductors has long been recognized as a central puzzle of the Hi T_c problem. Recent data show that the pseudogap is likely a distinct phase, characterized by a medium range and quasi-static charge ordering. However, the origin of the ordering wavevector and the mechanism of the charge order is unknown. At the same time, earlier data show that precursive superconducting fluctuations are also associated with this phase.
We propose that the pseudogap phase is a novel pairing state where electrons on the same side of the Fermi surface are paired, in strong contrast with conventional BCS theory which pair electrons on opposite sides of the Fermi surface. In this state the Cooper pair carries a net momentum and belong to a general class called pair density wave (PDW). The microscopic pairing mechanism comes from a gauge theory formulation of the resonating valence bond (RVB) picture, where spinons traveling in the same direction feel an attractive force in analogy with Ampere's effects in electromagnetism. We call this Amperean pairing. Charge order automatically appears as a subsidiary order parameter even when long range pair order is destroyed by phase fluctuations. Our theory gives a prediction of the ordering wavevector which is in good agreement with experiment. Furthermore, the quasiparticle spectrum from our model explains many of the unusual features reported in photoemission experiments. The Fermi arc, the unusual way the tip of the arc terminates and the relation of the spanning vector of the arc tips to the charge ordering wavevector also come out naturally. Finally, we propose an experiment which can directly test the notion of Amperean pairing.

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Mo-S06-IT2 / Ultrafast carrier localisation in the pseudogap state of cuprate superconductors

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Abstract
The studies of elementary excitations under non-ergodic conditions can reveal the dominant interactions responsible for the emergence of broken symmetry states which cannot be infered from equilibrium experiments. Using multiple pulse ultrafast spectroscopy we investigate the real time quasiparticle dynamics in the prototype high temperature cuprate superconductor Bi-2212, with particular focus on the broken-symmetry “pseudogap” state. Systematic temperature- and doping- dependence coherent quench experiments designed to study of the time-evolution of emergence of the “pseudogap” and superconducting state1,2,3 after photodestruction reveal a marked absence of critical behaviour of the elementary excitations associates with the formation of the “pseudogap” state. This effectively eliminates collective electronic ordering beyond a few (1~2) superconducting coherence lengths on femtosecond timescales at any level of doping within the superconducting region of the phase diagram. These findings are consistent with a “pseudogap” state, as originally introduced by Mott to describe a state of matter which has a minimum in the density of states at the Fermi level deep enough for states to become localized. The symmetry and dynamics of the ultrafast carrier localization we observe is consistent with the existence of a textured state of polaron clusters forming as a result of the competition between lattice strain and Coulomb repulsion.

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Mo-S07-IT2 / Spin-Orbital Coupling in a Triplet Superconductor-Ferromagnet Junction

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Abstract
In the last decades spin-triplet superconductivity has raised a lot of interest, due to the increasing number of theoretical predictions and experimental evidences about its possible realization in bulk materials and at the interface of hybrid systems. One of the most studied spin-triplet superconductor (TSC) is Sr2RuO4 [1], where the emergent consensus indicates triplet chiral pairing. Recent experimental results [2] have opened the way to the experimental realization of Sr2RuO4 based epitaxial heterostructures, where a great variety of novel phenomena are expected.
In a TSC-ferromagnet (FM) heterostructure the orientation of the FM moment relative to the TSC vector order parameter is a crucial variable that controls the physical behavior. In addition to the pair breaking effect, spin-flip reflection processes at the interface with the FM scatter the triplet Cooper pairs between the spin up and down condensates, setting up an effective Josephson-like coupling between them [3]. The pair-breaking and spin Josephson coupling both make significant contributions to the free energy of the junction but, although both depending upon the direction of the FM's exchange field, they do not necessarily act constructively.
Using a self-consistent spatially dependent mean-field approach, we have investigated the interplay between the spin and orbital structure of the TSC in setting the stable orientation of the FM's moment in a TSC-FM junction. For a single-component p-wave TSC, we found that the gap variation controls the orientation of the FM's moment and stabilizes the FM magnetization direction either parallel or perpendicular to the TSC vector order parameter, depending on the alignment of the TSC gap with respect to the interface, thus evidencing a unique form of spin-orbital coupling. The competing orbital components of the chiral px+ipy state generate a non unique behavior and a first-order transition from the perpendicular to the parallel configuration occurs as the FM exchange field is increased [4]. When the interface is imperfect or spin active, other processes can play the decisive role in setting the magnetic profile [5].
Work in collaboration with Mario Cuoco, Canio Noce, Alfonso Romano, Philip Brydon, Dirk Manske and Damien Terrade.

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Mo-S07-IT1 / Spin-orbit entanglement and the breakdown of singlets and triplets in Sr2RuO4

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Abstract
In this talk we will discuss the influence relativistic atomic spin-orbit coupling has on the normal and superconducting state in Sr2RuO4. The interaction between local spin-orbit coupling and k dependent band formation with particular accidental band degeneracies at the Fermi energy lead to a fundamental breakdown of singlet and triplet states, strong k-dependent spin-orbit entangled wave-functions in the normal state, and a highly anisotropic 3 dimensional gap function in the superconducting state.

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Mo-S08-IT1 / Single vortex dynamics at the nanoscale

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Abstract

Superconducting QUantum Interference Devices (SQUID) are traditionally the most sensitive devices for measuring magnetic field. However, because of their relatively large sizes (> 1 μm2) and limitations on reducing the device-to-sample distance to submicron range, SQUIDs were not used so far for magnetic imaging at the nanoscale. We have developed nanoSQUID that resides on the apex of a pulled quartz pipette that is ideally suited for scanning magnetic microcopy. The SQUID-on-tip (SOT) is made of Pb with an effective diameter of down to 46 nm, flux noise of Φn = 50 nΦ0/Hz1/2 at 4.2 K, corresponding spin sensitivity of Sn = 0.38 μB/Hz1/2, and operation in fields of up to 1 T [1]. The SOT was incorporated into a scanning probe microscope than allows magnetic imaging at nanometer scale proximity to the sample. Using this novel technique, we have carried out study of dynamics of single vortices in superconductors subjected to ac and dc drive. The outstanding sensitivity of the SOT allows probing vortex displacements as small as 10 pm [2] as a function of the driving force. As a result, the structure of disorder-induced pinning potential of an isolated vortex was measured as a function of the position for the first time with sub-nanometer resolution. The study finds rich internal structure of the pinning potential and of the restoring force, and reveals unexpected phenomena including large softening of the restoring force, nontrivial vortex trajectories within a single potential well, pronounced anisotropy, broken spring behavior leading to abrupt depinning, and hysteretic vortex trajectories between the various potential wells. The results shed new light on the importance of multi-scale random disorder and of the ripples in the potential landscape on vortex dynamics and on thermal fluctuations even at 4.2 K.

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Mo-S08-IT2 / Scanning Hall probe microscopy of vortex matter in type-1, type-1.5 and type-2 superconductors

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Abstract

Scanning Hall probe microscopy (SHPM) has been used to directly visualize vortex matter modifications in Pb wedge sample covering all the ranges from type-2 to type-1 superconductivity. Vortices in the intermediate state of a thick type-1 superconducting Pb film have been studied for different Pb thicknesses. In low fields we have observed the presence of stable (or quasi stable) single flux quantum vortices, as well as a few flux quanta vortices. Unusual vortex patterns have been observed in the type-II/1 and type-II-2 regimes in the vicinity of the dual point $\lambda/\xi=1/\sqrt{2}$. The role of surface barriers in stabilizing these vortex patterns has been discussed.

The existence of the novel superconducting state has been demonstrated in two-component high quality MgB_2 single crystals where a unique combination of both type-1 and type-2 conditions is realized in the same material: $\lambda_1/\xi_1<1/\sqrt{2}$ for the first and $\lambda_2/\xi_2>1/\sqrt{2}$ for the second component of the order parameter. Such materials are, in fact, neither type-1 nor type-2 superconductors (PRB 72, 180502 (2005)) and can be introduced as "type-1.5 superconductors". This leads to an appearance of unconventional vortex arrangements such as stable vortex stripes, clusters and gossamer-like vortex patterns. We have directly visualized these novel patterns by SHPM, Bitter decoration and scanning SQUID microscopy. The observed vortex patterns are in a good agreement with the molecular dynamics simulations based on the vortex-vortex interaction corresponding to type-1.5 superconductivity. In higher applied fields normal type-2 vortex patterns are recovered in MgB_2.

(*) In collaboration with: J.Y. Ge, J. Gutierrez, M. Timmermans, J. Van de Vondel, A.V. Silhanek, T. Nishio, Q.H. Chen, L.J. Li, V. H. Dao, L.F. Chibotaru, B.Y. Zhu, V. Gladilin and J.T. Devreese

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Mo-S09-IT1 / Neutron investigation of the ferromagnetic superconductor (Li-Fe)FeSeOD

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Abstract
The system (Li1-xFex)OH(Fe1-yLiy)Se has recently been reported to become superconducting at TC≈43 K and then developing ferromagnetism in terms of a spontaneous vortex lattice below TM≈10 K.[1] We have prepared the tetragonal (Li1-xFex)OD(Fe1-yLiy)Se phase by hydrothermal synthesis in D_2O to reduce the neutron incoherent scattering cross section. We also prepared the samples using isotopically purified ^{7}LiOD as a starting material to reduce the neutron absorption cross section. The lattice parameters at room, based on neutron and X-ray diffraction measurements, varied from 3.78 Å < a < 3.82 Å and 9.16 Å < c < 9.20 Å. However, the superconducting regime occurs at different values of the lattice parameters compared to the protonated system. We have carried out bulk magnetization, high resolution powder diffraction measurements to determine the crystal structure, high intensity diffraction measurements for the magnetic structure, and small angle scattering measurements to investigate the vortex lattice and interaction with the ferromagnetic order. The position of the vortex peak occurs at the expected position within uncertainties, without an apparent contribution from bulk magnetization at low temperature. The ferromagnetic contribution without applied field develops below 10 K, and is consistent with scattering from domains and domain walls.

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Mo-S09-IT1 / Magnetic, structural and superconducting phase diagram in bulk Fe chalcogenides: role of nematic fluctuations and biquadratic exchange

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Abstract
It has been recently realizied that even the bulk FeSe is distinctly unusual, compared to "old" pnictogen-based FeBS, which may be a clue to understanding more exotic FeSe-derivatives. The mystery starts with the FeSe phase diagram: numerous pnictides experience an orthorhombic transition, likely of "spin-nematic" nature, followed by a magnetic transition; external pressure favors superconductivity if the starting phase is magnetic, and suppresses it otherwise, consistent with pressure suppressing spin fluctuations. FeSe, however, experiences an orthorhombic transition with no apparent sign of magnetic ordering, and its Tc raises rapidly with pressure, before switching to the usual, opposite trend. In this talk I will revisit, based on DFT calculations, magnetic interactions in chalcogenides, and show that they, unlike pnictides, demonstrate unusual (and unanticipated) frustration, which supresses magnetic, but not nematic order, and fully explain the nonmonotonic Tc(P). Specifically, after the discovery of Fe based superconductors (FeBS) multiple attempts have been made to map the magnetic interactions in these systems (deemed to be crucial for superconductivity) onto a set of short range pairwise exchange interactions, initially in terms of the J1-J2 Heisenberg model (HM). This approach failed to explain the double-stripe magnetism in FeTe, so the model was extended to include J3. However, it was soon realized that this HM contradicts both ab initio calculations and neutron experiments in the magnetically ordered state of Fe pnictides. Thus the model was augmented to include a nearest neighbor biquadratic exchange K. It was also appreciated that the same interaction is essential for explaining the splitting between antiferromagnetic and orthorhombic phase transition in Fe pnictides. What has not been appreciated though was that (1) the double-stripe order is never a ground state of the HM, independent of the values of J_{1,2,3}; it can be stabilized only through K, (2) the HM model has, in addition to usually considered in FeBS phases, a highly competititive novel antiferromagnetic "staggered stripes" phase, which appears to be the ground state in ab initio calculations for FeSe (but not FeTe or for FeSe under pressure). Applying the full J_{1,2,3}+K model to the Fe(Se,Te) system demonstrates unusual frustration, not relevant for As-based FeBS (except NaFeAs), which can explain the phase diagram of the system, nonmonotonic behavior of Tc under pressure and unexpectedly large orthorhombic "nematic" region in the FeSe phase diagram.

References
An early version of this work was posted at http://arxiv.org/abs/1501.04946
This version does not include explicit calculations of pnictides, discussion of the applicability of the Mermin-Wagner theorem to the J1-J2-J3-K model, and phenomenological Ginzburg-Landau calculations by R. Fernandes.

Mo-S10-IT1 / Magnetism and electron-phonon interaction in the emergence of organic superconductivity

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Abstract
In this talk, we analyze the influence of electron-phonon interaction on unconventional superconductivity, as driven by spin fluctuations in correlated quasi-one-dimensional electron systems [1]. We employ the renormalization group method to treat on the same footing the electron-electron and the tight-binding electron-phonon interactions for the quasi-one-dimensional electron gas model. We show that for a momentum dependent phonon-mediated interaction that is weak compared to nonretarded repulsive interactions, spin fluctuations and in turn d-wave superconductivity are reinforced. As a function of phonon frequency, the results reveal a positive isotope effect for both anti ferromagnetic and d-wave superconducting orders, as well as for the amplitude of quantum critical spin fluctuations effects in the normal phase. We discuss the impact of these results for organic conductors like the Bechgaard salts, which stand out as a classical example of proximity between anti ferromagnetism and superconductivity.

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Mo-S10-IT2 / Strongly Correlated Superconductivity in Molecular Conductors: Electronic Correlations, electron-phonon coupling and the Phase diagram of Cs3C60

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Abstract
Alkali-metal doped fullerides provide us with a remarkable example of a superconductor in which the pairing is likely driven by electron-phonon interaction, but the standard Bardeen-Cooper-Schrieffer theory and its extensions can not be applied[1,2,3]. Despite the s-wave symmetry of the order parameter, these materials are strongly influenced by electron-electron correlations, which make Cs3C60 insulating at ambient pressure [2] and affect the properties of the superconducting phase which can be induced applying pressure in this material [2,3] and it is realized in ambient conditions in K3C60 and Rb3C60.
Using a completely ab-initio modeling of the bandstructure, the electron-phonon interaction and the interaction parameter [4] and solving the model with Dynamical Mean-Field Theory, we demonstrate that superconductivity in these materials arises from phonon pairing, but it benefits from strong correlations [1]. As a result, the superconducting phase shares many similarities with "exotic" superconductors in which the pairing is believed to be purely electronic, suggesting that the anomalies in the "normal" state, rather than the pairing glue, can be the real common element unifying a wide family of strongly correlated superconductors including the cuprates and the iron-based superconductors.
We also discuss if the same mechanism can be realized in other molecular superconductors like aromatic superconductors [5] and the general condtions for which a pairing interaction can survive and prosperate in the presence of strong correlations.
This work is the result of collaborarions with M. Fabrizio, E. Tosatti, C. Castellani, G. Giovannetti, Y. Nomura, S. Sakai, K. Nakamura and R. Arita. The research has been supported by the European Research Council (ERC) through the Starting Grant SUPERBAD, Grant Agreement 240524.

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Tu-S11-IT1 / Elusive charge-density-wave order is becoming manifest: a bridge between underdoped and overdoped Cuprate Superconductors

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Abstract
I will review and analyze how heterogeneous states in the entire pseudogap region form a bridge between highly-doped Fermi-Liquid and low-doped anti-ferromagnetic regions of the phase diagram. At very low doping, the doped charges aggregate in ferronematically ordered segments with broken C4 lattice rotational symmetry. This state with incommensurate spin order and low or no positional order, may evolve, by increasing doping, into charge ordered states of stripe type with tightly linked spin and charge incommensurations or in states with loose incommensurate spin and charge density waves. Charge order ends with a “hidden” Charge Density Wave Quantum Criticality around optimal doping as theoretically predicted since 1995 and recently observed.
In large regions of the phase diagram strong quasi-critical fluctuations of various nature mark this evolution of the heterogeneous state with specific signatures in the spectroscopic properties. In particular CDW fluctuations sign the onset of the pseudogap T* and appear favorable to the onset of superconductivity, while well developed CDW order is competing with it. A comprehensive scenario for the cuprates follows.

Tu-S11-IT2 / Subtle properties of charge order in cuprates studied by resonant x-ray spectroscopy and scattering

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Abstract
In superconducting layered cuprates the elusive nature of charge ordering has delayed its observation by bulk sensitive scattering techniques for several years. Resonant soft x-ray scattering has eventually emerged as the most sensitive method in this field: after the pioneering results on striped materials and the sensational discovery of charge density modulations in the 123 family by resonant inelastic x-ray scattering (RIXS) [1], the Cu L3 and O K edge resonant scattering without energy resolution has been mostly used to prove the ubiquity of charge ordering in hole and electron doped cuprates [2,3,4,5]. However the properties of this charge instability are still unclear. Here we present some recent experiments on the 123 and 214 families where we used various x-ray spectroscopy and scattering techniques to further unveil the symmetry of charge order in cuprates, such as the possible chirality, the 2D vs 1D character, and its possibly fluctuating nature.

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Tu-S12-IT1 / Anomalies in magnetotransport of iron pnictides due to "hot-spot" scattering and Fermi-surface reconstruction

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Abstract
Proximity to the spin-density-wave (SDW) instability is the key property of iron-based superconductors. Several parent and underdoped iron-pnictide compounds display anomalous magnetotransport properties, both in SDW and paramagnetic states. These properties include extended range of linear magnetoresistance and strong magnetic field dependence of the Hall resistance. Such anomalies are typically attributed to a Dirac-cone electronic spectrum. Most probably, however, they are caused either by the strongly anisotropic scattering on the SDW fluctuations or by Fermi-surface reconstruction due to the SDW order.
Above the SDW transition scattering on the SDW fluctuations is strongly enhanced at the Fermi surface locations where the nesting is perfect ("hot spots" or "hot lines"). Such "hot spots" do not dramatically change conductivity but lead to anomalous behavior in magnetotransport [1]. Magnetic field dependences are
characterized by the two field scales, the lower scale is set by the width of the "hot spots" and the higher scale is set by the total scattering amplitude. A conventional behavior is limited to fields below the lower scale. In the range in between these two scales the diagonal conductivity has linear dependence on the magnetic field and the Hall conductivity has quadratic dependence. The linear dependence of the diagonal component reflects growth of the Fermi-surface area affected by "hot spots" proportional to the magnetic field. Such "hot-spot" scattering chanism provides consistent description of the high-field magnetotransport for the P-doped BaFe2As2 compound. The SDW transition also leads to Fermi-surface reconstruction corresponding to strong modification of the lectronic spectrum near the nesting points ("hot spots" in the paramagnetic state). It is difficult for quasiparticles to pass through these points during their orbital motion in magnetic field, because they must turn sharply. Similar to the "hot-spot" regime, the Fermi surface area affected by the nesting points is proportional to the magnetic field leading to the linear magnetoresistance [2]. The crossover between the quadratic and linear regimes takes place at the field scale set by the SDW gap and scattering rate. The magnetotransport is likely influenced by the oth mechanisms at the vicinity of the transition.
This work was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division.

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Tu-S12-IT2 / Divergent nematic susceptibility of optimally doped Fe-based superconductors

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Abstract
High-temperature superconductivity often emerges in the proximity of a symmetry-breaking ground state in strongly interacting electronic materials. In the case of the superconducting iron pnictides, in addition to the antiferromagnetic ground state of the parent compounds, a ubiquitous but small structural distortion breaks the crystal's C4 rotational symmetry in the underdoped part of the phase diagram. It has been proposed that this structural transition is driven by an electronic nematic phase transition, below which the electronic system spontaneously organizes with an orientational order without developing additional spatial periodic order. In this talk I will show how the effects of this electronic nematic order can be explicitly revealed by differential elastoresistivity measurements, a technique quantitatively probing the response of the system to in-plane anisotropic strain. By performing these measurements on a wide range of iron based superconductors, including electron doped (Ba(Fe1-xCox)2As2, Ba(Fe1-xNix)2As2), hole doped (Ba1-xKxFe2As2), isovalent substituted pnictides (BaFe2(As1-xPx)2) and chalcogenides (FeTe1-xSex), we show that a divergent nematic susceptibility in the B2g symmetry channel appears to be a generic feature of optimally doped compositions. For the specific case of optimally "doped" (BaFe2(As1-xPx)2), the nematic susceptibility can be well fitted by a Curie-Weiss temperature dependence with critical temperature close to zero, consistent with expectations of quantum critical behavior in the absence of disorder. However for all the other optimal doped iron based superconductors, the nematic susceptibility exhibits a downward deviation from Curie-Weiss behavior, suggestive of an important role played by disorder.

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Tu-S13-IT2 / Muti-band aand multi-dome superconductivitivity and in n-doped SrTiO_3

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Abstract
The superconducting state of n-doped SrTiO3 occupies a singular place in the history of superconductivity. Besides being the first oxide superconductor, one of the earliest ``semiconducting superconductors'', the first experimentally-detected multi-gap superconductor and the first case of a superconducting dome, it remains the most dilute superconductor half a century after its discovery [1]. Superconductivity emerges when the carrier concentration is 10-5 per atom and vanishes when It exceeds 2 10-2 per atom.
We present a systematic study of quantum oscillations and superconducting transition in doped SrTiO3, over a wide range of carrier concentration from 1017 to 1020 cm-3 [2]. Mobile carriers were introduced either by removing oxygen or by substituting Ti by Nb. Superconductivity was found to persists down to an exceptionally low concentration of mobile electrons (n=3 1017 cm-3 and Tc=34 mK). At this concentration range, the Fermi temperature is below 10 K, restricting the relevant energy window and possible pairing scenarios. We identify two critical doping levels, which are the filling thresholds of the upper conduction bands. This clarifies the limits of single-band, two-band and three-band superconducting regimes. We find that the exceptionally-wide superconducting dome of SrTiO3 has two distinct domes, each peaking near a critical doping level. Moreover, in the dilute limit, the superconducting critical temperature is not the same in the dilute metals produced by oxygen deficiency and Nb substitution. A study of thermal transport in the superconducting state near optimal doping detects multiple nodeless siperconducting gaps[3].

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Tu-S13-IT1 / Nanoscopic disorder, intrinsic charge instability and metal-to-superconductor transition in oxide heterostructures

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Abstract
Motivated by experiments in oxide interfaces like LaAlO3/SrTiO3 or LaTiO3/SrTiO3 (LXO/STO) heterostructures, we investigate the metal-to-superconductor transition in a (nearly) two-dimensional electron system with inhomogeneity on the nanoscopic scale. Disorder induces a distribution of local superconducting critical temperatures accounting well for the transport and tunnel experiments in LXO/STO [1]. With lowering the temperature, global superconductivity establishes as soon as percolation occurs within the superconducting clusters. Microscopic mechanisms for electronic phase separation (EPS) based on Rashba spin-orbit coupling (RSOC) [2] and/or electrostatic electron confinement at the interface [3] are investigated to establish a possible intrinsic origin for the inhomogeneous character of LAO/STO or LTO/STO interfaces. Both RSOC and electrostatic confinement not only provide an intrinsic mechanism for the observed inhomogeneity, but also open the way to new interpretations of the observed quantum critical behaviour of LTO/STO [4]. We investigate the effects of temperature, gating, and magnetic field on the charge instability finding a novel type of quantum critical point related to the vanishing of the critical temperature of the EPS [2,3,5].

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Tu-S14-IT1 / Emergent surface superconductivity of nanosized Dirac puddles in a topological insulator

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Abstract
Surfaces of three-dimensional (3D) topological insulators have emerged as one of the most remarkable states of condensed quantum matter. These surfaces host robust spin-protected helical Dirac particles that emerge from topological order and can support unusual electronic phases when electron correlations are at play. One particularly exciting phase is topological superconductivity which, if found, could lead to a paradigm change in quantum information. Here we will report a discovery of surface superconductivity in a hole-conducting 3D topological insulator (Sb2Te3) with transition to zero resistance induced through a minor tuning of growth chemistry that depletes bulk conduction channels. The depletion shifts Fermi energy towards the Dirac point as witnessed by about two orders of magnitude reduced hole density and by the largest carrier mobility (~ 25,000 cm2/Vs) found in any topological material. The unconventional nature of this state is witnessed by the persistence of quantum oscillations inside the superconducting state and two-dimensional (2D) quantum beats arising from strong spin-orbit coupling. Direct evidence from scanning tunneling spectroscopy, unusual magnetic response, and transport reveal the superconducting condensate to emerge at first in surface puddles at unprecedentedly high temperatures, above 50 K and approaching liquid nitrogen. We will discuss how global coherence is mediated by interpuddle diffusion of quasiparticles and how the novel superconducting state we observe to form in puddles can be tuned by the topological material's parameters such as Fermi velocity and mean free path.

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Tu-S14-IT2 / Odd-frequency superconductivity in topological insulators and multiband superconductors

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Abstract
One of the key aspects of superconductivity is the fermionic nature of the superconducting pair amplitude. This leads to the traditional classification of spin-singlet even-parity (s-, d-wave) or spin-triplet odd-parity (p-wave) pairing. Superconducting pairing can also be odd in time, or equivalently frequency [1]. Odd-frequency pairing has, however, so far only been reported at surfaces and interfaces [2]. For example, at a superconductor-ferromagnetic interface, a conventional spin-singlet s-wave superconducting pair amplitude can be transformed into an odd-frequency spin-triplet s-wave amplitude [3].
In this work we establish that odd-frequency superconducting pairing is, in fact, quite common in many modern superconductors.We first show that odd-frequency spin-triplet s-wave superconductivity appears on the surface of a topological insulator (TI) proximity coupled to a conventional spin-singlet s-wave superconductor [4]. Using both analytical and numerical methods we demonstrate that the odd-frequency state is present whenever there is an in-surface gradient in the proximity-induced gap. This naturally includes superconductor-normal state junctions, but also e.g. homogenous systems with finite supercurrents. Generalizing the gap gradient condition to reciprocal space, we also find that a uniform p-wave superconducting order parameter in a TI always generates odd-frequency spin-triplet s-wave pairing [5].
Moreover, we show that odd-frequency pairing is ubiquitous in multiband superconductors [6]. In fact, odd-frequency superconducting pairing only requires a finite band hybridization, or scattering, and nonidentical intraband order parameters, of which only one band needs to be intrinsically superconducting. This situation is fulfilled in many known multiband superconductors, as well as in superconductor-TI junctions. Formally, we find that the band (or orbital) parity (O) of the pair amplitude in multiband superconductors, together with spatial parity (P) and time reversal (T), need to obey the rule PTO = +1(−1) for spin-singlet (spin-triplet) pairing. There is thus a complete reciprocity between pairing that is odd in frequency and odd under band index permutation. Generalizing these results to bilayer systems, we also find odd-frequency superconducting pairing in bilayer systems with finite interlayer coupling between non-equivalent layers [7].

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Tu-S15-IT2 / Time-resolved study of Higgs amplitude mode in s-wave superconductors

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Abstract
When a phase transition occurs associated with the spontaneous symmetry breaking, two kinds of collective excitations emerge; the gapless phase mode and the gapped amplitude mode of the complex order parameter. The latter is recently called as Higgs mode from its analogy to the Higgs boson in particle physics. The nature of the Higgs mode in superconductors has been intensively studied theoretically, while it has evaded the experimental study since the Higgs mode does not have a charge nor electric dipole nor spins, so it does not couple directly to the electromagnetic field within the linear response regime. Here we report on the time-resolved observation of the collective Higgs amplitude mode in s-wave superconductors, Nb1-xTixN films, by using THz-pump and THz-probe spectroscopy technique[1,2]. In order to excite the Higgs amplitude mode, we have adopted two independent approaches: 1) nonadiabatic excitation of quasiparticles near the superconducting gap with monocycle THz pulses[3], and 2) coherent nonlinear excitation of Higgs mode with sub-gap multicycle THz pulses[4]. In the first experiments, damped oscillations were observed in the transmission of the electric field of THz probe pulse after the nonadiabatic pump pulse excitation. The oscillation was also identified in the spectral weight of complex optical conductivity near the superconducting gap energy, indicating the oscillation of superfluid density. The oscillation frequency coincides with the value of asymptotic BCS gap energy after the THz excitation, which behavior indicates the character of Higgs amplitude mode. In the second experiments, a coherent nonlinear coupling between the Higss mode and electromagnetic field was elucidated. We found that, under the irradiation of multi-cycle THz pulse with its frequency (ω) tuned below the superconducting gap(2Δ), the order paratmeter oscillates with the frequency of 2ω. Further, the 2ω-order parameter oscillation showed a prominent enhancement when the incident frequency matched with Δ, and third harmonics (3ω) of the incident THz pulse was efficiently emitted. These results were well described by the collective precession of Anderson's pseudo-spins resonating with the Higgs mode[5].

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Tu-S15-IT1 / Dynamics of two dimensional bosonic superconductors

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Abstract
Charge 2e lattice bosons are a natural paradigm for Non Fermi Liquid behaviour of strong coupling superconductors. I will review recent work [1-3] on the dynamics of two dimensional lattice bosons including the resistivity and complex conductivity, which indeed exhibit unconventional, or "bad metal", phenomenology, such as linear resistivity above Tc.
The bosonic theory yields the magnitude of the proportionality between the superfluid density and the linear resistivity slopeabove Tc. Suprisingly, this constant seems to be similar to that found by systematic studies of optimaly doped cuprates, by Amit Keren's group.
Finally, lattice bosons predict the observability of a collective amplitude (Higgs) mode, especially close to a quantum critical point. Our calculations of the complex bosonic conductivity near the superconductor to insulator transition, have been found relevant to this transition by the discovery [4] of the Higgs spectral weight in Terahertz spectroscopy of disordered superconducting films.

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Tu-S16-IT1 / Quantitative Determination of the Excitation spectra Responsible for High Temperature Superconductivity in Cuprates

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Abstract
The fundamental problem in high temperature superconductivity is discovering and understanding the nature of the fluctuations and their coupling to fermions which lead to it as well as to the singular-Fermi-liquid phenomena in the metallic states invariably associated with it. Angle resolved photoemission spectra (ARPES), more than any other property, carries in absolute magnitude the finger-prints of this information. Historically, the quantitative analysis by McMillan and Rowell of the much simpler tunneling experiments, which integrates over the momentum dependence of the interactions, decisively confirmed that the exchange of phonons by the Fermions is responsible for the conventional s-wave superconductivity in metals such as Pb. This is sufficient for s-wave superconductors because the ``normal'' and the Cooper ``pairing'' interaction energies (self-energies) have the same symmetry. For high temperature superconductors, such as the cuprates, the normal self-energies have the full symmetry of the lattice but the pairing self-energies have D-wave symmetry. ARPES is then required because both momentum and frequency dependence of the interactions is necessary to decipher the fundamental physics. We report Laser based ARPES of unprecedented accuracy and stability, together with a method of analysis, to quantitatively reveal both the normal and the Cooper pairing self-energies. These are used to find the spectra of the fluctuations ${\cal F}({\bf k, k}', \omega)$ exchanged by the fermions in virtually scattering at energy ω from momentum states ${\bf k}$ to ${\bf k'}$ as well as the electron-fluctuation vertices $g({\bf k, k}')$. The analysis does not depend on any a priori assumption about the mechanism of high temperature superconductivity. The validity of the Eliashberg equations used and the consistency of the data and the procedure is tested and found to be accurate to about 10\%. To this accuracy, we find the remarkable result that near T_c, ${\cal F}({\bf k, k}', \omega)$ is independent of ${\bf k, k'}$ and of ω except at very small energy and with a high energy cut-off of about 0.4 eV. The {\it vertices} $g({\bf k, k}')$ alone determine the distinction between the normal and the pairing interactions. Their projection to the full symmetry of the crystal is repulsive and to the D-wave symmetry is attractive. These results were anticipated by a theory in which the pairing of fermions occurs through coupling to quantum-critical fluctuations of a loop-current order.

Tu-S17-IT1 / Scaling laws for AC conductivity from Holography

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Abstract
Holography models a class of strongly coupled quantum field theories at finite density, and therefore offer a new paradigm for strongly correlated charge carriers.
We analyze quantum critical holographic theories whose ground states are non-fermi liquids. We compute the AC conductivity and find that its quantum critical part provides generically scaling laws at intermediate frequencies that are of a similar nature to those observed in cuprates. We analyze the novel mechanisms for charge transport emerging from holographic models and we describe novel mechanisms driving insulating behavior.

References
Most of this work is in progress and will be publised in the next month
A part associated to transport in helical ground states has been published in arXiv:1406.6351

Tu-S18-IT1 / Magnetic and Superconducting Ground State of delta-doped La2CuO4 Superlattices

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Abstract
In cuprate superconductors, especially La2-xSrxCuO4 (LSCO), cation disorder has a strong impact on the electronic properties. One route to reduce disorder are tailored materials which can be grown by Molecular Beam Epitaxy (MBE). MBE provides the necessary facility since it allows to grow thin films of high-temperature superconductors in a layer-by-layer fashion [1]. Previous studies on LSCO heterostructures and superlattices (SLs) reveal rich and unexpected physics in these systems [4-5]. Low-energy muon spin rotation (LE-μSR) is a state-of-the art method for the depth-resolved profile of a local magnetization and superconductivity in various thin films and heterostructures [6-9]. Here we will present a LE-μSR study on so called δ-doped LCO superlattices (δ-LCON) which is given by the layer sequence M x [(SrO-LaO-CuO2) + N x (LaO-LaO-CuO2)], where N = 3, 7, 8, 9, 11 was chosen. M was fixed such that the overall thickness of these SLs was between 42-48nm. δ-LCON is solely doped from a single layer of SrO from within the structure. All these SLs show superconductivity with a Tc ranging from ~18 to 29 K, and a London penetration depth of λL ~ 220nm. δ-LCO11 shows clear zero field precession, with an measured internal field corresponding to the full Cu moment in La2CuO4 of m = 0.64 μB. The zero field oscillation amplitude can be used to estimate the magnetic layer thickness, and hence also gives an upper limit of the superconducting layer thickness of about 4-5 unit cells. Hence, these SLs show a layered structure of alternating antiferromagnetic and superconducting regions. All δ-LCON show a pronounced change in the magnetic volume fraction at Tc. This shows that the close proximity of the antiferromagnetic and superconducting ground state in δ-LCON is leading to a non-trivial interplay between the two orders.
One might think this situation being similar to superoxygenated La2CuO4+δ [10-11]. However, in the latter the magnetic moment is substantially reduced and the magnetic transition sets in at Tc only, whereas the δ-LCON SLs show the full magnetic moment and a magnetic onset temperature substantially higher than Tc.

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Tu-S20-IT1 / The involvement of the high energy scale in High-temperature superconductivity revealed by ultrafast optical spectroscopy

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Abstract
Out of equilibrium optical spectroscopy experiments offer the unique possibility to distinguish the interplay between the low-energy many body states, characteristic of strongly correlated materials, and specific high energy electronic excitations. By means of ultrafast broad-band optical spectroscopy, coherent oscillations of the superconducting condensate have been found to resonate at remarkably high energies in cuprates [1], suggesting the involvement of Mott physics in the pairing mechanism. A systematic investigation of this effect will be presented, spanning the phase diagram of cuprates in the directions of temperature and doping level, giving insights into the formation of Cooper pairs and their dynamics below and above the critical temperature.

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Tu-S21-IT2 / Atomic-layer engineering and the origin of high-Tc superconductivity in cuprates

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Abstract

Motivation. Superconductivity in cuprates has many mysterious facets, but the central question is why the critical temperature (Tc) is so high. Our experiments target this question.

Methods. We use atomic-layer-by-layer molecular beam epitaxy (ALL-MBE) to synthesize atomically smooth thin films, multilayers and superlattices of cuprates and other complex oxides. By atomic-layer engineering, we customize the samples and optimize them for the particular experiment. Using a continuous spread in composition ("Combinatorial MBE"), we fine-tune the doping level to the unprecedented precision of one per cent of one per cent. We use high-throughput measurements on combinatorial libraries to study magneto-resistance and Hall effect in fields up to 60 T. We measure the absolute value of penetration depth to accuracy better than 1%.

Results. By now, we have established the following. HTS cuprate samples can be quite homogeneous, in particular having a very uniform SC gap, with no signs of phase separation, electronic or conventional. While static or dynamic charge density wave and charge glass occur at some doping levels, neither is present in the samples with maximal Tc. Strong phase fluctuations are observed and drive the superconducting transition at every doping, but they fade out 10-15 K above Tc, so the pseudogap must have a different origin. Pairs exist on both sides of the superconducting transition, be it induced thermally or by doping. In-plane charge excitations are strongly coupled to out-of-plane lattice vibrations. HTS superfluid can be confined to a single CuO_2 layer, with Tc equal to that in bulk samples. In certain heterostructures, a large enhancement of Tc is seen compared even to optimally doped bulk samples.

Novelty. Here, we report for the first time the outcomes of a comprehensive study, probably without precedence in Condensed matter physics, which took nine years and encompassed thousands of cuprate samples. The large statistics enables us to identify clear trends and unravel intrinsic properties; this is essential when dealing with complex materials such as cuprates. We have measured the key physical parameters (Tc, λ and ξ) of the superconducting state and established their precise dependence on doping, temperature, and external fields. The findings bring in some great surprises, challenge the commonly held beliefs, and rule out many theoretical models or scenarios. They hint at the answer to the question we have posed at the outset.

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Tu-S21-IT1 / A dimer model for the pseudogap metal in underdoped cuprates

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Abstract

The pseudogap metal is one of the most tantalizing states of matter found in the copper-oxide superconductors and has been at the focus of much experimental and theoretical interest for more than two decades. The origin of the pseudogap is still controversially debated, however, and several experimental probes lead to seemingly contradictory interpretations. In this talk I'm going to introduce a simple model which captures several key features of the pseudogap metal, in particular small pocket Fermi surfaces of coherent, electron-like quasiparticles, visible as Fermi arcs in ARPES experiments. This model realizes a so-called fractionalized Fermi liquid (FL*) featuring a small Fermi surface with a non-trivial Luttinger count due to the presence of topological order, rather than broken symmetries. Possible low temperature instabilities of such a state include the recently observed charge density wave order.

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Tu-S22-IT2 / Magnetic fields above the superconducting ferromagnet UCoGe

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Abstract
We study how coexisting states of superconductivity and magnetism interact with each other by local measurements of the magnetic fields, with micron scale spatial resolution, above a single crystal of the ferromagnetic superconductor UCoGe using scanning superconducting quantum interference device microscopy. Our measurements show that the spontaneous ferromagnetic transition at TC =2.5K is characterized by Ising-like magnetization along the easy axis (c direction), with domain sizes of the order of 10 µm, magnetization amplitudes of 45 G, and are consistent with estimates of domain-wall widths of several angstroms. The measured magnetization amplitudes are in agreement with bulk magnetization measurements. In the superconducting state, which coexists with ferromagnetism below TSC =0.67K, both diamagnetic screening and Meissner expulsion of flux, but no shrinkage of the ferromagnetic domains, are detected. Although we could not resolve individual vortices, our measurements provide evidence for the existence of the spontaneous vortex state in UCoGe.

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Tu-S22-IT1 / Collective modes of spin-triplet models of Sr2RuO4, UPt3 and 3He-A

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Abstract
The spectrum of Bosonic excitations in superconductors reflects the broken symmetries of the ground state. In conventional superconductors these are phase and amplitude modes. The former couples to the electromagnetic field and is renormalized to the plasma frequency (Anderson-Higgs mechanism), while the latter (amplitude Higgs mode) has been observed via Raman spectroscopy through its coupling to CDW phonons in NbSe2.1 Strongly correlated fermions with unconventional pairing correlations, generally exhibit a much richer spectrum of Bosonic collective modes that provide spectroscopic signatures of the broken symmetries of the superconducting ground state.2
I report new theoretical predictions for the spectrum of Bosonic modes in spin-triplet superconductors, specifically multi-band models for chiral "p-wave" spin-triplet (E1u representation) superconductivity in Sr2RuO4, chiral "f-wave" spin-triplet (E2u representation) superconductivity in UPt3 and thin films of superfluid 3He-A, which is the neutral, 2D isotropic analog of the γ-band model for superconductivity in Sr2RuO4. In all three cases the order parameter belongs to a higher dimensional representation of the symmetry group of the normal-state, and as a result possesses additional branches of Bosonic modes. The number of Bosonic modes is at least 2N, where N is the dimensionality of the irreducible representation of the ground state. In the case of UPt3, the ground state breaks time-reversal symmetry as well as 2D reflection symmetries, and exhibits gapless Fermionic excitations in low-dimensional regions (line and point nodes) of the Fermi surface. The nodal spectrum plays two important roles - nodal states are responsible for the finite lifetime of the Bosonic excitations in UPt3 and Sr2RuO4, and they contribute directly to the current response to an electromagnetic field (micro-wave and Raman).
Results are reported on (i) the effects of Fermi surface and pairing anisotropy on the Bosonic excitation spectrum and (ii) their lifetimes due to coupling to the low-energy Fermionic continuum based on microscopic pairing models for UPt3 and Sr2RuO4. (iii) Selection rules for the coupling of the order parameter collective modes to an electromagnetic field are derived, and (iv) signatures of chiral symmetry in the mode spectrum are identified. Coupling of the current to the Bosonic modes leads to absorption resonances at frequencies below the pair-breaking threshold of 2Δ(p), and provides a mechanism for circular birefringence and dichroism from microwave to optical frequencies.3

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Tu-S22-KN1 / Spin-Triplet Proximity Effects between Ferromagnetic SrRuO3 and Superconducting Sr2RuO4

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Abstract
Spin-triplet superconductivity does not only exist in the bulk like Sr2RuO4 [1], but can also be generated at an interface between a spin-singlet superconductor (S) and a ferromagnet (F) if magnetic inhomogeneity exists at the interface [2]. In addition, there is another approach to realize the spin-triplet proximity effects with junctions between F and a spin-triplet superconductor (T). Theoretically, it has been predicted that spin-triplet proximity effect can be controlled by magnetization direction of F relative to the spin direction of the spin-triplet Cooper pairs in T, and is accompanied by interfacial super-spin current [3].
We developed F/T hybrids by growing epitaxial ferromagnetic SrRuO3 thin films on the ab-surface of Sr2RuO4 single crystals. The films are under compressive strain (about 2%) and exhibit ferromagnetic ordering below 160 K [4]. Conductance-vs-voltage curves under magnetic fields show Andreev-reflection features with a relatively large characteristic gap energy, revealing the presence of spin-triplet proximity effect at the SrRuO3/Sr2RuO4 interface.

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Tu-S23-IT1 / Crossing-field magnetization and vortex cutting in superconductors

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Abstract
We present detailed magneto-optical studies of flux patterns in a high-quality YBCO crystal under crossing magnetic fields. The dynamics of vortex motion under crossed-magnetic field is highly anisotropic with preferred vortex motion along in-plane components Hp of the applied field as opposed to strongly suppressed vortex motion transverse to Hp. In tilted fields we observe multiple vortex instabilities resulting in filamentation of the field induced currents and formation of intriguing vortex domains in a finite range of field angles. The vortex dynamic behavior in the crossing and tilted fields can be explained by the flux cutting processes and by the staircase vortex structure expected in anisotropic superconductors. The intriguing vortex domains are associated with a type-I phase transition in the vortex lattice accompanied by a sharp jump in the vortex angle with respect to the crystal's basal plane. We further elucidate the scenario of the crossing-field magnetization using time-dependent Ginzburg-Landau simulations, which reveal fine details of the vortex cutting and reconnection process at a moderate density of vortices. The simulations show left-handed helical vortex instabilities and formation of sharp vortex tilt fronts confirming our experimental observations.

Tu-S23-IT2 / Upper critical field and Nernst effect in slab superconductors

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Abstract
The occurrence of a superconducting state close to a magnetic phase appears to be a universal feature of layered superconductors. This situation occurs in organic superconductors, in cuprates and also in iron-pnictides. This proximity is believed to be at the origin of a phase segregation observed, at the border region between the superconducting ordering and the magnetic state. The phase segregation consists of superconducting regions separated by non superconducting regions which can be magnetic.
We address the possibility of enhanced upper critical field and Nernst signal in a stack of superconducting slabs alternating with non-superconducting domains. This enhancement is ascribed to the superconducting fluctuations which become more important as the dimensionality of the system is reduced. In the framework of the time dependent Ginzburg Landau theory1-2 we derive, as a function of the superconducting slab thickness L, the upper critical field Hc2 along the slabs and the Peltier coefficient on which depends the Nernst signal. We show that Hc2 exhibits an upward curvature in the two dimensional (2D) limit where the interplane coherence length is smaller than the superlattice periodicity D = L+d, d being the size of the non-superconducting domain. In this limit, Nernst signal is found to be strongly enhanced compared to the 3D case. The results are discussed in connection with experimental observations in quasi-1D organic superconductors, stripe ordered phase in cuprates and superlattices of high-Tc films.

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Tu-S24-IT2 / Josephson magnetic memory and phase inverters for RSFQ logics

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Abstract

Superconductivity (S) and ferromagnetism (F), two deeply antagonistic electronic properties, can coexist in form of Josephson SFS junctions (SFS JJ). The most impressive feature of the SFS JJ is the ability to be in a Josephson state with the phase difference inversion or pi-state [1,2]. This feature makes the SFS JJs valuable phase-shifting elements for utilization in superconducting circuits. Recently, a Toggle Flip-Flop (TFF) with the embedded SFS pi-junction was successfully demonstrated [3]. The SFS JJs are also suitable for integration with Josephson qubits. A quantum Josephson circuits, a pi-biased qubits, has been recently demonstrated too [3,4]. Another application is based on the simplest feature of a SFS JJ that its critical current can be changed significantly by remagnetization of the F-interlayer. A Josephson magnetic memory element proposed in Ref. [5,6] requires ferromagnet layer with an in-plane magnetic anisotropy and small coercive field. Specifically, an application of small external magnetic field changed the magnetization of the ferromagnetic layer that in turn changes the junction critical current Ic, allowing the realization of two distinct states with high and low Ic, corresponding to logical “0” and “1” states, respectively. The superconducting-ferromagnetic Josephson junctions are electrically compatible with traditional superconductor-insulator-superconductor (SIS) Josephson junctions used for digital energy-efficient single flux quantum (eSFQ/ERSFQ) circuits. Modern fundamental and applied researches make the actual implementation and study of planar multiterminal S/F/N structures with spin and quasipartical injection. The main goal of the talk is to review our published and new results on SFS structures applicable in digital and quantum electronics.

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Tu-S24-IT1 / Magnetic Field Modulated Microwave Spectroscopy (MFMMS) across phase transitions and the search for new superconductors

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Abstract

We will introduce Magnetic Field Modulated Microwave Spectroscopy (MFMMS) as a unique and high sensitivity technique for use in the search for new superconductors and to investigate other phase transitions. MFMMS measures reflected microwave power as a function of temperature. The modulation induced by the external ac magnetic field enables the use of phase locked detection with the consequent sensitivity enhancement. The MFMMS signal across several prototypical structural, magnetic, and electronic transitions were investigated. We show that MFMMS can be used to detect superconducting transitions selectively with very high sensitivity.

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Tu-S25-IT2 / infrared pseudogap in cuprate and pnictide high tc superconductors

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Abstract
We investigate infrared manifestations of the pseudogap in the prototypical cuprate and pnictide superconductors, YBa2Cu3Oy and BaFe2As2 (Ba122) systems. We find remarkable similarities between the spectroscopic features attributable to the pseudogap in these two classes of superconductors. The hallmarks of the pseudogap state in both systems include a weak absorption feature at about 500 cm−1 followed by a featureless continuum between 500 and 1500 cm−1 in the conductivity data and a significant suppression in the scattering rate below 700–900 cm−1. The latter result allows us to identify the energy scale associated with the pseudogap PG. We find that in the Ba122-based materials the superconductivity-induced changes of the infrared spectra occur in the frequency region below 100–200 cm−1, which is much lower than the energy scale of the pseudogap. We performed theoretical analysis of the scattering rate data of the two compounds using the same model, which accounts for the effects of the pseudogap and electron-boson coupling. We find that the scattering rates suppression in Ba122-based compounds below PG is solely due to the pseudogap formation, whereas the impact of the electron-boson coupling effects is limited to lower frequencies. The magnetic resonance modes used as inputs in our modeling are found to evolve with the development of the pseudogap, suggesting an intimate correlation between the pseudogap and magnetism.

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Tu-S25-IT1 / Two-dimensional Fermi gases

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Abstract
Systems of interacting Fermions are ubiquitous in nature. They exhibit fascinating phenomena like superconductivity, quantum magnetism, superfluidity of 3He, and the anomalous rotation of neutron stars. Ultracold atomic Fermi gases allow for a particularly clean experimental realization of these quantum many-body systems and for addressing long-standing open questions. In this talk, we focus on situations in which the motion of particles is confined to two-dimensional layers. Such low-dimensional, interacting many-body systems bear subtle effects, which are not encountered in three dimensions. We will review our recent experiments regarding quasiparticle spectroscopy and spin diffusion measurements.

We-S26-IT1 / Time Resolved Pump-Probe Photoemission studies of the High Tc Cuprate Superconductors

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Abstract
We have recently investigated the non-equilibrium properties of the normal state of optimally doped (Tc = 91 K) Bi2Sr2CaCu2O8+x (Bi2212) using time and angle resolved photoelectron spectroscopy (trARPES).[1] These studies reveal a pump-induced modification of the nodal mass renormalization at 70 meV as well as a longer-lived photodoping effect. Building on this work, we will present further findings related to the photodoping effect as it is manifested in the normal state of heavily underdoped (Tc = 50 K) Bi2212. The latter studies provide clear evidence for the presence of hole pockets consistent with those predicted in such models as the YRZ ansatz. Close examination of the decay of excited states above the Fermi level point to the presence of a mode consistent with the 70 meV mode observed in photoemission studies of the excitation spectra below the Fermi level.

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We-S27-IT1 / Universal V-shaped temperature-pressure phase diagram in the iron-based superconductors KFe2As2, RbFe2As2, and CsFe2As2

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Abstract

Discovering universal trends that do not depend on details of a specific material are of great importance in condensed matter physics. The collection of our pressure experiments on AFe2As2 with A = K, Rb, and Cs has revealed a V-shaped phase diagram for the pressure dependence of the superconducting transition temperature Tc in these Alkali 122 systems [1,2,3]. As a function of pressure, Tc in AFe2As2 decreases initially until a critical pressure Pc, where it reverses direction and increases. Comparing the V-shaped pressure dependence of Tc in these three materials reveals a universal trend in which (dTc/dP)P<Pc and (dTc/dP)P>Pc are identical in AFe2As2 independent of the chemical composition and the structural parameters. Apart from the pressure dependence of Tc, we also examined the pressure dependence of the critical field Hc2 in both RbFe2As2 and KFe2As2 and found a second universal property of the transition: a two-fold jump in the quantity at Pc in both compounds. Based on recent theoretical works, this quantity depends on the Fermi velocity and the gap structure. Our Hall effect measurements rule out any sudden changes of the Fermi surface parameters at Pc. Therefore, the two-fold jump originates from a change of the gap structure. Our interpretation for the Tc reversal at Pc in AFe2As2 is a change of pairing state induced by pressure. Several recent theoretical works proposed close competition between d-wave and s-wave pairing in these fully hole-doped AFe2As2 systems. Our serial pressure experiments provide firm experimental ground to support these ideas.

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We-S27-IT2 / Electronic structure, magnetism and superconductivity in strained or doped iron chalcogenides

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Abstract

Fe(Se,Te) systems remain intriguing because of fascinating properties and promising applications as high-Tc superconductors. They possess the simplest crystal structures but complex magnetic and superconducting phase diagrams and still an unclear mechanism of superconductivity (SC) [1]. The parent superconductor FeSe has the critical temperature Tc ~ 8 K. However, Tc rises upon its partial Te substitution (up to 15 K for FeSe0.5Te0.5) and also under hydrostatic pressure (up to 37 K) or compressive stress. Oppositely, tensile stress strongly decreases Tc in FeSe. Our ab initio electronic structure calculations have been performed based on the density functional theory. The results indicated that some modifications of the Fermi surface nesting with the (π,π) vector (spanning the electronlike and holelike cylinders) under different strain conditions are in accord with experimental changes of Tc in both pure FeSe [2] and FeSe0.5Te0.5 [3]. Furthermore, for FeSe substituted with S, Co, Ni or Cu atoms, we also obtained [4] an analogous relation between changes of the (π,π) nesting and experimental Tc values. These nesting modifications might tune antiferromagnetic (AFM) fluctuations (detected in e.g. NMR experiments) that can be responsible for SC in the iron chalcogenides. Interestingly, in the end member FeTe, an AFM double-stripe order with the (π,0) wave vector was observed experimentally in the non-superconducting ground state. Surprisingly, SC emerged only under Se or S substitution into Te sites in the bulk material as well as (contrary to FeSe) under tensile stress applied to FeTe thin films. Our first-principles results predict that in the pure FeTe tensile strain induces a phase transition from a double- to single-stripe AFM ordering with the (π,π) wave vector [5]. Moreover, the same transition can be also achieved by an S-doping [6] or hypothetical Ru-doping [7] of this compound. The final AFM state corresponds to the observed appearance of SC in the Fe(Te,S) thin films, which suggests that the SC in these systems is mediated by the single-stripe AFM fluctuations. In turn, such fluctuations can be driven (as in FeSe) by the imperfect (π,π) nesting [6,7,8]. Summarising, our findings support the scenario that AFM fluctuations, caused by the above nesting, play a crucial role in the SC of the iron chalcogenides. Nonetheless other (more complex) pairing mechanisms based on such a nesting are not excluded.

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We-S28-IT1 / Understanding the Kerr effect in the chiral state of strontium ruthenate superconductor

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Abstract

Strontium ruthenate is an interesting system with a Fermi liquid like normal state at low temperatures [1] and a very anomalous superconducting state [2]. Based on many experiments it has been proposed as a spin triplet odd parity superconductor. Unfortunately the proper interpretation of the data is challenging in many ways. The superconducting state of this tetragonal system breaks time reversal symmetry which points to the chiral state allowed by the group-theoretical analysis. Its thermodynamic properties, showing power low temperature dependence at low T, require a gap vanishing somewhere on the Fermi surface. The T independent spin susceptibilities measured with a magnetic field in the ab plane and along the c-axis are at odds with the theory which requires at least one of the components to change with temperature. The possibility of using optical methods to detect time reversal symmetry breaking (TRSB) pairing states in unconventional superconductors was first suggested in the late 1980's. Recently, such dichroism was observed in polar Kerr effect measurements of the Sr2RuO4 [3], which showed a small Kerr rotation of light of wavelength λ=1550nm, corresponding to a rotation of the plane of polarization by an amount approaching 90 nrad at T=0 and going to zero at Tc approximately linearly in Tc-T. The measurements provide clear evidence of the time reversal symmetry breaking below the superconducting transition temperature Tc. The theoretical interpretation of the Kerr effect, however, is challenging in many ways. As it has been established [4,5] the effect vanishes in a clean system described by the one-band model. We will discuss the model [6] which takes into account all three relevant orbitals and three dimensionality of the system. The model has been shown to provide good description of the many thermodynamic and electrodynamic properties of the material. It provides semi-quantitative description of the magnitude of the Kerr effect and its dependence on temperature in Sr2RuO4. For most frequencies, it varies with temperature as Δ(T)2 near to Tc while for others, Hebel-Slichter like enhancement or decrease below Tc are observed. The optical transitions leading to the effect will be discussed.

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We-S28-IT2 / Chiral d-wave Superconductivity in SrPtAs

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Abstract

Recent muSR measurements on SrPtAs revealed time-reversal-symmetry breaking with the onset of superconductivity, suggesting an unconventional superconducting state. We have investigated this possibility via functional renormalization group and find a chiral (d+id)-wave order parameter favored by the multiband fermiology and hexagonal symmetry of SrPtAs. This (d+id)-wave state exhibits significant gap anisotropies as well as gap differences on the different bands, but only has point nodes on one of the bands at the Brillouin zone corners. The topological characteristics of this superconducting phase include Majorana-Weyl nodes in the bulk, protected surface states, and an associated thermal Hall response. The lack of extended nodes and the spontaneously broken time-reversal symmetry of the (d+id)-wave state are in agreement with the muSR experiments. Our theoretical findings together with the experimental evidence thus suggests that SrPtAs is the first example of chiral d-wave pairing and a Weyl superconductor.

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We-S29-IT1 / Switching of magnetic domains reveals evidence for spatially inhomogeneous superconductivity in $CeCoIn_5$

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Abstract
The so-called cerium '115' heavy-fermions represent a prototypical material family for the study of quantum criticality and the interplay of different quantum phases, due to strong electron correlations [1]. In particular, the compound CeCoIn5 has been at the focus of intense research activity since the discovery of Tc = 2.3 K superconductivity [2] and serves a model material for studies of unconventional superconductivity in the proximity of magnetism. Though CeCoIn5 is paramagnetic in the normal state, magnetism is manifested two-fold in the superconducting phase: (i) A novel vortex structure occurs in the mixed state due to strong Pauli paramagnetic effects [3]. (ii) Long-range spin-density wave (SDW) order forms in the superconducting Q-phase close to the upper critical field Hc2 [4].
Using high-field neutron scattering we find that incommensurate SDW order in the Q-phase emerges in a continuous quantum phase transition as the magnetic field is increased, before SDW order and superconductivity break down simultaneously at Hc2, suggesting an intimate link between magnetism and the charge carriers [5]. Furthermore, we find that always only one of two possible SDW domains is populated in the Q-phase, which cannot be explained by a Zeeman term. Carefully rotating the magnetic field direction allows for direct control and hypersensitive switching of the SDW domain population [5]. This binary switching behavior provides strong evidence that the Q-phase physics is governed by a linear coupling term of singlet (d-wave) superconductivity, incommensurate SDW order and spatially inhomogeneous triplet (p-wave) superconductivity. Our approach not only allows us to manipulate a complex quantum state with extreme sensitivity via the control parameter of the respective quantum phase transition, but also provides evidence for the presence of a spatially inhomogeneous triplet Cooper pair-density wave.

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We-S29-IT2 / Chirality density wave of the "hidden order" phase in URu_2Si_2

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Abstract
A second-order phase transition is associated with emergence of an "order parameter" and a spontaneous symmetry breaking. For the heavy fermion superconductor URu2Si2, the symmetry of the order parameter associated with its ordered phase below 17.5 K has remained ambiguous despite 30 years of research, and hence is called "hidden order" (HO). Here we use polarization resolved Raman spectroscopy to specify the symmetry of the low energy excitations above and below the HO transition. These excitations involve transitions between interacting heavy uranium 5f orbitals, responsible for the broken symmetry in the HO phase. From the symmetry analysis of the collective mode, we determine that the HO parameter breaks local vertical and diagonal reflection symmetries at the uranium sites, resulting in crystal field states with distinct chiral properties, which order to a commensurate chirality density wave ground state. We explore the connection between the "hidden order" chirality density wave and the unconventional superconductivity at Tc = 1.5 K in URu2Si2 , which has recently been proposed to be of a chiral d-wave type.
Research at Rutgers was supported by US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0005463 and by the National Science Foundation under Awards NSF DMR- 1104884 and NSF DMR-1405303.

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We-S29-IT3 / Magnetically Mediated Cooper Pairing in Heavy Fermion Superconductors

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Abstract
To identify the microscopic mechanism of heavy-fermion Cooper pairing is an unresolved challenge in quantum matter studies; it may also relate closely to finding the pairing mechanism of high temperature superconductivity. Magnetically mediated Cooper pairing has long been the conjectured basis of heavy-fermion superconductivity but no direct verification of this hypothesis was achievable. Here, we use a novel approach based on precision measurements of the heavy-fermion band structure using quasiparticle interference (QPI) imaging [1], to reveal quantitatively the momentum-space (k-space) structure of the f-electron magnetic interactions of CeCoIn5. Then, by solving the superconducting gap equations on the two heavy-fermion bands with these magnetic interactions as mediators of the Cooper pairing, we derive a series of quantitative predictions about the superconductive state [2]. The agreement found between these diverse predictions and the measured characteristics of superconducting CeCoIn5, then provides direct evidence that the heavy-fermion Cooper pairing is indeed mediated by the f-electron magnetism.
This work was done in collaboration with J. Van Dyke, F. Massee, M. P. Allan, J. C. Davis, and C. Petrovic

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We-S30-IT1 / ARPES of single layer FeSe on STO

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Abstract
In this talk, I will discuss mono-unit-cell (UC) superconductor FeSe grown on SrTiO3, where the Cooper pairing temperature is reported to have dramatically enhanced from its bulk value of 8K to ~ 60K. A challenge is to understand the cause of the enhanced pairing strength, and possibly increase superconducting Tc. Using in-situ MBE grown samples, we show angle-resolved photoemission spectroscopy (ARPES) data that provide clear evidence for strong cross-interface electron-phonon coupling in single UC limit, suggesting that pairing is significantly enhanced by the strong interface mode coupling. In addition, the clean Fermi surface topology and quality of the in situ film permits a detailed mapping of the gap anisotropy, which can be used to constrain the pairing symmetry, and also theory.

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We-S30-IT2 / High-temperature superconductivity in atomically thin multilayer FeSe films on $SrTiO_3$

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Abstract
A recent report on possible high-temperature (Tc) superconductivity in a monolayer FeSe film1) has generated tremendous attention, because the Tc is relatively high, close to the liquid-nitrogen temperature, and the material is an atomically thin (a few angstrom thick) film. One of key questions is how the high-Tc superconductivity evolves from bulk to film, since bulk FeSe exhibits Tc no higher than 10 K. Another mysterious question is that multilayer (two or more) FeSe films have been reported to show no superconductivity. However, the difficulty in controlling the number of FeSe layers and/or the carrier density has hindered elucidation of these problems. In this talk, we report a novel approach to solve the problems, that is, an in situ deposition of potassium (K) atoms onto a film2). Using this technique, we have succeeded in accessing the heavily electron-doped region. Moreover we found evidence of the emergence of superconductivity in multilayer films with Tc as high as 48 K, and observed the dome-shaped superconducting region in the phase diagram. The magnitude of superconducting gap systematically increases on decreasing the thickness of film, indicating that the interface plays a crucial role in realizing the high-Tc superconductivity. The present results provide a new strategy to enhance and optimize Tc in ultrathin films of iron-based superconductors.

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We-S31-IT2 / The dynamics of the quasiparticle in various cuprate models

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Abstract
We use a variational method, whose accuracy is validated by comparison with available exact diagonalization results for small clusters, to study the quasiparticle that emerges when one hole is doped in an infinite CuO2 layer described (a) by the three-band Emery model in the limit where a large onsite Hubbard repulsion prevents double occupancy of Cu 3d orbitals, and (b) by the one-band t-t'-t"-J model. The variational method allows us to switch the spin-fluctuations of the antiferromagnetic background on or off, to understand their effect on the dynamics of the quasiparticle. Although for a suitable choice of parameters both models predict quasiparticles with very similar dispersion, we find that the spin-fluctuations have essentially no effect on the shape of this dispersion for the three-band model, whereas for the one-band model they play an essential role in setting the correct dispersion in a certain part of the Brillouin zone. This suggests that the two models describe qualitatively different quasiparticles.

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We-S31-IT1 / Witnessing quasi-particles in a strongly correlated electron system

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Abstract
This contribution focuses on the interaction between phonons and electronic excitations in correated electron systems. I will first review our recent results in archetypal strongly correlated charge-transfer insulator (La2CuO4) revealing that the interaction between electrons and bosons manifest itself directly in the photo-excitation processes of correlated materials and pilots the formation of itinerant quasi-particles which are suddenly dressed (<100 fs) by an ultrafast reaction of the bosonic field. I will introduce new ideas to address vibrational excitations in time domain experiments by means of resonant excitation of low energy modes and time domain quantum state reconstruction of ultrashort pulses.

We-S32-IT1 / Impact of superconductor/ferromagnet (SC/FM) interfaces on the transport properties of SC/FM heterostructures

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Abstract
The interfaces between complex oxides are of great interest since they can exhibit physical properties that are not inherent to the individual materials. A prominent example is the interface between the cuprate high Tc superconductor YBCO and the ferromagnetic (FM) manganite LCMO which reveals interesting superconducting (SC) and magnetic proximity effects. The latter involves a strong suppression of the Mn moment on the LCMO side and, yet, a FM moment of the interfacial Cu ions in YBCO. The same Cu ions also undergo an orbital reconstruction that arises from the covalent bonding between the 3d3z2-r2 levels of Cu and Mn and from the related charge transfer [1, 2]. The relationship between these intriguing phenomena, in particular, the origin of the FM moment of the interfacial Cu ions is still debated. Using X-ray magnetic circular dichroism (XMCD), we show that by changing the electronic and magnetic properties of the LCMO layers the strength of the antiferromagnetic exchange interaction (AEI) between the interfacial Cu and Mn moments can be strongly reduced, whereas the magnitude of the Cu moment is hardly affected. This finding suggests that this Cu moment is not induced by the AEI with Mn moment, but is intrinsic to the interfacial CuO2 plane.

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We-S33-IT1 / Topological RPdBi half-Heusler semimetals: a new family of non-centrosymmetric magnetic superconductors

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Abstract
We report superconductivity and magnetism in a new family of topological semimetals, the ternary half Heusler compounds RPdBi (R : rare earth). In this series, tuning of the rare earth f-electron component allows for simultaneous control of both lattice density via lanthanide contraction, as well as the strength of magnetic interaction via de Gennes scaling, allowing for a unique tuning of both the normal state band inversion strength, superconducting pairing and magnetically ordered ground states. Antiferromagnetism with ordering vector (0.5,0.5,0.5) occurs below a Néel temperature that scales with de Gennes factor, while a superconducting transition is simultaneously linearly suppressed. With superconductivity appearing in a system with non-centrosymmetric crystallographic symmetry, the possibility of spin-triplet Cooper pairing with non-trivial topology analogous to that predicted for the normal state electronic structure provides a unique and rich opportunity to realize both predicted and new exotic excitations in topological materials.

We-S34-IT1 / Terahertz Modulation of Spin-Density-Wave Gap Opening Induced by Coherent Lattice Motion in BaFe2As2

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Abstract
Studying the microscopic coupling mechanisms between charge, spin and lattice degrees of freedom is of great importance for the understanding of macroscopic quantum phenomena in complex solids such as high-temperature superconductivity. Over the last two decades, ultrashort and intense optical pulses have emerged as a novel tool to investigate the elementary dynamics of electrons in a regime where quantum coherence dominates the physical properties. Together with adequate resolution on fundamental time scales, ultrafast excitation into a non-equilibrium state adds a new set of parameters that may help to disentangle coupling phenomena that are hard to access with purely stationary methods operating in the frequency domain. We have employed few-cycle multi-terahertz pulses to resonantly probe the evolution of the spin-density-wave (SDW) gap of the iron pnictide parent compound BaFe2As2 following excitation with a near-infrared femtosecond pulse of a photon energy of 1.55 eV. In nominally undoped material, spin-density-wave ordering sets in when cooling below a temperature of 130 K and a characteristic energy gap opens at mid-infrared optical frequencies. Starting in the low-temperature ground state, optical excitation results in a melting of the SDW order, followed by ultrafast recovery on a time scale of 600 fs. In contrast, the SDW gap is induced when we excite the normal state above the transition temperature. Very surprisingly, the transient gap opening quasi-adiabatically follows a coherent lattice oscillation at a frequency as high as 5.5 THz [1]. This frequency corresponds to excitation of the A1g vibrational mode modulating the height of the As ion cores above the Fe square lattice. Around the maxima of coherent lattice displacement, the transient optical conductivity spectrum closely resembles the equilibrium optical properties measured at a stationary temperature of 100 K where the SDW gap is readily established. Our results indicate an efficient mechanism of spin-phonon coupling in iron pnictides that triggers rapid formation of spin ordering upon small vibrational displacement and even without breaking the symmetry of the crystal.

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We-S35-IT1 / High-temperature superconductivity induced by a hidden fermionic excitation

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Abstract
The superconducting gap function Δ in general depends both on the momentum (k) and frequency (ω) of pairing electrons. In conventional s-wave superconductors, the k dependence is negligible while the ω dependence shows a structure characterized by a relevant phonon frequency. On the other hand, in cuprate high-temperature superconductors, Δ shows a d-wavelike k dependence, which is well established experimentally and has been reproduced by many theories. However, much less attention has been paid to the ω dependence of Δ.
Cluster extensions of the dynamical mean-field theory (CDMFT) enables to numerically calculate the dynamical structure of Δ in microscopic models of the cuprates without any a priori assumptions on its symmetry and/or dominant fluctuations. The CDMFT does not even rely on the Eliashberg equation. In fact, the two-dimensional Hubbard and t-J models have been studied in previous works, which found a sharp low-energy peak in the imaginary part of Δ and the anomalous self-energy[1-4]. Since the peak in ImΔ makes a major contribution to the gap, ReΔ(ω=0), through the Kramers-Kroenig relation, the origin of the peak holds a key to the high-Tc superconducting mechanism.
By scrutinizing the CDMFT results on the two-dimensional Hubbard model, we identify the origin of the peak as a fermionic excitation, in contrast to the conventional theory where only a boson is relevant to the structure of Δ. We employ as a CDMFT impurity solver the exact diagonalization method extended to finite temperatures, which enables us to investigate precise real-ω properties. We find several nontrivial relationships between the real-ω structures of the normal and anomalous self-energies and Δ, which can be explained by the presence of a hidden fermionic excitation hybridizing with the quasiparticles. The peak in ImΔ is then attributed to the pole of the hidden fermion, which is in turn at the origin of boosting up Tc.[5]

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We-S36-IT1 / Thoughts on the Pseudogap

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Abstract
A variety of phenomena are associated with the pseudogap phase in the cuprates – novel commensurate magnetic order (perhaps due to orbital currents), incommensurate charge and spin order, and pairing correlations. This leads to the central question of who is leading whom. A way forward is to look at spectroscopic data such as photoemission and STM, which exhibit profound changes when entering into the pseudogap phase. I will review various explanations of these spectra, and their relationship to transport and other probes such as quantum oscillation studies, as well as to two particle spin and charge correlation functions as revealed by neutron, x-ray, EELS, and other scattering methods. I will also discuss possible analogies with other materials, such as indium oxide.

We-S36-IT2 / Giant Phonon Anomaly and other Anomalous Properties of the Pseudogap Phase in Underdoped Cuprates

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Abstract
As the hole density decreases and the Mott insulator is approached, umklapp scattering processes increase in importance. These transform the superconducting gap into an insulating pseudogap, starting at antinodal. Long range ordered superconductivity is then confined to 4 anisotropic pockets centered on the nodal directions. A consistent description of the breakup of the Fermi surface observed in ARPES experiments follows[1]. The umklapp scattering processes that drive the pseudogap also causes quantum interference between d-wave pairing and commensurate antiferromagnetic short range correlations. The Fermi surface surface breakup in turn leads to a breakup of the superconducting d-wave order parameter into two subband amplitudes and to a low energy Leggett mode due to phase fluctuations between them. This leads to a large increase in the temperature range of superconducting fluctuations due to an overdamped Leggett mode. Almost resonant scattering of intersubband phonons to a state with a pair of Leggett modes, causes anomalously strong phonon damping at wavevectors connecting the ends of the pockets, in this temperature range. A close connection in both temperature and hole density between the anomalously strong superconducting fluctuations and the Giant Phonon Anomaly follows[2].

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Y. H. Liu, R. M. Konik, T. M. Rice and F. C. Zhang. arXiv 1506.01258

We-S36-IT2 / Investigations of Density Wave Order and the Pseudogap in a Cuprate Superconductor

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Abstract
The cuprates exhibit a variety of complex phenomena, including high temperature superconductivity, a poorly understood pseudogap phase, and charge density wave (CDW) order. Yet despite years of study their relationships remain unclear. Using magnetic field- and temperature-dependent scanning tunneling microscopy to study the Bi-based cuprate family, we have previously demonstrated the relative independence of the pseudogap, distinct from yet coexisting with superconductivity and surprisingly insensitive to a Fermi surface reconstruction that occurs near optimal doping [1, 2]. Here I will report on a new investigation of the pseudogap and its relationship to observed CDW order, and in particular to a recently discovered density wave order with d-wave intra-unit-cell form factor [3].

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We-S37-IT2 / Anisotropy of nodal quasiparticle transport in the superconducting state of Sr2RuO4 : Evidence of a horizontal line node

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Abstract

There is strong experimental evidence that the superconductor Sr2RuO4 has a chiral p-wave order parameter. If so, symmetry does not require that the associated gap has nodes, yet specific heat, ultrasound and thermal conductivity measurements establish the existence of line nodes in the superconducting gap structure of Sr2RuO4. Theoretical scenarios have been proposed to account for the existence of accidental nodes within a p-wave state. To examine such scenarios, it is essential to know whether the line nodes are vertical (parallel to the tetragonal c-axis) or horizontal (perpendicular to the c axis). Here we report thermal conductivity measurements on high-quality single crystals of Sr2RuO4 down to 50 mK for currents parallel and perpendicular to the c-axis. We find that there is no quasiparticle transport along the c-axis in the T = 0 limit, in contrast with the large residual conductivity found in the basal plane. The immediate interpretation of this a-c anisotropy is that the line of nodes in Sr2RuO4 is horizontal. We discuss the implications of this finding and compare our data with similar data on the heavy-fermion superconductor CeIrIn5.

We-S37-IT1 / Vortex Lattice Anisotropy and Pairing Symmetry of Sr_2RuO_4

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Abstract

Despite intense studies the exact nature of the order parameter in superconducting Sr2RuO4 has remained elusive. Multiple experimental and theoretical studies provide compelling support for triplet pairing and an odd-parity, p-wave order parameter symmetry. At the same time, seemingly contradictory experimental results have left important open questions concerning the detailed structure and coupling of the orbital and spin parts of the order parameter. One example of this predicament is conflicting evidence as to whether the p-wave order parameter is chiral.

Here we present the results of extensive small-angle neutron scattering studies of the vortex lattice in Sr2RuO4 with the field applied close to the crystalline basal plane. Taking advantage of the transverse magnetization in this highly anisotropic superconductor, it is possible measure the vortex lattice anisotropy as a function of the field angle. From the measurements we were able to determine the intrinsic superconducting anisotropy between the c-axis and the Ru-O basal planes (~60), which greatly exceeds the upper critical field anisotropy (~20) at low field and temperature. In addition the field and temperature dependence of the anisotropy was explored. Our results impose significant constraints on possible models of triplet pairing in Sr2RuO4 and raises questions concerning the direction of the zero spin projection axis.

This work was supported by the US Department of Energy, Basic Energy Sciences under Awards No. DE-FG02-10ER46783.

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We-S37-IT2 / On the superconducting instabilities of metals near quantum critical points

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Abstract

We study the dynamics of a metal near a quantum critical point. We study both the intermediate regime where the Landau damping of the boson can be neglected and the strongly overdamped regime where the order parameter is strongly Landau damped. Using renormalization group and large N analyses, we consider controllable regimes in which superconducting instabilities are enhanced near continuous quantum phase transitions. We present renormalization group treatments of singular enhancement of superconductivity in the Cooper channel due to the exchange of a gapless (critical) order parameter field. The resulting log-squared and higher order divergences are treated in systematic fashion. We also discuss regimes in which superconductivity may develop out of a normal state with ill-defined quasiparticles.

We-S38-IT1 / Nodal superconductivity in quasi-one-dimensional $K_2Cr_3As_3$

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Abstract
The newly discovered quasi-one-dimensional superconductors A2Cr3As3(A=K, Rb, Cs) possess a unique crystal structure, which consists of quasi-one-dimensional double-walled tubes of [Cr3As3]2- along the c axis and lacks an inversion symmetry [1]. Unconventional features of superconductivity were inferred from the enhanced specific heat coefficient, the linear temperature dependence of the electrical resistivity above Tc and the huge upper critical field [Bc2(0)≈31.2 T] [1]. Thus, A2Cr3As3 may belong to a new family of unconventional superconductivity. In this presentation, we study the superconducting gap structure of K2Cr3As3 by precisely measuring the temperature dependence of the change in the penetration depth $\Delta\lambda(T)$ using a Tunnel Diode Oscillator [2]. Instead of the exponential behavior of conventional superconductors, $\Delta\lambda(T)$ of K2Cr3As3 shows a linear behavior for T<<Tc, indicating the existence of line nodes in the superconducting gap. Possible pairing states will be discussed in terms of the fits of the superfluid density $\rho s(T)$. Our results demonstrate strong evidence for unconventional behavior and may provide key information for identifying the pairing state of this novel superconductor.

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We-S39-IT1 / Vortex pinning in iron based superconductors

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Abstract
Pinning properties of Fe-based superconductors (FBS) have been widely studied in the recent years in particular in the LnFeAs(O,F), AEFe2As2 and Fe(Se,Te) phases. The most tunable FBS in terms of acceptance of high densities of secondary phases capable of acting as effective pinning centers is Ba(Fe1-xCox)2As2 (Ba122). Despite its high density of defects, the superconducting matrix properties are not suppressed and, differently from REBCO, no Tc decrease has been observed. In Ba122 self-assembled Ba-Fe-O nanorods generate a strong correlated pinning along the c-axis, enhancing the critical current density, Jc, in this direction and reducing the Jc anisotropy [1, 2]. However, when 20% of secondary phases are introduced, the reduction of the superconducting cross-section becomes significant, decreasing low-field Jc. To better control the defect density, artificially introduced pinning centers can be added by multilayer deposition [2] allowing an almost isotropic increase of Jc. Moreover it has been demonstrated that FBS are very sensitive to strain that can induce a significant Tc enhancement. In Ba122 the strain induced by the substrate improves Jc of both single and multilayer films by more than expected for the Tc increase alone. The pinning force density, Fp, reaches a maximum of 84 GN/m3 at 22.5T and 4.2 K in a multilayer Ba122 film grown on CaF2. This is the highest value ever reported in any 122 phase and it shows that the in-field performance of Ba122 widely exceeds that of Nb3Sn, potentially making FBS of interest for applications.
Although very little has been reported on the introduction of artificial pinning in the LnFeAs(O,F) phases, these materials are in principle of even greater potential because of their higher Tc. Studying single layer thin films, we found changes of the pinning mechanisms both with field and temperature. Fp maximum occurs above 45T and reaches more than 300 GN/m3 for H//ab in both the Sm [4] and Nd [5] cases, whereas Fp(4.2K) reached 60 GN/m3 at 27.5 T for Sm1111 and 38 GN/m3 for Nd1111 for H//c. At present, the larger Jc anisotropy of the LnFeAs(O,F) phases is an obvious drawback for applications.
Work made in collaborations between ASC-National High Magnetic Field Laboratory and University of Wisconsin-Madison, University of Michigan, Institute for Metallic Materials - IFW, Tokyo University of Agriculture and Technology, Central Research Institute of Electric Power Industry, Nagoya University.

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We-S40-IT1 / Impact of charge order on the electronic properties of underdoped cuprates

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Abstract
Over the last years, quantum oscillation measurements [1] have shown that the Fermi surface of underdoped cuprates suffer a drastic modification compare to the large hole-like cylinder observed in the overdoped side [2]. Many studies such as NMR measurements [3], x-ray scattering [4] point to a reconstruction of the Fermi surface due to charge order. Fermi-surface reconstruction and charge density wave modulations are two universal signatures of underdoped cuprates, which begs the following questions: what is the impact of charge order on the electronic properties of underdoped cuprates ? Is the Fermi surface seen by quantum oscillations compatible with a reconstruction by CDW modulations?
In this talk, I will present new thermodynamic and transport measurements in underdoped YBa2Cu3Oy and HgBa2CuO4+δ performed in high magnetic fields demonstrating that a phase transition takes place at low temperature in both compounds. Detected unambiguously in the temperature dependence of the sound velocity in some acoustic modes, this phase transition strongly affects the in-plane conductivity. Compelling evidence that the Fermi surface of YBCO is reconstructed by the CDW order detected by x-ray diffraction comes from our recent discovery of an additional small hole-like pocket in quantum oscillations measurements [5]. The consistency between our quantum oscillation measurements and models of Fermi-surface reconstruction by the CDW order will be discussed.

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Part of the work has not yet been published.

We-S40-IT2 / Optical evidence of broken C4 symmetry across optimal doping in $BaFe_2As_{1-x}P_{x2}$

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Abstract
The isovalently-doped high-T_{c} superconductor BaFe$_2$(As$_{1-x}$P$_x$)$_2$ is characterized by a rich temperature-doping phase diagram, which includes structural, antiferromagnetic, and superconducting phase transitions. In this work, we use photomodulated reflectance at 1.5 eV to detect the onset of linear birefringence in the normal state, and by inference, the breaking of 4-fold rotational (C$_4$) symmetry. We find that C$_4$ breaking takes place in the normal state over a range of x that spans the optimal P concentration, unlike the line of orthorhombic-tetragonal and magnetic phase transitions, which terminates at, or just below, the optimal value of x..

Th-S41-IT2 / Charge ordering in electron-doped cuprates

Eduardo H. da Silva Neto[1], Riccardo Comin[1], Feizhou He[2], Ronny Surtarto[2], Yeping Jiang[3], Richard Greene[3], George Sawatzky[1], Andrea Damascelli[1]
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Abstract
In cuprate high-temperature superconductors, an antiferromagnetic Mott insulating state can be destabilized toward unconventional superconductivity by either hole- or electron-doping. Following the early discoveries of stripe-like order in La-based cuprates [1,2], charge ordering (CO) instabilities were proven to be omnipresent in all hole-doped cuprate families [3-7]. However, the lack of evidence for CO in the electron-doped materials put in question the universality of charge ordering to the cuprates.
Here I will present resonant x-ray scattering (RXS) measurements that demonstrate for the first time the presence of charge ordering in the electron-type cuprate Nd2-xCexCuO4 (NCCO) near optimal doping [8]. Remarkably, the CO in NCCO occurs with similar periodicity, and along the same direction, as the CO in p-type cuprates. In contrast to the latter, the CO onset in NCCO is higher than the pseudogap temperature, and is actually in the same temperature range where antiferromagnetic fluctuations are first detected – thereby showing that CO and antiferromagnetic fluctuations are likely coupled in electron-doped cuprates. Beyond the already published results [8], new doping-dependent measurements of different families of electron-doped cuprates - and their connections to quantum oscillation and transport studies - will also be discussed.

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Th-S41-IT3 / Spontaneous Loop Currents and Incommensurate Charge Order in Three-Band Models of Cuprate Superconductors

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Abstract
Widespread experimental evidence has accumulated for charge order in hole and even electron doped cuprates. For hole doped materials, also time reversal symmetry breaking has been observed in the same doping range. Motivated by these experimental facts, we explore charge and current instabilities in three-band models of CuO2 planes. In our unbiased calculation of the charge and the current susceptibilities, charge instabilities and spontaneous current patterns can develop, and either one can be the leading instability depending on the choice parameters. The current instability is driven by the Coulomb interactions between Cud and Op orbitals, and it occurs at the wavevector (π,π). Surprisingly, the identified loop current order involves all Cu-O and O-O bonds, and the direction of the currents alternates between the adjacent unit cells. The charge order is driven by the Coulomb interaction between Op orbitals, and its ordering wavevector is (i) incommensurate with the underlying lattice and (ii) oriented along the Brillouin zone diagonal, which contradicts experimental findings. However, the ordering wavevector changes to axial direction if the charge order emerges from a phase with staggered order and the concomitant reconstructed Fermi surface. In this case, the charge ordering wavevector is found to connect the hole pockets of the reconstructed Fermi surface, and its magnitude, direction, and doping dependence thereby match the experimental results [1]. Hence, this result may clarify the discrepancy between many recent theoretical calculations and the experiments. We explore the possibility that the obtained staggered loop current order is the source for the time reversal symmetry breaking and the observed axial charge order.

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Th-S41-IT1 / NMR studies of charge order in YBa_2Cu_3Oy

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Abstract
In 2011, the NMR discovery that superconductivity competes, and coexists, with charge-density-wave (CDW) order in YBa2Cu3Oy was argued to strongly support the, hitherto controversial, view that underdoped cuprates are generically unstable towards CDW formation [1]. While this affirmation is now unanimously accepted, the exact nature of the CDW is not. In this talk, I will discuss insights into charge order from our NMR studies [1-4] in both the normal and superconducting states of YBa2Cu3Oy.
Work performed with T. Wu, M. Hirata, I. Vinograd, R. Zhou, H. Mayaffre, S. Krämer, M. Horvatić, C. Berthier (LNCMI Grenoble), P.L. Kuhns & A.P. Reyes (NHMFL, Tallahassee, USA), W.N. Hardy, R. Liang & D. A. Bonn (University of British Columbia, Vancouver, Canada).

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Th-S42-IT2 / Identifying the superconductivity mechanism and pairing gap in iron based superconductors by scanning tunneling spectroscopy

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Abstract
The pairing mechanism and gap structure in the iron pnictides remains unresolved yet. We have conducted low temperature and high magnetic field scanning tunneling spectroscopy (STS) study on the Ba1-xKxFe2As2, Na(Fe1-xTx)As (T=Co, Cu, Mn) and KFe2As2 single crystals. First, we show the clear evidence of the in-gap quasi-particle states induced by the non- or very weak magnetic Cu impurities in Na(Fe0.97-xCo0.03Cux)As by measuring the scanning tunneling spectroscopy, giving strong evidence of the S± pairing[1]. Furthermore, we show the presence of the bosonic mode[2,3] with the energy identical to that of the neutron resonance with a simple linear relation W/kBTc » 4.3. This mode can also be explained very well as the consequence of the S± pairing. Recently we accomplished the STS measurements on the KFe2As2 and discovered a huge peak at about -4 meV on the STS below and above Tc. After a detailed analysis, we conclude that this peak is induced by the Von Hove singularity[4] and explains many interesting features in this interesting material. Our data together with the ARPES data can give a very strong constraint on the pairing gap function. These observations strongly suggest that the antiferromagnetic spin fluctuation is the key factor for superconductivity.
In collaboration with: Huan Yang, Zhenyu Wang, Delong Fang, Lei Shan, Qiangua Wang, Chenglin Zhang, Pengcheng Dai, and Hong Ding, Jiangping Hu and Pierre Richard et al..

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Th-S42-IT1 / Strong and local pairing in iron-based superconductors as seen by photoelectrons

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Abstract
Iron-based superconductors (FeSCs), with their highest Tc at 57K, have been added since 2008 to the family of high-Tc superconductors which has been solely occupied by cuprate superconductors for more than 20 years. In this talk I will report our extensive ARPES results on FeSCs, which demonstrate unequivocally that a strong pairing gap is mainly determined by its location in the momentum space, basically following a coskxcosky function which is likely determined by the local next-nearest-neighboring antiferromagnetic super-exchange J2, in much the same way that the d-wave gap of cuprates is caused by its nearest-neighboring exchange J1. In the example of Li(Fe,Co)As, the low-energy spin fluctuations, while sensitive to the Fermi surface nesting condition, are found not directly tie to its superconductivity. Instead the strong pairing was found to even exist in an insulting hole band. We conclude that the same pairing mechanism, at least phenomenologically, must be in work for both FeSCs and cuprates.

Th-S43-IT2 / Electron Pairing Without Superconductivity

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Abstract
Strontium titanate (SrTiO3) is the first and best known superconducting semiconductor. It exhibits an extremely low carrier density threshold for superconductivity, and possesses a phase diagram similar to high-temperature superconductors—two factors that suggest an unconventional pairing mechanism. Despite sustained interest for fifty years, direct experimental insight into the nature of electron pairing in SrTiO3 has remained elusive. Here we perform transport experiments with nanowire-based quantum dots localized at the interface between SrTiO3 and a thin layer of LaAlO3. Electrostatic gating of the quantum dot reveals a series of two-electron conductance resonances—paired electron states—that bifurcate above a critical magnetic field Bp~1-4 Tesla, an order of magnitude larger than the superconducting critical magnetic field. For $B<B_p$, these resonances are insensitive to applied magnetic fields; for $B>B_p$, the resonances exhibit a linear Zeeman-like energy splitting. Electron pairing is stable at temperatures as high as T=900 mK, far above the superconducting transition temperature (Tc~300 mK). These experiments demonstrate the existence of a robust electronic phase in which electrons pair without forming a superconducting state. Key experimental signatures are captured by an attractive-U Hubbard model that describes real-space electron pairing as a precursor to superconductivity.

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Th-S43-IT1 / Superconductivity and magnetism in SrTiO3/LaAlO3 probed by transport through nanowires

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Abstract
Resistance as a function of temperature down to 20 mK and magnetic fields up to 18 T for various carrier concentrations is measured for nanowires made from the SrTiO3/LaAlO3 interface using a hard mask shadow deposition technique. The narrow width of the wires (of the order of 50 nm) allows us to separate out the magnetic effects from the dominant superconducting ones at low magnetic fields. At this regime hysteresis loops are observed along with the superconducting transition. From our data analysis, we find that the magnetic order probed by the giant magnetoresistance effect vanishes at TCurie=954±20 mK. This order is not a simple ferromagnetic state but consists of domains with opposite magnetization having a preferred in-plane orientation.

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Th-S44-IT1 / Superconductor-Insulator Transitions and Related Problems

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Abstract
I will provide a review of the current state of a theory of strongly disordered amorphous superconductors close to the quantum transition to an insulating state. I will discuss three major scenario for superconductivity suppression by disorder: (a) Coulomb-to-Josephson energy competition in granular arrays, (b) suppression of Cooper attraction due to disorder-induced revival of inter-electron Coulomb interaction, and (c) competition between superconducting correlations and Anderson localization. I will demonstrate that the most appropriate description of the data for amorphous highly resistive materials characterized by low density of conduction electrons is given by the scenario (c).
I will give basic points of a theory [1,2] corresponding to scenario (c) of superconductivity suppression and its qualitative predictions for two regimes: “fractal superconductivity” and “pseudo-gaped superconductivity”. The former regime is realized when Fermi-level nearly coincides with the mobility edge, the latter on the localized side of the Anderson transition relatively close to the transition point. I will show the data [4] that borne out the theoretical predictions for these two regimes. In particular I will discuss an nature of single-particle excitations and collective excitations in the superconducting state, and show that only one type (longitudinal mode) of collective excitations is observable in relatively thick ($d > \xi$) films. In contrast, the transverse mode is pushed to very high energies due to Higgs-Anderson mechanism. Finally, I will discuss the nature of disorder-induced quantum phase transition [3,5] from the pseudo-gaped superconductivity to the “paired insulator” state.

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Th-S44-IT2 / Tunneling spectroscopy of localized preformed Coopers pairs in highly disordered superconducting Indium oxide films

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Abstract
We have performed tunneling spectroscopy on superconducting indium oxide films in the vicinity of the disorder-driven superconductor-insulator transition. Tunneling spectroscopy highlights a pseudogap regime above the critical temperature Tc which is the signature of preformed Cooper pairs. It evolves at low temperature into an inhomogeneous superconducting system due to spatial fluctuations of the disorder at the mesoscopic scale. These preformed Cooper pairs can locally remain localized at zero temperature. We showed that the absence of BCS coherence peaks at the gap edges in the local one particle density of states is the signature of these localized Cooper pairs [1]. Besides, using our STM, we have continuously analyzed the local conductance between the tunneling regime and the point-contact regime. In the latter, Andreev spectroscopy reveals a new energy scale related to the quantum coherence energy and independent from spatial fluctuations of the pairing energy [2].

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Th-S45-IT1 / Classification of topological surface states in nodal superconductors

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Abstract
Topological superconductors have become a subject of intense research due to their potential use for technical applications in device fabrication and quantum information. Besides fully gapped superconductors, unconventional superconductors with point or line nodes in their order parameter can also exhibit nontrivial topological characteristics. In this talk, I review recent progress in the theoretical understanding of nodal topological superconductors, with a focus on the classification of reflection-symmetry-protected nodal superconductors. Using selected examples, the bulk topological properties and the surface states of these systems are discussed. Furthermore, I survey some candidate materials for topological superconductivity, such as CePt$_3$Si, and discuss different experimental signatures of topological surface states.

Th-S46-IT2 / Fractional flux quantization in loops of unconventional superconductors

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Abstract
The magnetic flux threading a conventional superconducting ring is typically quantized in units of the flux quantum hc/2e. The factor of 2 in the denominator originates from the existence of two different types of pairing states with minima of the free energy at even and odd multiples of the flux quantum. Here we show that spatially modulated pairing states exist with energy minima at fractional flux values, in particular, at multiples of half a flux quantum [1]. In such states, condensates with different center-of-mass momenta of the Cooper pairs coexist. The proposed mechanism for fractional flux quantization naturally applies to pair-density wave states. These concepts are discussed in the context of cuprate superconductors, for which hc/4e flux periodicities have been detected [2].

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Th-S46-IT1 / New light on the subgap states seen by STM in YBa2Cu3O7-d

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Abstract
The interaction responsible for high-temperature superconductivity in the cuprates has remained elusive until now. Various charge orders suggest that the electronic matter in these compounds experiences competing interactions, while some spectroscopic data support the scenario of preformed pairs gaining coherence at low temperature. The vortices offer a chance to disentangle the spectral features related to pairing from those that are unrelated. In this context, the observation of discrete low-energy states in the vortex cores has been a considerable challenge for the theory, because the expected tunneling spectrum in a vortex of dx2-y2 symmetry presents a broad continuous maximum centered at zero bias. We performed high-resolution STM measurements in optimally doped YBa2Cu3O7-d single crystals, and found that the low-energy states are not exclusively bound to vortices. This spectral feature is ubiquitous in zero field, even in spectra without superconducting coherence peaks. The new phenomenology reshuffles the cards for the theory of vortex cores.

Th-S47-IT2 / Fermi surface deformation in a simple iron-based superconductor, FeSe

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Abstract
One of the outstanding problems in the field superconductivity is the identification of the normal state out of which superconductivity emerges. FeSe is one of the simplest and most intriguing iron-based superconductors, since in its bulk form it undergoes a structural transition before it becomes superconducting, whereas its single-layer form is believed to be a high-temperature superconductor. The nature of the structural transition, occurring in the absence of static magnetism, is rather unusual and how the electronic structure is stabilized by breaking of the rotational symmetry is the key to understand the superconductivity in bulk FeSe. Here we report angle-resolved photoemission spectroscopy measurements on FeSe that gives direct access to the band structure and orbital-dependent effects. We complement our studies on bulk FeSe with low-temperature angular-dependent quantum oscillation measurements using applied magnetic fields that are sufficiently strong to suppress superconductivity and reach the normal state. These studies reveal a strong deformation of Fermi surface through the structural transition driven by electronic correlations and orbital-dependent effects.

References
This work was supported by EPSRC, UK (EP/I004475/1), Diamond Light Source, UK and HFML, Nijmegen.

Th-S47-IT1 / Correlations and magnetism in iron superconductors: Hund's coupling and orbital differentiation

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Abstract
The strength and nature of correlations in iron superconductors have been discussed since their discovery in 2008. Different proposals describe iron superconductors in terms of weakly correlated electrons, localized spins or the combination of weakly and strongly correlated electrons. The strength of interactions controls the origin of magnetism which has been described in terms of a Fermi surface induced spin density wave, exchange interactions between localized spins and double-exchange like models [1]. Due to their multi-orbital character, correlations in iron superconductors are strongly affected by Hund's coupling and these materials have been classified as Hund metals. For a long time there has been a strong controversy on the nature of correlations induced by Hund's coupling and its relation to Mott physics. While some authors describe Hund metals as strongly correlated systems which are not in proximity to a Mott insulating state, others, have described iron superconductors as doped Mott insulators[2]. Recently we have clarified the nature of correlations in Hund metals and the relationship between Hund's correlations and Mott physics[3]. On the basis of these results, in this talk I will discuss the nature and origin of correlations in iron superconductors and their effect on the magnetic state

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Th-S48-IT1 / Using High Magnetic Fields to Study Cuprate Superconductivity and – conversely – Using Cuprate Superconductors to Generate High Magnetic Fields

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Abstract
This talk surveys the cuprate phase diagram from the perspective of twenty years of magnetotransport in LSCO, Bi-2201, and YBCO using intense magnetic fields. These experiments – the collective work of many groups – provide evidence of a quantum critical point near optimum doping in the resistive state. We then focus on our own electronic specific heat, Celec , measurements of underdoped YBCO and discuss constraints they impose on any model of the underdoped regime. [1] Our latest results on samples near 1/8 doping find two magnetic field regimes in the low temperature limit: below a characteristic magnetic field H′ ≈ 12T, Celec/T obeys the H1/2 behavior expected of a d-wave superconductor; however, near H′ there is a sharp inflection followed by a linear-in-H behavior. [2] We note that H′ rests deep within the zero-resistance superconducting phase and ascribe it to a magnetic-field-driven quantum phase transition. We conclude with a survey of new magnet technologies and applications that we believe will be enabled by high-temperature superconductors.

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Th-S48-IT2 / Whither Superconductivity for Electric Power?

Paul Grant
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Abstract
As we encounter the 27th year following the historic 1988 M2S conference "over the hill" in Interlaken, two issues remain for the future: 1) Is the pairing mechanism primarily "shakes or spins," and 2) when will the Bednorz-Mueller discovery enable the electricity enterprise of the future? Both are cosmic. In this talk, we will address both, the first very, very briefly in the context of DFT models of phonon mediated pairing (for more, see our poster submission), and the second in much more detail, reviewing past and current efforts worldwide, and compelling opportunities to surface in the future, especially related to dual use of emerging worldwide natural gas pipeline rights-of-way to transport both chemical and electronic energy resources to sustain the human condition.

Th-S49-IT2 / On the spectral features of the in-gap states in cuprate high temperature superconductors

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Abstract
Leaving aside the so-far unresolved question of what causes pairing in the cuprate High Temperature Superconductors, we address their features on thebasis of fundamental physical principles, related to basic symmetries which encode the intrinsic crystalline metastability of those systems. In such an approach, their high temperature parent state represents a metastable highly polarizable infinitely degenerate quantum vacuum in hich itinerant electrons move in a self-induced locally fluctuating environment. They thereby get momentarily aptured in form of diamagnetic bound spin-singlet bonds on spontaneously fluctuating olecular clusters, which nvolve pairs of Cu ions linked together by a bridging O in the CuO_2 planes, which fluctuates in and out of this lane. As a consequence, electrons manifest themselves simultaneously as (i) ocalized diamagnetic spin-singlet bound states having a finite fluctuating amplitude and as (ii) pairs of unbound lectrons, momentarily traversing such fluctuating molecular clusters. The high temperature parent state thereby cquires features of an electronic magma in which bound diamagnetic electron-pairs pop in and out of existence n the back-ground of a Fermi-sea of itinerant electrons. We encode this physics in terms of a single free parameter phenomenological Boson Fermion Model, characterized by a Feshbach resonance coupling g between unbound and localized bound electron-pairs on fluctuating molecular clusters. This model accounts for (i) the onset of a pseudo-gap phase below some T*, when a local symmetry breaking locks the bound and the unbound electron-pairs in a quantum superposition which breaks the translational as well as rotational lattice symmetry and (ii) an n evolution of the pseudo-gap with decreasing temperature which smoothly gets empted out of the spectral weight f in-gap states, as it traverses the superconducting transition. The spectral properties of the in-gap states, escribing non-Fermi-liquid excitation, are characterized by branch-cut rather than single pole singularities, as our atest Renormalization group approach study confirm or initial speculations (PRL-1995) of it.

Th-S49-IT1 / Optical Study of Unusual Insulator-Superconductor Transition

Setsuko Tajima, Ece Uykur, Kiyohisa Tanaka, Takahiko Masui, Shigeki Miyasaka
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Abstract
To investigate the optical spectral weight and its transfer behavior is a powerful method to understand the electronic state. In the present work, the precise T-dependences of c-axis polarized optical spectra were studied for Zn-doped YBa2Cu3Oy over a wide range of oxygen and Zn-contents. There were two important findings. One is that the pseudogap persists even below Tc[1], which implies the coexistence of superconductivity and the competing order below Tc. The other finding is that a precursor of superconductivity persists up to very high temperatures above Tc (but lower than the pseudogap temperature T*)[2]. It indicates the coexistence of two orders also above Tc.
The temperature for precursor of superconductivity (Tp) increases with underdoping, which is similar to the behavior T*. This suggests that as the system approaches a Mott insulator the pairing interaction becomes stronger but the simultaneously developed competing order (pseudogap) suppresses superconductivity. Although these two (superconductivity and pseudogap) are distinct orders, they may originate from the same interaction (strong correlation with large U).
In the very underdoped regime near the boundary to insulator, carrier density is very low but Tp is very high, which suggests the system is close to the BEC-BCS crossover.
This work was supported by a Grant-in-Aid of for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan. (No.19204038 and No.24340083)

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Th-S50-IT1 / Enhancement of superconductivity near a nematic quantum critical point

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Abstract
The effect of near-critical nematic fluctuations on superconducting pairing is analyzed in a controlled weak coupling limit. The most important qualitative findings are that such fluctuations enhance superconducting pairing in all pairing channels, the enhancement is comparably strong in the symmetric and nematic phases, and it is stronger in 2d than in 3d. In this sense, nematic order is the ideal "helper" order for superconductivity. Thus, under a broad range of circumstances, even when nematic fluctuations are not the primary driver of superconductivity, optimal conditions for superconductivity may be tied to the existence of a nematic quantum critical point. It is also stressed that, in contrast with most other critical phenomena involving patterns of spatial symmetry breaking, a nematic quantum critical point survives in the presence of quenched disorder up to a (potentially substantial) critical value.

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Th-S50-IT2 / Glide Plane Symmetry and η-Pairing for a Fe-pnictide layer

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Abstract
This talk will discuss the implications of the glide plane symmetry of a single Fe-pnictide/chalcogen plane on the structure of the superconducting gap. It will show that "η-pairing" with non-zero total momentum occurs when there is orbital weight at the Fermi level from orbitals with even and odd mirror reflection symmetry perpendicular to the Fe-layer. It is shown that the superconducting gap function, which appears in observable quantities, is identical to that found in 1 Fe per unit cell pseudo-crystal momentum calculations. Finally, it will discuss microscopic calculations of the gap structure that show that η-pairing is an important ingredient in the superconducting condensate and that it contributes with the usual even parity symmetry in band space and that time reversal symmetry is preserved.

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Fr-S51-IT1 / ARPES studies of low energy excitations in cuprate superconductors

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Abstract
Angle-resolved photoemission spectroscopy (ARPES) measures electronic structure in momentum-space and is a powerful tool for investigating quantum materials, including the cuprate high temperature superconductors. ARPES has made many contributions to our understanding of these compounds, including helping to elucidate the superconducting order parameter. A recent development in the technique involves using a narrow-bandwidth UV laser as a light source, and the superior energy and momentum resolution of laser-ARPES provides unprecedented access to the lowest lying excitations relevant to ground state properties. In the superconducting state of cuprates, the lowest energy excitations are found at the node where the superconducting order parameter is zero. We have studied the components of the nodal Fermi velocity both tangential to and perpendicular to the Fermi surface at the node using laser ARPES, and the measured doping dependencies of these quantities challenge earlier data. These results have implications for interpreting low-temperature thermodynamic and transport experiments and for understanding the cuprate phase diagram in terms of low energy excitations.

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Fr-S51-IT2 / Three-Dimensional Charge Density Wave Order in YBa2Cu3O6.67 at High Magnetic Fields

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Abstract
Charge density wave (CDW) correlations have recently been shown to universally exist in cuprate superconductors. However, their nature at high fields inferred from nuclear magnetic resonance [1] is distinct from that measured by x-ray scattering at zero and low fields [2,3]. Here we combine a pulsed magnet with an x-ray free electron laser to characterize the CDW in $YBa_2Cu_3O_{6.67}$ via x-ray scattering in fields up to 28 Tesla [4]. While the zero-field CDW order, which develops below T ~ 150 K, is essentially two-dimensional, at lower temperature and beyond 15 Tesla, another three-dimensionally ordered CDW emerges. The field-induced CDW onsets around the zero-field superconducting transition temperature, yet the incommensurate in-plane ordering vector is field-independent. This implies that the two forms of CDW and high-temperature superconductivity are intimately linked.

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Fr-S52-IT1 / Cubic H3S around 200 GPa: an atomic hydrogen superconductor stabilized by sulfur

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Abstract
The multiple scattering-based theory of Gaspari and Gyorffy for the electron-ion matrix element in close packed metals is applied to bcc Im-3m structure hydrogen sulfide H_3S, one compound in the H-S system that has been predicted by Duan et al. and Bernstein et al. to be the stable phase at this stoichiometry around 190 GPa, thus is the leading candidate to be the phase observed to superconduct at 190K by Drozdov, Eremets, and Troyan. The nearly perfect separation of vibrational modes into those of S and of H character provides a simplification that enables identification of contributions of the two atoms separately. The picture that arises is pairing due to electron-phonon coupling, with coupling strength lambda of ~2 but with extremely high H vibrational frequencies. At the most basic level, H_3S is superconducting atomic H stabilized by strong covalent mixing with S 3p and 3d character. The evolution with pressure of the various contributions (H 1s, S 3p, S 3d) to the electron-ion scattering that drives pairing will be presented, and relevant aspects of the phonon spectrum will be discussed. The H isotope effect evaluated in the harmonic approximation differs from the experimental value of Drozdov et al., suggesting the likelihood of strong anharmonicity in this superconductor. Given the relative unimportance of sulfur, hydrides of lighter atoms at similarly high pressures may also lead to high temperature superconductivity. Comparision will be made with another classic anharmonic superconducting hydride, PdH.

References
This work has just been submitted for publication.

Fr-S52-IT2 / Superconductivity and structural studies of highly compressed hydrogen sulfide

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Abstract
Superconductivity above 190K was reported in the highly compressed hydrogen sulfide [1]. The superconducting “material” was found to be synthesized by pressure above 90 GPa by the dissociation of hydrogen sulfide. Here we report the crystal structure at the superconducting phase by the synchrotron x-ray at room temperature and low temperature.
H_2S and D_2S were compressed up to 160 GPa in diamond anvil cells and cooled down from room temperature to 10 K in the cryostat for X-ray diffractometer in SPring-8. The resistivity was monitored at all cooling process. The critical temperature and zero resistivity were confirmed and the collected X-ray diffraction data in both cells showed good agreement with the theoretically predicted structures of R3m and Im-3m [2]. No structural transition was observed at temperature from 10 K to room temperature.
This work was supported by JSPS KAKENHI Grant Number 26000006 and the European Research Council 2010-Advanced Grant 267777.

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Fr-S53-IT2 / Electron-Phonon mechanism for superconductivity at a LaAlO3-SrTiO3 interface

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Abstract
The interaction between electrons and longitudinal optical phonons has been invoked to explain superconductivity in bulk strontium titanate by Takada [1]. In the present work, we investigate the role of the electron-phonon coupling in the occurrence of surface superconductivity at the interface between lanthanum-aluminum oxide and strontium titanate (LAO-STO). For polar crystals with sufficiently high optical-phonon frequencies and/or low carrier densities such as strontium titanate, the conditions for the Migdal theorem are not fulfilled. Therefore we use the dielectric function method [2] to treat the superconductivity caused by the electron-phonon interaction with polar optical phonons. We reformulate this method for a multilayer structure with several polar layers [3]. In these structures, the electrostatic electron-electron interaction, the optical-phonon spectra, and the amplitudes of the electron-phonon interaction are strongly modified compared to those in bulk. For the calculations, we use well-established material parameters without fitting, except for the acoustic deformation potential of strontium titanate, for which the values reported in the literature show a considerable spread. Our calculation [3] yields critical temperatures within the same range as the experimental data [4]. Even taking into account the apparent uncertainty of the present experimental results for the critical temperatures and the uncertainty of the published values of the acoustic deformation potential, the suggested theoretical explanation of the superconducting phase transition in a quasi 2D electron gas at a LAO-STO interface is a plausible interpretation. The present study calls for further experiments leading to a reliable value of the acoustic deformation potential and to more precise critical temperatures for different densities.
This work was supported by the Flemish Research Foundation (FWO-Vl), project nrs. G.0370.09N, G.0180.09N, G.0115.12N, G.0119.12N, G.0122.12N and by the Scientific Research Network of the Research Foundation-Flanders, WO.033.09N, and by the Research Council of Antwerp University, project DOCPRO 2014 - 29778.

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Fr-S53-IT1 / Scanning SQUID Imaging of SrTiO3 Heterostructures

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Abstract
KA Moler1, C Aruta4, C Bell1 8, JA Bert1, E Di Gennaro4, F Miletto Granozio4, Y Hikita1, M Hosodo1 2, HY Hwang1, H Inoue1, R Jany5, A Kajdos6, B Kalisky1 7, M Kim1 2, JR Kirtley1, BB Klopfer1, J Mannhart3, H Noad1, KC Nowack1, G Pfanzelt3, C Richter5, AJ Rosenberg1, HK Sato1 2, EM Spanton1, S Stemmer6, F Tafuri4, US Uccio4, C Watson1, C Woltmann3, Y Xie1 1 SLAC and Stanford University, United States of America. 2 University of Tokyo, Japan. 3 Max Planck Institute for Solid State Research, Germany. 4 CNR-SPIN, Italy. 5 University of Augsburg, Germany. 6 UCSB, United States of America. 7 Bar Ilan University, Israel. 8 University of Bristol, United Kingdom The potential of oxide interface engineering was famously demonstrated by the appearance of conductivity at the {001} interface of the band insulators LaAlO3 (LAO) and TiO2-terminated SrTiO3 (STO). We used scanning superconducting quantum interference devices (SQUIDs) to image magnetic fields from this interface and other complex oxide heterostructures, mapping several physical phenomena. DC measurements show sparse patches of static ferromagnetism. Low-frequency AC measurements of the shielding response to locally applied magnetic fields allow us to map superconductivity and paramagnetism, identifying samples with fairly uniform superfluid density. The superfluid density is consistent with a single gap and is not affected by the presence of isolated magnetic patches. Measurements of the magnetic field produced by transport current flowing in LAO/STO and related interfaces allowed us to map spatial variation in the current flow. We find that the local conductivity is also modified by the STO tetragonal domain structure. In SrTiO3 samples, the superfluid density is noticeably modified by the twin domains of the SrTiO3. In this talk I will speculate on the origins of the interplay between structural domains, conductivity, and superconductivity.

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Fr-S54-IT2 / From BCS to brand new forms of superconductivity with holography

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Abstract
Strongly correlated systems have a remarkable holographic reformulation in terms of Einstein's general relativity in an anti-de Sitter spacetime. These systems have a very natural connection with quantum critical phenomena, that are thought to explain the phenomenology of the strange metal phase in high Tc superconductors. I will discuss the range of superconducting phenomena that the holographic reformulation of correlated systems reveals. To benchmark, the starting point will be a holographic description of ordinary Cooper-pairing and its phenomenology. However, in holography pairing-induced superconductors are only part of a far wider novel class of so-called holographic superconductors that form a natural extension of BCS-theory. Holography also indicates that these ordered phases go hand-in-hand with a companion "(semi-)local quantum critical phase" --- systems with a very high dynamical critical exponent. These are a manifestion of Anderson's idea of intermediate fixed points. At each stage I will discuss novel phenomenological features that arise in macrocopic observables.

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Fr-S54-IT1 / Incoherent Strange Metals and Superconductivity

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Abstract
Transport in Bad Metals challenges weakly interacting quasiparticle descriptions of physics. Furthermore, different classes of bad metals exhibit unexpectedly similar transport behavior. I suggest that this "universal incoherent" bad metal transport can be understood starting from a certain universal bound on charge and heat diffusivities.
The cuprate high temperature superconductors are especially important examples of bad metals. Transport in the most puzzling, strange metal, part of the cuprate phase diagram is characterized by multiple scaling laws. I will show that at least five of these scaling laws can be understood from only two nontrivial critical exponents. One of these is the usual dynamical critical exponent whereas the other is an anomalous dimension for the charge density operator.
This talk shows what predictive physics without quasiparticles can look like. The ideas are inspired by properties of black hole horizons that can be related to strongly correlated electron systems through holographic duality.

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Fr-S55-IT1 / Charge Order and Superconductivity in Low-Dimensional Organic Conductors

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Abstract
Some of the two-dimensional quarter-filled BEDT-TTF salts are superconductors, while some of them remain metallic down to low temperatures; others undergo a sharp metal to insulator transition. Why do these materials behave electronically so differently although they are similar in structure? Optical spectro¬scopy reveals that these compounds are subject to charge order to a different degree. The interplay of charge order and superconductivity suggest superconductivity mediated by charge order fluctuations.
We present infrared and THz investigations on these two-dimensional organic metals with a quarter-filled conduction band, in particular 5 K superconductor β"-(BEDT-TTF)2SF5CH2CF2SO3. Raman and infrared measurements indicate a charge disproportionation of 0.2e. The optical conductivity evidences inter¬action of the charge carriers with charge-order fluctuations: Strong localization due to nearest neighbor Coulomb interaction significantly reduces the spectral weight of the Drude response and an intense charge-fluctuation band forms around 300 cm-1. An interaction of charge carriers with charge fluctuations becomes evident by the linear dependent spectral weight of the Drude component as well as a collective charge-order excitation at 30 cm-1 intensity, which is linked to the intensity of Drude response. Below Tc = 5 K we observe a superconducting gap (2Δ = 12 cm-1), corresponding to 2Δ/kBTc = 3.3. Also its temperature and magnetic field dependences are consistent with predictions for weakly coupled superconductors. The overall results suggest that superconductivity in this compound is mediated by charge-order fluctuations.

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Fr-S55-IT2 / Emerging Evidence for FFLO States in Layered Organic Superconductors

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Abstract
More than 50 years after the prediction of Fulde and Ferrell (FF) as well as Larkin and Ovchinnikov (LO) that, under certain conditions, unconventional inhomogeneous superconducting states can exist at high magnetic fields and low temperatures, there is now growing evidence that such a state is realized in quasi-two-dimensional (2D) organic superconductors. These are mostly clean-limit superconductors and when the magnetic field is aligned parallel to the conducting planes the orbital critical field is greatly enhanced, much beyond the Pauli-limiting field. We performed high-resolution specific-heat and torque-magnetization experiments in high magnetic fields for such 2D organic superconductors. Besides an upturn of the upper critical field towards lowest temperatures, we observe a second thermodynamic transition within the superconducting phase signaling the existence of an additional superconducting phase. These features appear only in a very narrow angular region close to parallel-field orientation as evidenced by comprehensive angular- and field-dependent specific-heat measurements. The in-plane orientation of the magnetic field does not influence the superconducting phase diagram. Our results, together with recent NMR results, give strong evidence for the realization of the FFLO state in organic superconductors.
Work done in cooperation with R. Beyer, B. Bergk, P.H.M. Böttger, A. Demuer, E. Green R. Lortz, Y. Nakazawa, M. Naumann, I. Sheikin, S. Yasin, Y. Wang, R. Zahn, G. Zwicknagl, and J.A. Schlueter.

Mo-S01-CT2 / Charge Excitation in L-Edge Resonant Inelastic X-Ray Scattering: Detecting Enhanced Small-Momentum Charge Fluctuation of Underdoped Electron-Doped Cuprates

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Abstract
Resonant inelastic x-ray scattering (RIXS) tuned for Cu L edge is a possible tool to detect momentum-dependent intra-orbital charge excitations in cuprate superconductors [1]. We theoretically investigate the possibility for observing the low-energy charge excitation with the same energy scale as spin excitation by RIXS [2]. We find that the core-hole Coulomb potential enhances the spectral weight of the charge excitation in electron-doped systems. Furthermore, from a large scale density-matrix renormalization group calculation, we find that electron-dopes system enhances small-momentum low-energy dynamical charge structure factor, whose energy is lower than that of spin excitation. This indicates a nontrivial mechanism of charge-spin coupling and superconductivity in electron-doped cuprates.

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Mo-S01-CT1 / Mott physics in the three-band model of the CuO2 plane

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Abstract
High temperature superconductivity emerges in the CuO2 plane upon doping a Mott insulator. To ascertain the influence of Mott physics plus short-range correlations, we solve a three-band copper oxide model in the charge-transfer regime using cluster dynamical mean-field theory with continuous-time quantum Monte Carlo as an impurity solver. We report the normal-state phase diagram of this model as a function of doping, charge-transfer energy, interaction strength and temperature. Upon hole doping of the charge-transfer insulator, a first-order transition occurs at finite doping between a pseudogap and a correlated metal. This transition is connected to the metal to charge-transfer insulator transition in the undoped model.

Mo-S02-CT1 / Superconductivity in topological half-Heusler compounds

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Abstract
Half-Heusler compounds crystallize in a cubic structure with 1:1:1 composition. They attract ample attention because of their flexible electronic structure. By playing with the chemical composition a wide range of materials properties, ground states and functionalities can be realized. New in this respect is the topological insulating ground state, which is insulating in the bulk, but has conducting states at the surface that are protected by topology. This non-trivial topology is related to an inverted band order caused by strong spin-orbit interaction. Yet another attractive aspect is that selected topological half-Heusler compounds, like LaPtBi, YPtBi, LuPtBi and LuPdBi, superconduct (for a survey see [1]). Superconductivity is expected to be unconventional and theory predicts mixed even and odd parity Cooper pair states.
We present a review of superconductivity in topological half-Heusler compounds, with a focus on a new candidate for topological superconductivity: the semi-metallic noncentrosymmetric half-Heusler compound ErPdBi [2]. ErPdBi was discovered to superconduct at Tc = 1.22 K, but moreover, the Er moments order antiferromagnetically at TN = 1.06 K. Since Tc ~ TN, the interaction of superconductivity and magnetism is expected to give rise to a complex ground state. Electronic structure calculations show ErPdBi has a topologically nontrivial band inversion and thus may serve as a new platform to study the interplay of topological states, superconductivity and magnetic order.

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Mo-S02-CT2 / Topological superconductivity in heavy fermion superlattices

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Abstract
Topological state of matter is recently regarded as a new paradigm in the condensed matter physics. Topologically nontrivial superconducting state attracts particular interests because it is a platform realizing a Majorana fermion, an exotic particle which has not been found in the particle physics. In this presentation, we propose a topological superconducting state which is stabilized in an artificially grown heavy fermion superlattice CeCoIn5/YbCoIn5 and in oxide interfaces.
The odd-parity pair-density wave (PDW) state is induced by the spin-singlet pairing interaction through the spin-orbit coupling in the locally non-centrosymmetric multilayer superconductors [1]. We show that the s-wave PDW state is a topological crystalline superconductor protected by the mirror symmetry [2], although it is topologically trivial according to the classification based on the standard topological periodic table [3]. The topological property is characterized by a nontrivial mirror Chern number, and two chiral Majorana fermions appear on the edge. We also show that the d-wave PDW state is a topological crystalline superconductor. In contrast to the s-wave PDW state, a topological phase transition occurs when the magnetic field is increased [4]. We propose that the heavy fermion superlattice CeCoIn5/YbCoIn5 is a platform for the realization of the topological superconductivity and Majorana fermions.
In spite of vast efforts devoted to realize the topological superconducting state, the presence of Majorana fermion has not yet been evidenced experimentally. That is mainly because we hardly encounter spin triplet superconductors, although most of topological superconductors belong to the spin triplet superconductor. We resolved this problem by designing the topological superconducting state based on the familiar spin singlet superconductivity. Contrary to the other proposals for the spin singlet topological superconductivity, any fine tuning of parameters is not needed. Thus, the design of the topological superconductor is feasible by using the available technology.

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Mo-S03-CT2 / Scanning Tunneling Spectroscopy of Josephson Vortices in the Surface Superconductor Si(111)-(r7 x r3)-In

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Abstract
Si(111)-(√7×√3)-In, one of the reconstruction surfaces induced by In adatoms on Si(111), has recently been found to be superconducting below 3 K[1,2]. It is regarded as a superconductor in the two-dimensional limit, as the conduction electrons are expected to be confined in the atomically thin layer on the surface. Direct transport measurements performed in an ultra-high vacuum condition demonstrated that supercurrents can travel over macroscopic distances on this material[2]. This was unexpected because the surface always have atomic steps that may decouple the superconducting atomic layers on the terraces. The temperature dependence of the critical current suggested that the atomic steps work as Josephson junctions[2]. There was, however, no direct information on how the individual atomic steps disturb the flow of supercurrents.
To address this question, we carried out low-temperature scanning tunneling microscopy and spectroscopy on Si(111)-(√7×√3)-In in magnetic fields applied in the direction perpendicular to the surface[3]. Vortex cores were observed by mapping zero-bias conductance as a function of position in an area consisting of flat terraces separated by several atomic steps. In the terrace regions, vortex cores have an isotropic round shape and superconductivity is nearly completely suppressed at their centers. In contrast, vortex cores trapped at the atomic steps have an anisotropic shape elongated along the steps and superconductivity is only weakly suppressed there. These experimental results can be understood in terms of a crossover from a normal vortex to a Josephson vortex, and are well reproduced by numerical calculations based on the Bogoliubov-de Gennes formalism[4]. We conclude that the atomic steps allow supercurrents to flow in a limited rate depending on the quality of film growth near the steps.

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Mo-S03-CT1 / Remarkable effects of disorder on superconductivity of single atomic layers of lead on silicon

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Abstract
It is well known that conventional superconductivity is very robust against non-magnetic disorder [1]. Nevertheless for thin and ultrathin films the structural properties play a major role in determining the superconducting properties, through a subtle interplay between disorder and Coulomb interactions [2]. Unexpectedly, in 2010 superconductivity was discovered in single atomic layers of lead and indium grown on silicon substrate using scanning tunneling spectroscopy [3] and confirmed later on by macroscopic transport measurements [4]. Such well-controlled and tunable crystalline monolayers are ideal systems for studying the influence of various kinds of structural defects on the superconducting properties at the atomic and mesoscopic scale. In particular, Pb monolayers offer the opportunity of probing new effects of disorder because not only superconductivity is 2D but also the electronic wave functions are 2D. Our study of two Pb monolayers of different crystal structures by very-low temperature STM (300 mK) under magnetic field reveals unexpected results involving new spatial spectroscopic variations [5]. Our results show that although the sheet resistance of the Pb monolayers is much below the resistance quantum, strong non-BCS corrections appear leading to peak heights fluctuations in the dI/dV tunneling spectra at a spatial scale much smaller than the superconducting coherence length. Furthermore, strong local evidence of the signature of Rashba effect on the superconductivity of the Pb/Si(111) monolayer is revealed through filling of in gap states and local spatial variations of this filling. Finally the nature of vortices in a monolayer is found to be very sensitive to the properties of step edges areas.

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Mo-S04-CT1 / Impact of fundamental material properties of REBCO-tapes on cable applications

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Abstract
The second generation High Temperature Superconductor, the REBCO-tape, is meanwhile available as industrial product from different sources and is enabling a couple of applications as superconducting Fault Current Limiters, Transformers, Generators, Power Cables and in particular inserts of high field magnets (upgrade of LHC dipoles). The various production routes used for REBCO-tapes lead to materials with strongly different properties addressing flux pinning mechanism, current anisotropy in magnetic background fields, mechanical and thermal stability and current capacity as function of temperature. Flux pinning behavior depends on the REBCO deposition method and can be influenced modifying the flux pinning centers and their orientation in the tape. This allows to design and optimize the conductor performance. For a couple of applications high DC or AC transport currents are needed which require tapes assembled to a cable. We review the different high current cable concepts actually under investigation and present in more detail the Roebel cable concept of KIT. The properties of REBCO cables correspond sensitively with the specific tape properties, in particular with the current anisotropy of tapes. The Roebel cable was investigated as straight sample and as coil and the superconducting properties were measured and modeled by FEM. We present data showing the strong influence of the individual tape features on the cable performance, as created self field, current homogeneity (role of defects) and transport current capacity at different operation temperatures. Applying filament structures in the superconducting layers is an additional feature providing lower losses with AC currents and information about the homogeneity of the material. An outlook will address the actual trends and the expected progress in the REBCO material research and the consequence for the conductor performance.

Mo-S04-CT2 / Tomographic examination of superconductors

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Abstract
The microstructure, porosity, filament connectivity and homogeneity in multifilamentary composites can have a strong influence on the superconductor properties. Several tomographic techniques are available to visualize and to quantify these features. We compare non-destructive tomographic methods with different contrast mechanisms, notably the absorption contrast in the transmitted X-ray beam, the X-ray diffraction contrast in the scattered X-ray beam and destructive FIB nano-tomography with secondary and backscattered electron imaging. We present case studies that show the potential of these methods in terms of spatial and temporal resolution, and we discuss possible artefacts.

Mo-S06-CT1 / Onset of nematicity in the pseudogap phase of the cuprate superconductor YBa2Cu3Oy : Interplay with charge order and superconductivity

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Abstract
Underdoped cuprates display a complex set of anomalous properties whose organizing principle has yet to be found. Translational [1] and rotational [2] symmetries are broken, the Fermi surface is reconstructed [3], and superconductivity is suppressed. Here we disentangle these intertwined phenomena by mapping their onset temperatures in YBa2Cu3Oy , detected in transport measurements across the doping phase diagram. We show that transport anisotropies can be used to define the onset temperature of nematicity and explore its interplay with charge-density-wave order, superconductivity and the pseudogap phase. The nematic phase emerges as a central feature of the cuprate phase diagram. We argue that nematicity is linked to the pseudogap, whether the pseudogap is a high-temperature precursor of charge order or charge order is an instability of the pseudogap.

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Mo-S07-CT1 / Fermi liquid behaviour in strongly correlated metals

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Abstract
A reference point for research on a wider range of correlated behaviour is provided by the so-called Fermi liquids, characterized by a relaxation rate (ħω)2 + (pπkBT)2. The theoretical prediction2 for the relaxation rate appearing in the optical conductivity is p = 2 when considering the experimentally most accessible range ħω>kBT. A number of recent optical studies3 have addressed the issue of Fermi-liquid characteristics, reporting indeed ω2 and T2 for the optical scattering rate of a number of different materials. However, a perfect match to the prediction p = 2 has not been observed. One possible scenario that has been proposed to explain this discrepancy is the presence of magnetic impurities. In a recent study1 we have investigated Sr2RuO4, a material which can be synthesized in very pure form, with well established T2 resistivity below 25 K. Here we observe a perfect scaling collapse of 1/τ as a function of (ħω)2+(pπkBT)2 for ħω < 36 meV, and temperature below 40K, with p = 2. We also observe features in the spectrum at higher energy, which are manifestly beyond the Fermi-liquid model. The sign and size of these features agree quantitatively with the notion of resilient quasiparticles predicted by dynamical mean field theoretical calculations for this compound.

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Mo-S08-CT1 / Dynamics of core-less Abrikosov vortices

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Abstract
One usually considers two types of vortices in superconductors, Abrikosov vortices in the bulk and Josephson vortices inside the Josephson junction or in strongly layered superconductors when the magnetic field is parallel to the layers. There are situations where vortices are something in between. Away from the core they look like conventional Abrikosov vortices, but inside the core the order parameter is not fully suppressed. Examples are vortices on plane defects or junctions with transparency ~ 1 (they are similar to Abrikosov Josephson vortices introduced in [1]) and vortices in layered superconductors with relatively low anisotropy (ξc ≤ d) [2] . For both examples the order parameter inside the core is not fully suppressed, thus they don't have an Abrikosov core. On the other hand, when the transparency of the boundary (or the anisotropy) is ≤ 1, one cannot talk about a Josephson core anymore. This incomplete suppression of the order parameter in the core does not affect the properties of the vortex in the London region. Also if the order parameter drops, e.g., to the half of the equilibrium value within the same coherence length, pinning would be qualitatively the same. However, the low temperature dynamics of such a vortex would be completely different. A non-vanishing order parameter induces an energy gap for quasi-particles and thus their absence at low temperatures. As a result, the Bardeen Stephen dissipation vanishes when T → 0. The dynamics then would be given by the electromagnetic vortex mass. In weakly layered materials this vanishing dissipation can be probed by measuring of the imaginary part of the ac susceptibility (penetration depth measurement) for both dc and ac fields parallel to the layers. The current voltage curve would show hysteresis with a voltage jumping from zero below the critical current to a finite voltage ~ B v0/c with v0 ~ Δξ1, where ξ1 is the appropriate core dimension along the vortex motion.

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Mo-S09-CT2 / New Superconductivity Dome in LaFeAsO1−xFx Accompanied by Structural Transition

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Abstract
High temperature superconductivity is often found in the vicinity of antiferromagnetism. This is also true in LaFeAsO1−x Fx (x≤ 0.2) and many other iron-based superconductors, which leads to proposals that superconductivity is mediated by fluctuations associated with the nearby magnetism. Here we report the discovery of a new superconductivity dome without low-energy magnetic fluctuations in LaFeAsO1−x Fx with 0.25≤x≤ 0.75, where the maximal critical temperature Tc at xopt = 0.5~ 0.55 is even higher than that at x≤ 0.2. By nuclear magnetic resonance and Transmission Electron Microscopy, we show that a C4 rotation symmetry-breaking structural transition takes place for x> 0.5 above Tc . Our results point to a new paradigm of high temperature superconductivity.

Mo-S10-CT1 / NMR study of the FFLO phase in the organic superconductor beta"-$(ET)_2SF_5CH_2CF_2SO_3$

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Abstract
β"-(ET)2SF5CH2CF2SO3 is an all-organic, quasi-two dimensional organic superconductor with Tc=4.5K and notably weak interlayer coupling. As such, it is considered a candidate for inhomogenous superconductivity, sometimes referred to as FFLO. Results of prior thermodynamic and transport experiments were consistent with a transition to a high-field superconducting phase at ~9T for in-plane fields and temperatures below 1.5K. In our measurements, precise alignment (<0.1º) was achieved using a piezo-rotator. The transition to the high-field phase is detected in 13C NMR measurements, namely spin-lattice relaxation and in the development of inhomogenous hyperfine fields. Both are consistent with FFLO stabilization for fields greater than Bc=9.5T. The distribution of the spin polarization is modeled as resulting from a single-Q modulation of the order parameter. At low fields, the NMR results are consistent with an order parameter with line nodes on the Fermi surface. In the normal state, there is a clear absence of spin fluctuation contributions to the spin lattice relaxation rate when compared to the results of other organic superconductors. We discuss these results in the context of a proposal that the superconducting pairing is mediated by charge-order fluctuations, rather than spin fluctuations.

Tu-S11-CT2 / The energy spectrum of superconducting cuprates in the pseudogap phase

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Abstract
Details of the electronic spectrum in the pseudogap (PG) phase are critical for understanding mechanisms of high-temperature superconductivity (SC) in cuprates. The angle-resolved photoemission spectroscopy (ARPES) finds coherent excitations only at so-called “Fermi arcs” (FAs). Another branch - small electronic pocket [1, 2] is seen in the quantum oscillations (QOs). With tendency to a charge ordering (CO) revealed in few recent X-rays experiments [3] the view became popular [4] that pockets emerge via reconstruction of the Fermi surface (FS) in vicinity of the nodal points in a CO transition. However the residual metallic contribution into the specific heat deep in the SC phase of YBCO observed in [2] contradicts the reconstruction scenario, as SC suppressing the CO would thereby destroy such pocket.
Based on the analysis of transport data in the PG phase for the three families of underdoped (UD) cuprates (YBCO, LSCO and Hg1201) both above and below the CO transition we show [5, 6] that: 1) from data for resistivity and the Hall coefficient it follows that at low dopants concentration (x) excitations on FAs are indeed the only charge carriers (holes) in the system; 2) the Hall data at higher doping x>0.08-0.10 allow identifying the pocket as a permanent feature of the PG phase, contrary to the idea of a FS reconstruction in the CO transition. In fact, the experimental Hall numbers in LSCO and YBCO owing to contributions from a pocket of electrons dragged by the FAs holes deviate from proportionality to x; 3) on lowering the temperature the holes scattering strongly off fluctuating incommensurable charge density waves (CDW), their mobility rapidly decreases and their contribution to transport properties gives way to that of electrons on the pocket.
In summary, we provide the self-consistent interpretation of the (T, x)-phase diagram and of the recent transport, X-ray and NMR data. In particular, at x>0.08-0.10 the energy spectrum of UD cuprates is shown to consist at all T of the holes on FAs arcs and the electronic pocket at the zone center. When SC is suppressed by a strong magnetic field at low T, CDW fluctuations destroy Fermi arcs leaving electrons as the only mobile carriers.
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Tu-S11-CT1 / Long-range order and pinning of charge-density waves in competition with superconductivity

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Abstract
We consider the possibility of long-range charge-density wave order in a non-linear sigma model of a clean layered system where such order competes with superconductivity. Using a large-N approximation, and Monte-Carlo simulations, we show that weak inter-layer coupling can stabilize long-range order only in the presence of a magnetic field, which suppresses the superconducting order parameter inside vortex cores. This fact is related to the low temperature behavior of the charge-density wave structure factor, which vanishes linearly with decreasing temperature in the absence of a magnetic field and diverges in the presence of a field.
Such behavior is inconsistent with recent x-ray scattering measurements of the structure factor in cuprate high-temperature superconductors. On the other hand, qualitative agreement with experiments is obtained when the effect of a random pinning potential is taken into account in our simulations and large-N analysis. In particular, we find that at low temperatures the structure factor attains a non-zero finite value, which grows linearly with magnetic field.

Tu-S12-CT1 / Fermi surface in FeSe: Quantum oscillation measurements

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Introduction
FeSe is an intriguing member of the iron-based superconductors. Despite the fact that it is isoelectronic to the (FeAs)-1 layers of iron-pnictide parent compounds such as LaFeAsO or BaFe2As2, it does not order magnetically but becomes superconducting below Tc ~ 8 K [1]. Moreover, Tc is substantially enhanced by application of pressure [2] and a possibility that Tc > 50 K in single layer FeSe has been reported [3].
Recently, Böhmer et al. succeeded in growing very high-quality single crystals of FeSe using a chemical vapor transport technique [4]. We here report Shubnikov-de Haas oscillation measurements on those crystals [5].

Methods
Standard four-contact resistivity measurements were performed in a 35-T resistive magnet and 3He or 3He/4He dilution refrigerator at the NHMFL.

Results and Discussion
We have observed four fundamental frequencies, all of which are small, corresponding to only 0.2-2.3% of the Brillouin zone cross section for B // c. We attribute them to maximal and minimal cross sections of two quasi-two-dimensional Fermi surface cylinders. The associated effective masses are in a range between 1.9 and 7.2 me. The contribution of the two observed Fermi surface cylinders to the Sommerfeld coefficient is estimated to be ~6 mJ/molK2, which is close to the value found in specific heat measurements [6] and hence suggests that the entire Fermi surface has been observed. Accordingly, we assign the two observed cylinders to a hole and an electron cylinder. The carrier number is estimated to be ~0.01 carriers per Fe.
Band-structure calculations predict three hole and two electron cylinders located at the zone center and corners, respectively, and the calculated carrier number is 0.17 carriers per Fe, an order-of-magnitude larger than observed. At present, it is elusive to explain why the real Fermi surface is so different from the band-structure calculations, but it seems clear that both of electronic correlations and orbital ordering have to be included in future theoretical studies.

Conclusion
We have observed the Fermi surface in FeSe, which is very small and radically differs from that expected from band-structure calculations. Hopefully, we will also be able to present high-pressure data at the conference.

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Tu-S12-CT2 / Interplay between strong correlations and superconductivity in AFe2As2 with A = K, Rb, and Cs

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Abstract
Superconductivity in iron pnictides and chalcogenides occurs in close proximity to antiferromagnetic order, suggesting that superconductivity originates from electron-electron interactions. So far, experimental and theoretical studies underpin this assumption without, however, being able to unravel the pairing mechanism. A central question is the role of electronic correlations. We have investigated the thermal expansion and magnetostriction of the stoichiometric compounds AFe2As2 with A = K, Rb, and Cs. The magnetostriction measurements exhibit quantum oscillations beyond the upper critical fields which allow determining the electronic structure and the effective quasiparticle masses m*. With growing unit-cell volume along the AFe2As2 series the strength of the electronic correlations becomes much stronger evidenced by a huge increase of m*. This behavior is in line with the pressure dependence of the Sommerfeld coefficient determined from the thermal expansion above the superconducting transition temperature Tc. The measurements suggest that CsFe2As2 is in close proximity to a quantum phase transition. The relation between superconductivity and electronic correlations will be discussed in terms of effective quasiparticle masses, uniaxial pressure dependences of Tc, and upper critical fields.

Tu-S13-CT2 / Top gating control of superconductivity at the LaAlO3/SrTiO3 interfaces

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Abstract
Transition metal oxides display a great variety of quantum electronic behaviors where correlations often play an important role. The achievement of high quality epitaxial interfaces involving such materials gives a unique opportunity to engineer artificial materials where new electronic orders take place. It has been shown recently that a superconducting two-dimensional electron gas 2DEG could form at the interface of two insulators such as LaAlO3 and SrTiO3 [1], or LaTiO3 (a Mott insulator) and SrTiO3 [2]. An important feature of these interfaces lies in the possibility to control their electronic properties, including superconductivity and spin-orbit coupling (SOC) with field effect [3-5]. However, so far, experiments have been performed almost exclusively with a metallic gate at the back of the substrate, which makes difficult to control these properties at a local scale.
In this presentation, we will report on the realization of a top-gated LaAlO3/SrTiO3 device whose physical properties, including superconductivity and Rashba SOC, can be tuned over a wide range of electrostatic doping. In particular, we will present a phase diagram of the interface and compare the effect of the top-gate and back-gate on the mobility, superconducting properties and Rashba SOC. Finally, we will discuss the field-effect modulation of the Rashba spin-splitting energy extracted from the analysis of magneto-transport measurements[6]. Our result paves the way for the realization of mesoscopic devices where both superconductivity and Rashba SOC can be tuned locally.

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Tu-S13-CT1 / Tunable spin polarization and superconductivity in LAO/ETO/STO heterostructure

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Abstract
We engineered an oxide heterostructure based on $SrTiO_3$, $EuTiO_3$ and $LaAlO_3$ (LAO/ETO/STO)[1] with the aim of tailoring a spin-polarized 2D electron system. Two unit cells of ETO act as δ-doping material between LAO and STO band insulators, giving rise to a novel oxide structure with a rich phase diagram, including ferromagnetism, Kondo effect and superconductivity.
We performed polarization dependent x-ray absorption spectroscopy, demonstrating that the LAO/ETO/STO interface is characterized by the same orbital reconstruction of the LAO/STO system and robust spin-splitting of titanium 3d-states [2]. Magneto-transport measurements give evidence of spin-orbit coupling, of an itinerant ferromagnetism, established at electron doping above $n_{2D}=1.9 \times 10^{13} cm^{-2}$, and of a Kondo-like behavior in the underdoped region. Finally, ultra low temperature measurements show a superconducting transition with a maximum critical temperature of 140mK. All these properties are tunable using field effect.
The interplay among magnetic exchange interactions, superconductivity and spin-orbit coupling could make the LAO/ETO/STO system an extraordinary platform to realize topologically non-trivial edge states at the interface between transition metal oxides [3].

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Tu-S14-CT1 / Giant Nernst effects due to Berry phase fluctuation in chiral superconductors

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Abstract
In chiral superconductors, Cooper pairs possess nonzero total angular momentum, breaking time-reversal symmetry. The chiral pairings accompanying the nontrivial Berry curvature give rise to exotic transverse transport such as the anomalous thermal Hall effect below the transition temperature T_c. It is naturally expected that even in the superconducting fluctuation regime near but above T_c, anomalous transverse transport may be raised by chiral superconducting fluctuations, which induce the Berry phase fluctuation. Here, we discuss this possibility. We found that in the fluctuation regime above T_c, the anomalous Nernst effect can be raised by dynamical skew-scattering due to chiral superconducting fluctuations. This mechanism is in analogy with the skew-scattering mechanism of the anomalous Hall effect without Lorentz force. Furthermore, our sccenario successfully explains the recent experimental obesrvation of the giant Nernst signal for URu_2Si_2 which is a candidate of a chiral $d_{zx}+id_{yz}$ wave superconductor. This provides a strong evidence of the chiral pairing state in URu_2Si_2, which implies the realization of a Weyl superconductor. We also discuss the application of our scenario to Sr_2RuO_4,and other topological superconductors with broken time-reversal symmetry.

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Tu-S14-CT2 / Topological superconductivity from phonons

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Abstract
Doping a topological insulator has been proposed as a simple route to realizing a topological superconductor [1]. Much excitement has been generated by the apparent observation of topologically-protected edge states in superconducting $Cu_xBi_2Se_3$ [2], but the experimental situation remains controversial. Since these materials are weakly-correlated, the pairing is likely mediated by phonons. Although this usually favours a nontopological even-parity state, the presence of strong spin-orbit coupling has been suggested to favour topological odd-parity pairing. We resolve this controversy by proving that that for a purely phonon-mediated pairing interaction, the critical temperature of the leading odd-parity state cannot exceed that of the leading even-parity state [3]. Electronic interactions are thus crucial for stabilizing a topological superconductor. Furthermore, for a given odd-parity state, we show how to identify the pair-forming and pair-breaking electron-phonon vertices. To exemplify the power of our method, we determine the electron-phonon vertices which produce an attractive or repulsive interaction for the topological state in $Cu_xBi_2Se_3$, and hence propose and solve a microscopic model for the pairing.

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Tu-S15-CT1 / Theory for superconductors in non-equilibrium: Higgs oscillations and generation of coherent phonons

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Abstract

We study the nonequilibrium dynamics of *s*- and *d*-wave superconductors, which are induced by a ultra-short pump pulse or a quench, respectively [1-5]. The dynamics is studied by use of the density matrix formalism as well as by analytical calculation. For *s*-wave superconductors the nonadiabatic evolution of the order parameter is well established in the collisionless regime. It shows a $1/\sqrt{t}$ decaying oscillation, which is the Higgs mode in a superconductor [1,3,5]. Furthermore, inspired by recent THz pump-probe experiments on NbN films [6], we theoretically study the pump-probe response of non-equilibrium superconductors coupled to optical phonons. For ultrashort pump pulses a nonadiabatic regime emerges, which is characterized by both Higgs oscillations of the superconducting gap and by the generation of coherent phonons. We can then compute the pump-probe response of the superconductor in the nonadiabatic regime and determine the signatures of the order parameter and of the phonon oscillations in the pump-probe optical conductivity [3,5]. In that regime we find that Higgs oscillations can become resonant as a function of the delay time and fluence. We also consider two-band superconductors and study the interplay of the two Higgs modes [4] and apply our theory to explain time-resolved Raman data of cuprates and manganites [2,7].

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Tu-S15-CT2 / Amplitude "Higgs" mode under pressure in 2H-NbSe2 superconductor

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Abstract

When a spontaneous breaking of a continuous symmetry takes place, as happens during a superconducting transition, collective excitations of the order parameter emerge among which the massive amplitude mode, an excitation analogous to the Higgs boson in the standard model. At equilibrium, this 'dark' mode couples weakly to physical observables and thus remains elusive.

In the dichalcogenide 2H-NbSe2, a charge density wave (CDW) superconductor, a unique electronic excitation of the superconducting electrons was observed in 1980 by Raman spectroscopy [1]. After this observation, many theories emerged including the association of this mode to the amplitude mode [2]. This mode could be observed in the case of 2H-NbSe2 thanks to a coupling with the low energy phonon induced by the CDW. But there are still controversies about the nature of the mode it-self and the mechanisms involved in his observability [3].

In this context, we studied the compound 2H-NbSe2 under pressure with Raman spectroscopy and using the diamond anvil cell technique. The improvement of this experimental technique allowed us to obtain Raman spectroscopy measurements in extremes conditions at low temperatures (down to 4 K), high pressures (up to 20 GPa) and probing very low energy Raman excitations (under 8 cm−1).

When applying a sufficiently high pressure (7 GPa) to 2H-NbSe2 the CDW disappears and only remains the superconductivity. We then show that when the CDW disappears the superconducting collective mode also disappears leaving only a simple Cooper breaking peak identical to the one observed in the compound 2H-NbS2 which lacks the CDW [4]. Most of our results are consistent with the scenario of the amplitude mode but they also rise many questions. Indeed we show that new informations, especially on the symmetry dependence of the amplitude mode, need to be taken into account for a full model.

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Tu-S16-CT1 / Wiedemann-Franz law in the underdoped cuprate YBCO : Constraint on the non-superconducting ground state of the pseudogap phase

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Abstract

We report a direct determination of the upper critical field Hc2 in the cuprate superconductor YBCO from high-field measurements of the longitudinal thermal conductivity κxx [1]. The appearance of vortices below Hc2 causes a rapid drop in conductivity as the long mean free path of high-quality crystals in the normal state is suddenly curtailed by vortex scattering. The doping dependence of Hc2 shows two peaks located at the beginning and end of the phase of charge-density-wave (CDW) order, confirming the strong competition between CDW order and superconductivity in the center of the phase diagram of hole-doped cuprates.

We further report measurements of the thermal Hall conductivity κxy of YBCO at a doping p = 0.11, in magnetic fields above Hc2 = 24 T. In agreement with prior measurements of the electrical Hall [2] and Seebeck [3] coefficients, the negative sign of κxy confirms the dominance of the small electron pocket in the Fermi surface of underdoped YBCO [4]. We find that the Wiedemann-Franz law (κxy / T = L0 σxy) is satisfied in the limit of T = 0, immediately above Hc2. This places strong constraints on the nature of the non-superconducting ground state in the pseudogap phase of cuprates.

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Tu-S16-CT2 / A close up into the paradigm of Hg superconductors: the case of $HgBa_2CuO_{4+\delta}$

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Abstract

Among all superconducting cuprates, the mercury family is unquestionably the most paradigmatic one. While exhibiting the highest Tc both in ambient conditions and under pressure their atomic structure seems to be quasi-perfect, in clear contrast to the other superconducting families. In this contribution we address this paradigm by a combined x-ray single crystal diffraction and transport measurements study of the one layer Hg compound: HgBa2CuO4+d(Hg1201) With only one CuO2 layer per formula unit its superconducting critical temperature, Tc, can reach up to 97K, which is higher than the that of Bi2212 and YBCO with two CuO2 per formula unit. The experimental data show that the short range order discovered in Hg1201 compounds [1,2] experiences significant modifications when cooling below the superconducting temperature. Furthermore, it also undergoes significant modifications with pressure that are unambiguously correlated with the observed non-monotonous pressure variation of Tc. Our result demonstrate that the observed short range order might be related with high temperature superconductivity in Hg cuprates. Furthermore, it brings Hg1201 structurally closer to the other superconductor families with high Tc.

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Tu-S18-CT1 / Magnetotransport and superconductor-insulator transition in the Si/Nb/Si trilayers

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Abstract
It is well established that upon the reduction of the thickness of superconducting film the film resistance increases and the superconductivity (SC) is suppressed, and eventually leading to the superconductor-insulator transition (SIT). The SIT may also be induced by the external magnetic field or by the change of the concentration of carriers. The SIT is usually observed in highly disordered films. There exists also a class of weakly disordered materials, in which a transition takes place to the disordered metallic state ("bad metal") instead of insulating state.
We study the structural and magnetotransport properties of Si/Nb/Si trilayers grown by magnetron sputtering at room temperature, with a hickness of Nb, d, varied from 50 nm down to 1.1 nm, and a fixed Si thickness of 10 nm. With decreasing d, the structure of the Nb layer changes from polycrystalline to amorphous at d about 3.3 nm, while the superconducting transition temperature monotonically decreases, reaching zero for d < 1.2 nm. The Hall effect measurements reveal that the positive Hall coefficient, characteristic for bulk Nb, starts decreasing for d below 6 nm, and eventually changes sign into negative for d below 2 nm. It indicates that two types of carriers contribute to the conduction. The analysis of the magnetotransport and Hall effect suggests that the transport properties in ultrathin films are affected by electron-electron interactions. Finally, the destruction of superconductivity leads to a metallic, disordered state. The possible origins of the negative Hall coefficient and the nature of metallic state will be discussed.

Tu-S18-CT2 / Proximity effect through YBCO/Au Nanogaps: A route for hybrid devices

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Abstract
The advances of nanotechnologies applied to HTS have opened new perspectives for the realization of hybrid devices, where HTS materials are interfaced with Topological Insulator, or Graphene. The higher values of the superconductive gap and of the Bc of HTS compared to conventional superconductors, together with the d-wave symmetry of the order parameter, promise the exploitation of a much richer Josephson phenomenology in SNS where the N is a Dirac material.
HTS nanogaps are the platform to realize hybrid devices. There are many challenges to overcome in nanostructuring YBCO. in particular oxygen out diffusion during the Ar etching and resist bakin. In this work we have developed a novel fabrication technique, using Au encapsulation to minimize damages occurring during the nanopatterning. In this way we have achieved YBCO nanogaps as small as 35 nm. To assess their quality, we have measured, the IV and RT of encapsulated YBCO nanowires. By analyzing the superconducting transition with a thermally activated vortex entry model, we determined the maximum damage the nanowires undergo during the patterning. The damaged region gives an upper bound for the dimension of the nanogap, which is 100 nm at the transition temperature.
To induce a sizeble supercurrent in YBCO hybrid devices based on our nanogap technology, one first need to proximize the Au metal that we use to encapsulate the electrodes. This requires highly transparent YBCO/ Au interfaces.. By using an in situ deposited Au we obtained , which is among the lowest value reported in literature. To demonstrated the feasibility of the YBCO nanogaps for hybrid devices we have bridged the nanogap with a thin Au layer. In several devices we have observed a critical current up to 80 K. Such structures were characterized by record values of the Jc up to 107A/cm2 at T=4.2 K. To prove the Josephson nature of the weak coupling through the nanogap we have recorded the magnetic field patterns. We have measured almost ideal Fraunhofer-like dependence of the critical current as a external magnetic field. Moreover the detected Shapiro steps, by irradiating the junction with microwaves, support the exhistence of josephson effect through the Au film. For some devices we observed the formation of half-integer Shapiro steps at low temperatures, which might be attributed to non-sinisuoidal CPR of the SNS junction and/or of the d-wave symmetry of the YBCO order parameter.
Our study clearly shows that these YBCO nanogaps can represent a novel platform for realizing hybrid devices beyond the present state of the art.

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Tu-S19-CT1 / Properties of superconductivity emerging deep into the spin-density wave state in $(TMTSF)_2ClO_4$

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Abstract
It is now well established [1-4] that in Bechgaard salts spin-density wave (SDW), near its critical point, coexists with small superconducting (SC) domains elongated, counterintuitively, in the direction of the weakest conductivity. The mechanism behind the formation of such unusual spatial texture is still being debated [1,3,4], with the two approaches, soliton phase theory [5] and macroscopic segregation [4], being most promising. However, neither of them consistently accounts for all the observed effects in the coexistence region [3].
First, based on the behavior of hysteresis in temperature dependences and field-induced SDW transitions throughout the coexistence region we argue that there exist two distinct parts within this region. One of this parts is close to SDW endpoint and is dominated by macroscopic segregation, e.g. due to sample inhomogeneities. We focus on another part of the coexistence region – the one close to the boundary with the homogeneous spin-density wave, where our studies of nonlinear transport along with the absence of field-induced SDW points towards coexistence of SDW and metal/superconducting phases on quite small scale – a possible soliton phase candidate. Least is known about superconductivity in this part of the phase diagram. Here we present comprehensive critical field measurements, performed both in the regime of linear and nonlinear transport, to elucidate the nature of superconductivity in this state. Whereas Tc is well within the range of that in homogeneous superconducting state, we observe that critical field Hc2||c determined from the transport data demonstrates reentrant-like behavior and SDW is not restored even in very high fields. We discuss possible mechanisms for such behavior.

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Tu-S19-CT2 / Pressure-induced electronic phase separation in CrAs

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Abstract
The superconductivity induced by the pressure in binary helimagnet CrAs has attracted recently much attention [1-5]. At ambient pressure (p) CrAs is characterized by relatively high N\'{e}el transition temperature $T_N\ simeq 270$~K [6-8]. T_N decreases by an approximately factor of 3 for p approaching $\simeq7$~KBar, above which the magnetism completely disappears [1-3]. The superconductivity, in their turn, starts to set in for pressure exceeding $\simeq4$~KBar thus suggesting that within the range of $4\lesssim p \lesssim 7$~KBar the superconductivity and magnetism suppose to coexist. In this paper we report on the muon spin rotation ($\ mu$SR) studies of the magnetic and the superconducting properties of CrAs. The magnetism remains bulk up to $p\simeq3.5$~KBar, while the purely paramagnetic state develops for pressures exceeding 7~KBar. In the intermediate pressure region ($3.5\lesssim p\lesssim 7$~KBar) the magnetic phase volume decreases continuously and the superconductivity develops in parts of the sample remaining paramagnetic down to the lowest temperatures. Both, the superconducting transition temperature T_c and the zero-temperature superfluid density $\rho_s(0)$ decrease with increasing pressure in the intermediate pressure region and saturate for p exceeding $\simeq7$~KBar i.e. in the region where the magnetism becomes completely suppressed. Our results suggest that the pressure induced transition of CrAs sample from the magnetic to the superconducting state is characterized (i) by separation the sample on macroscopic size magnetic and superconducting volumes and (ii) by electronic phase separation. In later case, the more insulating magnetic phase provides additional carriers (doping) to the superconducting parts of CrAs sample thus leading to substantial increase of T_c (from 0.9~K to 1.2~K) and the superfluid density (up to $\simeq 150$\%) in the coexistence region.

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Tu-S20-CT2 / Quantitative comparison between electronic Raman spectra and angle-resolved photoemission spectra in superconducting state of Bi2212

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Abstract
Both electronic Raman scattering (ERS) and angle-resolved photoemission (ARPES) are known as powerful tools to directly observe the electronic structure in the different momentum space. In cuprates, two energy scales of an energy gap were observed in the different momentum space by those methods, however, their interpretation of the results was different. While two scales were understood as different gaps (i.e. superconducting gap and pseudogap) in ARPES [1], it was considered as a single gap (superconducting gap) in ERS [2]. Moreover, there is difference in the doping dependence of the energy gap around the nodal region; the energy gap size decreases with underdoping in ERS, while there is almost no doping dependence of the gap in ARPES [3]. To clarify these issues, we have performed ERS and ARPES measurements on the same sample of Bi2212 and calculated ERS spectra from ARPES spectra to directly compare results from two different experiments. We found that the electronic structure around the nodal region observed by ERS and ARPES can be consistently understood by assuming particular spectral weight distribution along the Fermi surface, which means ERS results can be interpreted by two gaps as ARPES. We also found that there were significant differences in the antinodal region in the underdoped region, which implies the effect of pseudogap observed in ERS and ARPES is different.

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Tu-S20-CT1 / Huge (~10 meV) Broadening of the Bond-Stretching Phonon Mode Below Tc in Optimally Doped $YBa_2Cu_3O_{7-\delta}$

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Abstract
We use inelastic x-ray scattering (IXS) to investigate the phonons in the high temperature cuprate superconductor, YBa2Cu3O7-δ. (YBCO). We find that as the temperature is decreased below Tc~93 K, the bond-stretching phonon mode at ~60 meV broadens dramatically at specific values of the momentum transfer: the phenomenological linewidth increases from 12 to 18 meV near to (η 0 0) and from 7 to 20 meV near to (0 η 0) where η ~ 0.27 reciprocal lattice units (rlu). This broadening, which is closely coupled to the opening of the superconducting gap, and is comparable to the linewidths of the E2g mode of MgB2, suggests there is huge electron phonon coupling in this material, at least at selected momentum transfers. It occurs at very nearly at the same momentum transfers where charge density order has recently been observed in under-doped materials [1], and one may speculate it represents the dynamical extension of that order.

These measurements were possible using a new facility for IXS at SPring-8: the RIKEN Quantum NanoDynamics Beamline, BL43LXU [2] that is now commissioning. While generally IXS offers nice characteristics including access to small samples (with mg samples being typical and μg possible) and extremely small backgrounds, as well as good energy resolution, the method suffers from serious flux limitations. The new facility has 3 specialized insertion devices (a total of 15m of magnets) in order to overcome this limit, and, even at approximately half strength, provides an extremely strong beam, 0.8 meV in bandwidth 50 microns in size, onto the sample. This, coupled with a large, 2-dimensional, analyzer array (presently with 24 analyzers) has made it possible to finally get good data on high-energy phonon modes of de-twinned, YBCO.

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Tu-S21-CT1 / Genesis of Charge Orders in Cuprates

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Abstract
One of the most puzzling facts about the cuprate high temperature superconductors is the observation of a variety of low-energy charge-ordered states in coexistence with the superconductivity and/or antiferromagnetism in the lightly doped regime. These states could have a unidirectional charge density wave like structure or a bidirectional checkerboard structure. Recent experiments have discovered these charge density waves exhibiting dominant d-like symmetry in their intra-unit-cell form factor. In this talk we will present calculations to show that these states are all originated from the same strong correlation inherent in the cuprates if we consider the strong correlation or the Mott physics correctly.
By carrying out the renormalized mean field theory based on Gutzwiller approximation, we showed that the t-J model or the strong coupling Hubbard model, depending on the doped hole concentration, a number of nearly degenerate solutions with unidirectional and bidirectional patterns besides the uniform superconducting states and states with long range antiferromagnetic orders. All of them have a modulation of pair field or a pair density wave intertwined with a charge density wave and some times also with a spin density wave together. Some of these patterns have large d-form factors for the intra-unit cell as seen by scanning tunneling spectroscopy[1]. Almost all the charge-ordered states vanish in the underdoped regime except one with a large d-form factor vanishes around 19% doping of holes as observed[2]. These states could also have a weak but uniform d-wave superconducting order. We predict that the bidirectional checkerboard pattern has a d-form factor as well. The genesis of these many kinds of stripes and checkerboards is purely due to the strong local Coulomb interaction. Charge orders and superconductivity are connate properties of cuprates.
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Tu-S22-CT1 / Recent advances in ferromagnetic superconductors

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Abstract
The coexistence of ferromagnetism and superconductivity(SC) in three uranium compounds UGe2, URhGe and UCoGe attracts much interest[1], because the spin-triplet state with equal spin paring and the unusual field-induced phenomena are realized. Their ordered moments are 1.5, 0.4 and 0.05 muB, respectively, and the 5f electrons with itinerant nature are believed to be responsible both for magnetism and for superconductivity. We focus on pressure (P) and magnetic field (H) response on the magnetic fluctuations and Fermi Surfaces and their feedback on superconductivity.
In UGe2, superconductivity mainly appears in the ferromagnetic state FM1 in the pressure range between Px and Pc, where the ferromagnetism switches from FM2 (strongly polarized phase) to FM1 (weakly polarized phase) at Px, and then the paramagnetism appears above Pc. The superconducting upper critical field Hc2 reacts with the metamagnetic transition between FM1 and FM2 when the field is applied along the easy-magnetization axis. Special attention is given on the field-reinforced superconductivity and the ferromagnetic fluctuations in URhGe and UCoGe. When the field is applied along the hard-magnetization axis (b-axis), the upper critical field Hc2 shows the unusual S-shaped or field-reentrant behavior in (H,T) phase diagram[2,3], extremely exceeding the Pauli limit. The strong Ising-type magnetic fluctuations are demonstrated by the anisotropic field-dependent effective mass. Quite recent Hall effect[4] and thermopower macroscopic measurements[5] in URhGe and UCoGe suggest Fermi surface change at high fields. Direct evidences are confirmed by dHvA, SdH effect and the quantum oscillations in thermopower[5].
In URhGe, pressure moves the system deeper in the ferromagnetic domain, H reentrant SC collapses more rapidly than low field ones. On the other hand, in UCoGe, the great interest is that a moderate pressure Pc of 1GPa is sufficient to enter in the paramagnetic ground state. Furthermore as the initial sublattice magnetization is low, collapse of ferromagnetism may be dominated by the ferromagnetic fluctuations; new careful pressure studies of Hc2(T) with anisotropic field response will be reported[6] and discussed on the basis on the interplay between magnetic fluctuations and Fermi surface topology. Finally, thermal conductivity experiments on UCoGe at ambient pressure emphasize the multiband character of its superconductivity[7].

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Tu-S23-CT1 / Berry phases and the intrinsic thermal Hall effect in high temperature cuprate superconductors

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Abstract
Bogolyubov quasiparticles (qps) move in a practically uniform magnetic field in the vortex state of high temperature cuprate superconductors. When set in motion by an externally applied heat current, jQ, the qps' trajectories may bend, causing a temperature gradient perpendicular to jQ, and the applied field H, and resulting in the thermal Hall effect. Here we relate this effect to the Berry curvature of qp magnetic sub-bands, and calculate the dependence of the intrinsic thermal Hall conductivity on T, superconductor's temperature, H, and Δ, the amplitude of the d-wave pairing. The intrinsic contribution to the thermal Hall conductivity displays a rapid onset with increasing T, which compares favorably with existing experiments at high H on the highest purity samples. Because such temperature onset is related to Δ, our finding may help to settle a much-debated question of the bulk value of the pairing strength in cuprate superconductors in magnetic field.

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Tu-S24_CT1 / Fluctuations in the electron system of a superconductor exposed to a photon flux

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Abstract
In a superconductor, in which electrons are paired, the density of unpaired electrons should become zero when approaching zero temperature. Radiation detectors based on breaking of pairs promise supreme sensitivity, which we demonstrate using an aluminium superconducting microwave resonator. We show that the resonator also enables the study of the response of the electron system of the superconductor to pair-breaking photons, microwave photons and varying temperatures. A large range in radiation power (at 1.54 THz), from zeptowatts to picowatts, can be chosen by carefully filtering the radiation from a blackbody source. We identify two regimes. At high radiation power, fluctuations in the electron system caused by the random arrival rate of the photons are resolved, the fundamental source of fluctuations in this type of detectors, a measurement of which also gives a straightforward measure of the optical efficiency. We demonstrate an unprecedented detector sensitivity for microwave resonators [1]. At low radiation power, fluctuations are dominated by excess quasiparticles, the number of which is measured through their recombination lifetime. These excess quasiparticles are shown to be created by the microwave readout signal. The latter is an intricate effect, because microwaves cannot directly destroy Cooper pairs. We will briefly touch upon the redistribution of quasiparticles due to microwave absorption, which on top of creating excess quasiparticles causes fascinating effects in the electrodynamics of the superconductor [2].

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Tu-S25-CT1 / Fluctuating orders and quenched randomness in the cuprates

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Abstract
We study a quasi-2D classical Landau-Ginzburg-Wilson effective field theory in the presence of quenched disorder in which incommensurate charge-density wave and superconducting orders are intertwined. The disorder precludes long-range charge-density wave order, but not superconducting or nematic order. We select three representative sets of input parameters and compute the corresponding charge-density wave structure factors using both large-N techniques and classical Monte Carlo simulations. Where nematicity and superconductivity coexist at low temperature, the peak height of the charge-density wave structure factor decreases monotonically as a function of increasing temperature, unlike what is seen in X-ray experiments on YBa2Cu3O6+x. Conversely, where the thermal evolution of the charge-density wave structure factor qualitatively agrees with experiments, the nematic correlation length, computed to one-loop order, is shorter than the charge-density wave correlation length.

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We-S26_CT1 / Correlation strength and Tc: quantum oscillations in YBa2Cu408 under hydrostatic pressure

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Abstract
The unusual normal state electronic structure of the cuprates is widely believed to be at the heart of understanding high-temperature superconductivity in these materials. Recent quantum oscillation measurements in YBa2Cu3O7-d (Y123) have found a strong increase in the quasiparticle effective mass close to two separate critical points in the temperature-doping phase diagram [1]. Here we present a study of quantum oscillations in the double chain cuprate superconductor YBa2Cu4O8 (Y124). Instead of varying the doping by changing d (in Y123) we study the evolution of the quantum oscillations under hydrostatic pressure. Pressure increases Tc by around 0.6K/kbar, primarily, it is thought, by increasing charge transfer between the chains and planes. Unlike in Y123, where the increase in Tc close to optimal doping is accompanied by a strong increase in quasiparticle mass, in Y124 we find that the mass decreases. Our results suggest that the mechanism that leads to the mass enhancement in the cuprates (most likely the emergence of a competing charge density wave instability) does not directly lead to an enhancement of the superconducting critical temperature.

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We-S26-CT2 / Diffuse electron density in optimally doped YBa2Cu3O7-δ: A Compton scattering study

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Abstract
The Fermi surface topology is one of the most important properties of metallic systems. While the angle-resolved photoemission experiments on underdoped YBa2Cu3O6.5 have shown disconnected Fermi-arcs [1], quantum oscillation measurements in high magnetic fields have found small Fermi surface pockets [2-3], leading to recent excitement about the Fermi surface of cuprates. Here we present results using a bulk-sensitive probe of the two-dimensional electron momentum density (2D-EMD) of optimally doped, de-twinned, YBa2Cu3O7-δ by high-resolution X-ray Compton scattering [4]. The results provide a clear and detailed picture of the EMD. The 2D-EMD is reconstructed from directional Compton profiles, which show a strong in-plane anisotropy. The trace of the Fermi surface can be found in the gradient plot of the reconstructed occupation density. The shape and contrast in momentum density are broadly similar to local-density approximation (LDA) based calculations but also show significant differences from those calculations. In addition, detailed features at the Brillouin zone center are found. Modeling of possible Fermi surface pockets with the consideration of limited momentum resolution, we conclude that there is no trace of pockets in the optimally doped sample.

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We-S27-CT2 / Nematic fluctuations in iron-based superconductors probed by Raman scattering

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Abstract
Electronic analogues of nematic states, in which rotational symmetry is broken but translational invariance is preserved, have been proposed in a variety of correlated materials, such as quantum Hall systems, cuprates, ruthenates, heavy fermions , and, more recently, iron based superconductors. In the iron-based superconductors (Fe SC) several experiments have collected evidence that the tetragonal- to-orthorhombic structural transition is driven not by the lattice, but by electronic nematicity [1]. However it remains a challenge to disentangle the roles of the spin, charge, and orbital degrees of freedom in driving the nematic instability. Here we report electronic Raman scattering measurements which demonstrate the presence of charge nematic fluctuations in the tetragonal phase of several Fe SC systems [2,3,4], ranging from electron to hole doped (Ba,Sr)Fe2As2. In the case of electron (Co) doped (Ba,Sr)Fe2As2 these fluctuations extend over a significant doping range which include the superconducting dome. The diverging behavior of the fluctuations indicates the presence of an underlying charge nematic order in the Fe SC phase diagram. Our recent Raman results on FeSe will also be presented [4]. In FeSe the structural/nematic transition appears to be driven by charge/orbital degrees of freedom alone. This is evidenced by the presence of charge nematic fluctuations detected by Raman scattering, but the corresponding absence of spin fluctuations as indicated by NMR measurements in the tetragonal phase [5]. The findings have strong implications for the mechanism of the nematic/orthorhombic transition, but also on the possible role of nematic fluctuations in the Fe SC superconducting mechanism.

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We-S27-CT1 / A Reentrant C4 Phase in Hole-Doped $BaFe_2As_2$

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Abstract
The origin of nematicity and its implications for unconventional superconductivity is one of the most active topics of research in the iron-based superconductors [1]. Superconductivity emerges when antiferromagnetism is suppressed with doping or pressure, but the magnetic transition is also associated with a structural phase transition from tetragonal (C4) to orthorhombic (C2) symmetry, sometimes loosely called a nematic transition. Nematicity could be caused either by orbital order that induces antiferromagnetism or by magnetic fluctuations that break C4 symmetry and induce orbital order. Since the ground states are the same, it is difficult to distinguish these two models. We have recently observed an entirely new magnetic phase in hole-doped Ba1-xNaxFe2As2, in which C4 symmetry is restored below the C2 transition [2]. Like the C2 phase, the C4 phase is magnetic, but with a reorientation of the moment direction along the c-axis. It appears only when the C2 transition is close to being suppressed and superconductivity has emerged [3]. The C4 phase appears above Tc and coexists with superconductivity below, but shows evidence of much stronger phase competition with superconductivity than the C2 phase. A C4 phase is predicted by spin-nematic models, in which the original C2 phase results from a breaking of the symmetry of Fermi surface nesting between the hole pockets at Q=0 and electron pockets at QX and QY, respectively. When the nesting is weakened by hole-doping, magnetism can be stabilized by simultaneous coupling along both directions, restoring C4 symmetry. We have now established that the same phase is also present in other hole-doped BaFe2As2 and SrFe2As2 compounds, and we will discuss how differences in their phase diagrams throw light on the conditions necessary to stabilize the new phase.

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We-S28-CT1 / Breaking time reversal symmetry with pair density wave superconductivity

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Abstract
A variety of measurements reveal broken time reversal symmetry in the vicinity of the charge ordered region of the cuprate pseudogap phase. One candidate for the explanation of charge order, and for anomalous quasi-particle features seen in angle resolved photoemission (ARPES) measurements, is pair density wave (PDW) superconductivity. Here we show that PDW superconductivity naturally accounts for signatures of broken time reversal symmetry. In particular, we propose a PDW phase that accounts for intra-cell magnetic order and the Kerr effect, has charge density order consistent with x-ray scattering and nuclear magnetic resonance observations, and quasi-particle properties consistent with ARPES measurements.

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We-S28-CT2 / Spontaneously broken time-reversal symmetry in d-wave superconductors

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Abstract
Conventional superconductors are strong diamagnets that through the Meissner effect expel magnetic fields. It would therefore be surprising if a superconducting ground state would support spontaneous magnetics fields. Such time-reversal symmetry broken states have been proposed for the high-temperature superconductors, but their identification remains experimentally controversial.
Here we show a route to a low-temperature superconducting state with broken time-reversal symmetry that may accommodate currently conflicting experiments. This state is characterised by an unusual vortex pattern in the form of a necklace of fractional vortices around the perimeter of the material, where neighbouring vortices have opposite current circulation.
This vortex pattern is a result of a spectral rearrangement of current carrying states near the surfaces.

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We-S30-CT2 / Direct evidence of nodeless superconductivity in single layer FeSe grown on STO revealed by Muon spin rotation spectroscopy

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Abstract
FeSe is superconducting only with a Tc of 8 K [1] and SrTiO3 (STO) is insulating in nature, yet their interface effect on the single-layer FeSe exhibits possible two-dimensional superconductivity with a Tc as high as 109 K [2-6]. All the experiments performed to date have some but not enough conclusive evidence that the gap appearing in single-layer FeSe below critical temperature is induced due to the formation of cooper pairs and excludes others, such as magnetic, charge or spin density wave gaps. Thus the field awaits 'smoking gun' experiments that quell skepticism beyond reasonable doubt. It is therefore highly interesting to clarify the existence of the superfluid density if this system is indeed superconducting, its pairing mechanism, and gap symmetry in the single-layer FeSe. Here, we use low-energy (LE) muon spin rotation/relaxation (muSR) technique to directly observe superconductivity and its properties in the single-layer FeSe grown on STO. Our results clearly demonstrate that a superconducting gap appears in single-layer FeSe below 65 K. Zero-field muSR data shows that the ground state is non-magnetic and rule out the possible existence of a magnetic gap in this system. Transverse-field (TF)-muSR results reveal that the observed superfluid density can be well described by a simple BCS s-wave model which indicates for nodeless superconducting state in the single-layer FeSe and is consistence with its bulk counterpart.

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We-S30-CT1 / Quasiparticle Interference Imaging of One-Unit-Cell FeSe/$SrTiO_3$

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Abstract
The discovery of enhanced superconductivity in one-unit-cell (1 UC) FeSe/SrTiO3(001) with transition temperature (Tc) up to 110 K has generated much excitement, both to understand the mechanism underlying this interface effect and to engineer novel heterostructures with even higher Tc. We use a combined molecular beam epitaxy and scanning tunneling microscopy (MBE-STM) system to investigate 1 UC FeSe/SrTiO3(001) at the nanoscale. As-grown defects induce quasiparticle interference (QPI), by which we can map filled and empty electronic bands in momentum space. We uncover a Γ electron pocket 80 meV above the Fermi energy, which density functional theory (DFT) suggests arises from a hybridization of Fe 3d and Se 4p states. Furthermore, we extract the orbital characters and coherence factors of the scattering states from the QPI patterns. Comparisons are made with multilayer FeSe, which possesses a nematic order and nodal superconducting gap, in contrast to 1 UC FeSe/SrTiO3.

We-S32-CT1 / High Tc superconductivity and antiferromagnetism in Hg-based six-layered cuprates by Cu-NMR study

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Abstract
Superconducting transition temperature (Tc) generally rises in going from single(n=1) to three-layered (n=3) cuprates, however, it goes down from n=3 to 6 even when the carrier is optimally doped.
We report the emergence of antiferromagnetic(AFM) order at the inner planes (IPs) on the six-layered cuprates HgBa2Ca5Cu6O14+d (Hg1256) by means of site-selective Cu-NMR study. The AFM order takes place at IPs when n exceeds 5 even in the n layered cuprates with highest Tc in association with increase of the carrier imbalance between OP and IPs. On the one hand, the nearly paramagnetic outer plane (OP) is in optimally-doped state in such cases, which mainly sustains high Tc superconducting transition of Tc~100K at n=5 and 6. We present unique coexistence of AFM and superconductivity in n=6, and discuss the close relationship between AFM and high Tc superconductivity through the effects of the number of CuO2 planes in the optimally doped Hg-based cuprates from n=1 to 6.

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We-S32-CT2 / Electric Field Effect Studies in High-Tc Cuprates and Related Materials

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Abstract
We overview our systematic studies on electric field effect with ionic liquid gating applied to a range of electronic materials, including high-Tc cuprates. Such an approach may be crucial to modulate the carrier concentration in systems where chemical doping proved itself unpractical or failed. Initially we studied thin film devices that were made in an electrical double layer gating (EDLG) configuration on gated LSCO-214 monolayers grown by Molecular Beam Epitaxy. The shifts in Tc of up to 30 K were induced in films by an external electric field, reversibly driving the insulator-to-superconductor quantum phase transition. We have mesured the critical resistance, and it turned out to be precisely equal to the quantum resistance for pairs, RQ = h/(2e)2 = 6.5 kΩ. This is suggestive of a phase transition driven by quantum phase fluctuations. It implies the existence of 2D (interface) superconductivity, as well as of the 'Bose' insulator state with localized pairs. Furthermore, we have extended our studies to other related materials, including Sr0.9La0.1CuO2, SrCuO2, SrFeO3, SrRuO3, WO3, FeTe, highly ordered pyrolytic graphite and grapheme. So far, we have observed field-induced metallicity only in WO3. We have also developed a method to apply Coherent Bragg Rod Analysis (COBRA) to LSCO-214 samples while they are exposed to the EDLG. We discuss the implications of our results in light of emerging physics of high-Tc cuprates and related quantum materials.

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We-S33-CT1 / Observation of nodal superconductivity and superconducting dome in new layered superconductor $Ta_4Pd_3Te_{16}$

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Abstract
We measured the low-temperature thermal conductivity of a new layered superconductor with quasi-one-dimensional characteristics, the ternary telluride Ta4Pd3Te16 with transition temperature Tc = 4.3 K. The signicant residual linear term of thermal conductivity in zero magnetic field and its rapid field dependence provide evidences for nodes in the superconducting gap. By measuring resistivity under pressure, we find a superconducting dome in the temperature-pressure phase diagram. The existence of gap nodes and superconducting dome suggests unconventional superconductivity in Ta4Pd3Te16, which may relate to the competition between superconductivity and charge-density wave in this low-dimensional compound.

We-S33-CT2 / Superconductivity and Magnetism in TlCo2-xNixSe2 System

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Abstract
A series of single crystals TlCo2-xNixSe2 were successfully grown by using a self-melting method. The measurements of their structure, resistivity, magnetic susceptibility, specific heat and upper critical field were carried out. We have made the first observation of superconductivity in TlNi2Se2 at Tc=3.7K, and it appears to involve heavy electrons with an effective mass m*=(14-20)me, as inferred from the normal-state electronic specific heat and the upper critical field, Hc2(T). It was found that the TlCo2Se2 is an antiferromagnet with Neel temperature TN=89K, and that the TN value for TlCo2-xNixSe2 sytem varies non-monotonically with the Ni substitution concetration x, and reaches a maximum TN=129K at x=0.8. The AFM long-range oder disappeares in the compound with x=0.2. At the same time we determined their magnetic structure by the Neutron diffraction experiments. A new magnetic and superconducting phase diagram for TlCo2-xNixSe2 system was obtained, which is similar to that in cuprate- or iron-based, as well as the conventional heavy-fermion superconductors. We will present the discussions on its superconductivity in this system using the electronic structure determined by ARPES, the result of penetration depth and thermal conductivity measurements, the effect of pressure on its superconducting transition temperature, Tc, et al. TlNi2Se2, as a d-electron system with heavy electron superconductivity may be a bridge between cuprate- or iron-based, and the conventional heavy-fermion superconductors.

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We-S34-CT2 / Theoretical study of THz laser-induced Higgs-mode resonance in superconductors

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Abstract
A collective amplitude-mode oscillation inherent in superconductivity order parameter is known as "Higgs mode" in analogy with the Higgs particle in high-energy physics. The Higgs mode is a scalar-boson excitation without electric charge, magnetic moment, etc., so that the Higgs mode has long been eluded excitation and detection by external perturbations. Recently, a THz laser experiment revealed that intense laser fields irradiated to an ordinary superconductor induce a coherent oscillation of the order parameter with a frequency twice that of the pump light [1]. Even more interestingly, the induced oscillation is found to become resonant with the Higgs mode that gives rise to a giant third-harmonic generation, when the pump frequency matches half of the superconducting gap.
Here we provide a fundamental theory for describing this Higgs-resonance phenomenon and analyze various aspects [2]. Microscopically, the order-parameter oscillation is viewed as a collective precession of Anderson pseudospins. We analytically solve the Bogoliubov-de Gennes equation to show that the Anderson-pseudospin resonance emerges with a characteristic power-law divergence of the amplitude oscillation precisely at the resonance condition observed in the experiment. The resonance is accompanied by an anomalous jump in the phase by $\pi/2$. We further reveal how the resonance structure depends on temperature and on the electron-phonon coupling. Another interest is the effect of impurity scattering, which is here studied as well within the Abrikosov-Gor'kov theory. As for strongly-correlated superconductors, we employ the nonequilibrium dynamical mean-field theory [3] to take account of the effect of electron-electron scattering, which shows that the electron correlation generates a finite resonance width that corresponds to the lifetime of the Higgs mode.

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We-S34-CT1 / Photo-Enhanced Antinodal Conductivity in the Pseudogap Phase of High-Tc cuprates

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Abstract
A major challenge in understanding the cuprate superconductors is to clarify the nature of the fundamental electronic correlations that lead to the pseudogap phenomenon. We used ultrashort light pulses to prepare a non-thermal distribution of excitations, and we performed time-resolved broadband reflectivity measurements in order to capture novel properties that are hidden at equilibrium. Our framework unveils a universal pseudogap-like region in the temperature (T) and hole-doping (p) phase diagram, delimited by a well-defined T*neq(p) line. In this region the photoexcitation process leads to a quench of local correlations triggering the evolution of antinodal excitations from gapped (localized) to metallic (delocalized) quasi-particles characterized by a longer lifetime. This photoinduced antinodal metallicity finds a natural explanation in terms of the single-band Hubbard model, in which the short-range Coulomb repulsion leads to a k-space differentiation between “nodal” quasiparticles and antinodal excitations, whose self-energy diverges as in the insulating state.

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Nature Communications 5, 4353 (2014) and http://arxiv.org/abs/1405.5462
Photo-enhanced antinodal conductivity in the pseudogap state of high-Tc cuprates
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We-S35-CT2 / Kinematical spin-fluctuation pairing in cuprates

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Abstract
A microscopic theory of superconductivity in systems with strong electron correlations as cuprates is presented within the extended Hubbard model where the intersite Coulomb repulsion V and electron-phonon interaction are taken into account [1]. Both weak and strong Coulomb repulsion V is considered. The Dyson equation for the normal and pair Green functions expressed in terms of the Hubbard operators is derived using Mori-projection technique. The self-energy is calculated in the noncrossing approximation. A new energy scale of the order of kinetic energy of electrons W~ 2 eV emerges in the itraband hopping induced by the kinematical interaction for the Hubbard operators which is much larger than the exchange interaction J induced by the interband hopping. We found the d-wave pairing with high-Tc mediated by the kinematical spin-fluctuation interaction. Contributions coming from the realistic in cuprates intersite Coulomb repulsion and phonons turned out to be small since only L=2 harmonic of interactions gives a contribution to the d-wave pairing. Superconductivity can be suppressed only for a large intersite Coulomb repulsion V > W [2]. The kinematical interaction is absent in the spin-fermion models and is lost in the slave-boson (-fermion) models treated in the
mean-field approximation.

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We-S35-CT1 / Thermodynamic phase diagram under high magnetic fields in underdoped YBa2Cu3Oy single crystals

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Abstract
The interplay between superconductivity and any other competing order is a fundamental issue in various systems such as heavy fermions, organic or iron based superconductors and cuprates. In all those systems a superconducting dome develops in the vicinity of a quantum critical point and the possible role of critical fluctuations associated with this competing phase transition has rapidly been considered as a possible alternative to the standard phonon mediated coupling. The discovery of a major Fermi surface reconstruction in underdoped YBa2Cu3Oy (YBCO) [1] leading to the existence of a charge order [2] (CO) revived the debate on the origin of the coupling mechanism in high Tc cuprates. A first direct consequence of the competition between the CO and superconducting states is a drastic reduction of the upper critical field Hc2 down to Hc2(0) ~ 24 T for dopings p ~0.11-0.12 [3]. This offers the unique opportunity among cuprates to study the entire field-temperature (H-T) phase diagram down to the lowest temperatures.
We present here a detailed calorimetric study of this phase diagram in underdoped YBCO crystals (p ~ 0.10-0.12) through specific heat measurements, up to 34T. We have detected a clear anomaly in both the temperature and magnetic field dependence of the specific heat. The location of this anomaly in the H-T plane is compared to that found by other probes such as thermal conductivity, ultrasound attenuation and magnetic measurements. We will discuss the constraints imposed by these data on the Fermi surface reconstruction scenarios.

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We-S36-CT1 / Evidence for Pre-Formed Cooper Pairs in the Pseudogap Phase of Slightly Underdoped NdBa2Cu3O6+x

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Abstract
In the last years ultrafast experiments have contributed to shed new light on high-temperature superconductivity. In particular, tailored excitation in the mid-infrared spectral range was demonstrated to suppress competing structural and electronic orders and to promote a highly coherent state in several underdoped cuprates [1 - 4]. In $YBa_2Cu_3O_{6+x}$ this transient state was found to persist up to room temperature, evidenced by the enhancement of the superfluid strength in the THz response. The question whether the high coherence is the signature of a perfect conducting or of an exotic superconducting state at nonequilibrium still remains open. Here we address this problem from a spectroscopic point of view, by investigating a slightly underdoped sample of $NdBa_2Cu_3O_{6+x}$ through ultrafast spectroscopy in the optical regime. The use of a broadband detection scheme enables us to reveal evidence for quasiparticle (QP) excitation in a wide range of temperatures up to the pseudogap temperature scale T*. The existence of a QP spectral signature in the pseudogap phase, together with its peculiar temporal evolution and temperature dependence, can be directly related to the presence of a pairing gap for QP excitation. This observation leads to the hypothesis that the selective melting of a competing order using intense resonant mid-infrared pulses can establish coherence in pre-formed Cooper pairs underlying the pseudogap phase.

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We-S37-CT1 / Is Sr_2RuO_4 a chiral p-wave superconductor? Insights from edge currents and uniaxial strain

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Abstract
The prevailing candidate for the superconducting order parameter in Sr_2RuO_4 is chiral p-wave and signatures of this phase have been looked for experimentally. In this work, we discuss two of these experiments at the light of theoretical results obtained from a weak coupling RG calculation.
First, we show that the most favored chiral superconducting order parameter in Sr_2RuO_4 has Chern number $|C|=7$ in the weak coupling limit, owing to a dominant second neighbor pairing. Since it was shown that the edge currents of a $|C|>1$ superconductor vanish exactly in the continuum limit, and can be strongly reduced on the lattice, this form of order parameter could help resolve the conflict between experimental observation of time-reversal symmetry breaking and yet the absence of observed edge currents in Sr_2RuO_4 [1-2].
Second, the p-wave order parameter obtained from the RG calculation exhibits a large Tc enhancement under uniaxial strain along 100. This enhancement is symmetric for tensile and compressive strain, and shows no measurable cusp at zero strain, in agreement with experiments [3]. The absence of such a cusp is therefore not incompatible with a chiral p-wave state. Finally, we make predictions about the evolution of the superconducting state as a Van Hove singularity is crossed at larger strain.

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We-S38-CT1 / Superconductivity in the Ternary HfV_2Ga_4 compound

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Abstract
In this work we report superconductivity in the stoichiometric HfV_2Ga_4 compound with critical superconducting temperature close to 6 K. The samples were prepared from stoichiometric mixtures of Hf, V and Ga pieces (high purity > 99.999%) melted on a water cooled Cu hearth in an arc-furnace under Ar atmosphere with a Ti sponge getter. The single HfV_2Ga_4 phase was confirmed by x-ray powder diffraction. The superconducting bulk properties of this compound are confirmed and described by means of magnetization, electronic transport properties and specific heat measurements. In the framework of magnetization and resistivity measurements analyses, we obtain the thermodynamic critical field Hc from both heat capacity and magnetization data. The Heat capacity data are in agreement with conventional BCS theory which suggesting conventional superconducting behavior in this material. Those results show for the first time superconductivity in an $YbMo_2Al_4$ prototype structure.

We-S38-IT2 / Novel electronic state in the electron-doped high-Tc T'-superconductors observed by transport properties and muon spin relaxation

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Abstract
In order to investigate the electronic state relating to the Ce-free superconductivity in the parent compound of electron-doped high-Tc cuprates with the so-called T' structure [1,2], we have performed transport and muon-spin-relaxation (muSR) measurements of T'-Pr1.3-xLa0.7CexCuO4+d (PLCCO) single crystals and Ce-free T'-La1.8Eu0.2CuO4+d (LECO) polycrystals [3,4]. It has been found from the ab-plane electrical resistivity in PLCCO with x = 0.10 that a strongly localized state of carriers in the as-grown sample changes to a metallic state with a Kondo effect in the reduced superconducting (SC) sample. The Hall resistivity of the reduced SC sample of x = 0.10 has revealed the existence of both hole and electron carriers. The muSR spectra of PLCCO with x = 0.10 and LECO have revealed that, in the ground state, a long-range magnetic order of Cu spins in the as-grown sample changes to a short-range one coexisting with the superconductivity in the reduced SC sample. The formation of the short-range magnetic order due to a tiny amount of excess oxygen in the reduced SC sample suggests that the T'-cuprate exhibiting the Ce-free superconductivity is regarded as a strongly correlated electron system. These results can be explained in terms of a band picture based on the strong electron correlation [3]. That is, the collapse of the charge-transfer gap between the upper Hubbard band of the Cu3dx2-y2 orbital and O2p band due to the square planer coordination of oxygen in the T'-cuprate results in the generation of a finite density of states at the Fermi level due to O2p holes and Cu3dx2-y2 electrons without Ce substitution.

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We-S39-CT1 / High-resolution imaging of magnetic flux distributions in superconductors using polarized-rays

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Abstract
Magnetic flux structures in high-temperature superconductors can be observed using a high-resolution technique based on x-ray magnetic circular dichroism (XMCD) [1]. For that purpose superconducting samples have been coated with thin soft-magnetic layers of CoFeB as magnetic field sensors. Spatial resolved resonant x-ray absorption measurements are performed in an x-ray microscope under the influence of external magnetic fields at low temperatures. Both penetration and pinning of magnetic flux lead to an inhomogeneous reorientation of the ferromagnetic layer. Measuring the local magnetization of the ferromagnet with polarized x-rays allows the imaging of the magnetic flux distribution in the superconductor with high spatial and magnetic resolution [2]. Consequent optimization of the novel technique will enable the quantitative magnetic analysis of superconductors on the nanoscale.

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We-S40-CT1 / New insight into the cuprate phase diagram from neutron and X-ray scattering studies of $HgBa_2CuO_{4+\delta}$

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Abstract
I will review our extensive collaborative effort to understand the properties of the simple tetragonal cuprate superconductor $HgBa2CuO4+\delta$, with particular focus on recent neutron [1,2] and X-ray scattering [3] experiments that reveal an unusual magnetic response and charge-density-wave correlations below optimal doping. Comparison of these results with those for cuprates that feature a higher degree of disorder and/or lower structural symmetry gives new insight into the phase diagram of the cuprates.
This work has been supported by the US Department of Energy, Office of Basic Energy Sciences.

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Th-S42-CT2 / Structural instability, nearly-critical spin fluctuations, and superconductivity in KFe_2As_2 revealed by high-pressure NMR

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Abstract
KFe2As2 is a heavily hole-doped iron pnictide superconductor with d5.5 band-filling, which has a low TC (approx. 3.8 K) but shows strong spin fluctuations. Under pressure, TC first decreases as the pressure is increased, but rises again at pressures above 2 GPa. This peculiar behavior has drawn intensive attention to the distinctive Fermi surfaces, to orbital properties and selectivity, and to the pairing symmetry in the heavily hole-doped regime. Here we report a high-pressure 75As NMR study on KFe2As2 up to 2.42 GPa. At low pressures, we find no evidence for a structural transition, but at P = 2.42 GPa we observe a line splitting of the 75As satellite spectra below T = 40 K, which suggests the onset of a structural transition with associated orbital ordering. The low-energy spin fluctuations, measured from the spin-lattice relation rate 75T1, are very strong and decrease with pressure, suggesting a magnetic quantum critical point at a negative pressure of -0.6 GPa. We find in addition that the spin fluctuations change in lockstep with TC, showing the same non-monotonic pressure dependence: the onset of the structural transition is accompanied by the increase of spin fluctuations and of TC. These data demonstrate the complex electronic correlation effects dictating not only the spin and pairing fluctuations, but also the charge (valence) fluctuations, which determine the nature of superconductivity in iron pnictides near half band-filling (n = 5.5).

TH-S42-CT1 / Superconducting FeSe iron selenide: multi-techniques studies of new high quality crystals

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Abstract
Since mid-2013, a low-temperature growth method using chlorides and vapor transport has improved the quality of FeSe single crystals. This important step have boosted recently more detailed studies on this superconducting material with a very simple crystallographic structure and which does not order magnetically at low temperatures. Only an orthorhombic structural distortion occurs at about 10 × Tc before the superconducting state, linked to a nematic electronic state whose characteristics are currently widely investigated.
The crystals we obtained at Néel Institute by this method contain much less defects than the crystals obtained previously using high temperature or flux processes. Magnetic measurements showed very sharp transitions (~0.7K width) with onset Tc = 8.7K. Transport and specific heat measurements have confirmed these results and have clearly shown the signature of the tetragonal-orthorhombic structural transition at Ts = 85K. The temperature dependence of the London penetration length was also measured and modeled. High-temperature transport measurements in the 300-600K range showed a resistivity maximum at 350K, never reported before in single crystals studies. New high pressure measurements are ongoing.
Finally transport measurements until 8T and tunnel diode oscillator (TDO) based measurements in pulsed magnetic field up to 55T in Toulouse have established the temperature dependence of the Hc2 critical field. In particular a Pauli paramagnetic contribution has been found for H applied in the ab-plane. These measurements have also probed the topology of the Fermi surface in the normal state, with the observation of Shubnikov-de Haas quantum oscillations. Several Fourier components enter the SdH oscillations spectrum with frequencies definitely smaller than predicted by band structure calculations. ARPES measurements have also been performed in various conditions using SOLEIL synchrotron radiation. A splitting between the dxz and dyz energy bands as large as 50 meV at the M point in the Brillouin zone is clearly found providing a proof of the orbital order below Ts. Both high field TDO and ARPES measurements point towards a significant reconstruction of the Fermi surface at low temperature.

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Th-S43-CT1 / Superconductivity and quantum phase transitions at oxide interfaces

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Abstract
At the interface between insulating oxides such as SrTiO3/LaAlO3 or LaTiO3/SrTiO3, a superconducting two-dimensional electron gas (2DEG) has been discovered [1-3], whose carrier density can be tuned by applying a gate voltage. The unique possibility of modulating the superfluid density easily and continuously opens new perspectives to tackle fundamental issues in condensed matter physics, such as the Superconductor to Insulator Quantum Phase Transition (QPT) in a two-dimensional system.
Using two different external parameters, the magnetic field and the electric field, we explored the phase diagram of the 2DEG. As proposed theoretically [5], we point out that the system can be described as a disordered array of coupled superconducting puddles. Depending on the conductance, the observed critical behaviour is single (corresponding to the long-range phase coherence in the whole array) or double (one at intermediate distances belonging to the (2+1)D clean XY universality class related to local phase coherence, the other one to the array of puddles)[4]. Moreover, by retrieving the coherence-length critical exponent ν, we show that the quantum critical behaviour can be clean or dirty according to the Harris criterion, depending on whether the phase-coherence length is smaller or larger than the size of the puddles.
Finally, the electric-field driven QPT reveals an anomalous critical behavior. It can be understood if we assume that the dynamics in the Cooper pair channel is dominated by (nearly critical dynamical) density fluctuations in the low doping regime. This shades a new light on unexplained critical exponents found in the literature.

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Th-S43-CT2 / Magnetotransport Studies of Gated LaAlO3/SrTiO3 Interfaces

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Abstract
The two-dimensional electron liquid (2DEL) present at the interface between the insulating oxides LaAlO3 and SrTiO3 exhibits several fascinating properties, including superconductivity and a large spin-orbit coupling [1]. This system has attracted much attention for fundamental and applied studies due to the rich physics displayed and the possibilities offered to realize field-effect transistors and nanoscale devices [2]. Both the superconducting transition temperature and the spin-orbit interaction are tunable by an electric field using the SrTiO3 substrate as a back gate dielectric [3,4].
In this work, we report a detailed characterization of the magneto-transport and superconducting properties of top- and back-gated LaAlO3/SrTiO3 heterostructures. Efficient field effect tuning is achieved by using the LaAlO3 film and SrTiO3 substrate as top and back gate insulators respectively. A large asymmetry in the evolution of the sheet resistance, Hall resistance, and magneto-resistance is observed between top- and back-gate operation modes. Moreover, a more significant reduction in the mobility with the back-gate depletion mode is observed compared with the top-gate depletion mode. These asymmetric behaviors might be explained by the different effects of the top and back gates on the confinement potential of the electrons.

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Th-S44-CT1 / Mott Transition in Granular Aluminum films

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Abstract
Films consisted of 2 nm Al grains embedded in amorphous insulating Al oxide, known also as Granular Aluminum, show an enhanced Tc compared to that of bulk Al [1]. Recently, this enhanced superconductivity was shown to coexist with a Kondo-like behavior observed in the resistivity curves and negative magnetoresistance (MR) which scales as H/T [2]. All of these are indications for a spin-flip scattering mechanism between the conduction carriers and localized magnetic moments likely to be attributed to the granular structure. We show in this work [3] a direct evidence for free spins in granular Al films by muSR measurements. We use the measured spin concentration in order to investigate the origin of the MR increase as a function of the film resistivity [2]. We show that the electronic properties such as the effective mass and effective Fermi energy are altered as the film resistivity increases and grains are decoupled. At high resistivities a Heavy-Fermion like behavior is shown in the MR of our films. The effective Fermi energy reduces to the value of the electrostatic energy of the grain. We detect a Mott transition likely to occur at high resistivities due to the strong electron-electron interactions. The critical resistivity for the Mott transition is in agreement with the experimental evidences for a metal to insulator transition and superconducting to insulator transition in granular Al films.

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Th-S44-CT2 / The Higgs Mode in Disordered Superconductors Close to a Quantum Phase Transition

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Abstract
The concept of mass-generation via the Higgs mechanism was strongly inspired by earlier works on the Meissner-Ochsenfeld effect, as both, the Higgs mechanism and superconductivity, incorporate breaking of a continuous local symmetry. In quantum field theory, the excitations of longitudinal components of the Higgs field manifest as massive Higgs bosons, which just discovered only recently. Over decades, the analogous excitation in superconductors, the so-called Higgs mode, also remained elusive: Apart from its rapid decay into particle-hole pairs, its scalar nature prevents a direct coupling to optical probes and renders the Higgs mode usually invisible in BCS superconductors.
Following recent theories [1,2, 3], however, in two-dimensional superconductors close to the superconductor-insulator transition (SIT) the Higgs-mode threshold should shift in energy below the pairing gap 2Δ and become stable and well-defined. Furthermore, vicinity to the quantum critical point renders the superconducting state electronically inhomogeneous and the Higgs mode optically active. Strongly yet homogeneously disordered quasi-2D films of BCS superconductors InO or NbN, which have been identified as prime candidates for the SIT, therefore should provide an ideal testbed for tracing a stable Higgs mode.
For experimental verification, we measured the complex terahertz transmission and tunneling density of states of various disordered thin films of superconducting NbN and InO [4]. While the Higgs mode remains invisible to transport experiments, dynamical probes measure a convolution of the BCS-like response of the condensate and possible other collective excitations. By comparison, we identify an excess absorption at energies below 2Δ which cannot be accounted for by ordinary BCS-like quasiparticle dynamics and an absorption threshold that vanishes towards the SIT. General features of this excess absorption such as lineshape and disorder-dependence are in good agreement with theory. Consequently, we identify the excess absorption as a strong evidence of the Higgs mode in quantum critical superconductors.
Going beyond disordered superconductors, our findings can play a role in tracing collective modes in other quantum critical condensed matter systems and might influence related fields such as Bose-condensed ultra-cold atoms, quantum statistical mechanics and high energy physics.

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Th-S45-CT1 / Topological superconductivity and unconventional pairing in oxide interfaces

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Abstract
To pinpoint the microscopic mechanism for superconductivity has proven to be one of the most outstanding challenges in the physics of correlated quantum matter. Thus far, the most direct evidence for an electronic pairing mechanism is the observation of a new symmetry of the order parameter, as done in the cuprate high-temperature superconductors. Alternatively, global, topological invariants allow for a sharp discrimination between states of matter that cannot be transformed into each other adiabatically. In this talk we present an unconventional pairing state for the electron fluid in two-dimensional oxide interfaces and establish a direct link to the emergence of nontrivial topological invariants. Topological signatures, in particular Majorana
edge states, can then be used to detect the microscopic origin of superconductivity. In addition, we show that the density wave states that compete with superconductivity have very rich spatial textures (magnetic vortices, Skyrmions) and sensitively depend on the nature of the pairing interaction.

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Th-S45-CT3 / Chern structure in Sr2RuO4 thin films

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Abstract
The mathematical structure characterized by Chern numbers has yielded very important findings in both condensed-matter and high-energy physics. The quantum Hall effect in graphene provides the quantized Hall conductance of σH = (p/q)e2/h with p and q coprimes. The quantization of the Hall conductance and the statistics of quasiparticles are described from the Chern-Simons (CS) term in (2+1)-dimensional topological field theory. Recently, the magneto-electric effect of topological insulators/superconductors have been predicted theoretically from the existence of the Chern-Pontryagin term (topological θ-term with $\theta = \pm\pi$) in 3+1 dimensions. In strongly correlated superconductors and insulators, fractional Chern structures are particularly expected based on an analogy with the relation between the integer and fractional quantum Hall effects. The Chern structures may clarify the universality in nature. However, experimental evidence of Chern structures in superconductors has not yet been found.
Sr2RuO4 is a candidate for a spin-triplet and chiral p-wave superconductor in quasi-twodimensional electron systems , which is also known as a Chern superconductor with a non-zero Chern invariant. The spontaneously broken time-reversal and parity symmetry induced by the internal degrees of freedom of Cooper pairs provide topological transport phenomena such as gapless Majorana excitations in an edge or the core of vortices, the dynamics of unconventional vortices and zero-magnetic-field quantum Hall effects. To investigate the Chern structure for these novel phenomena, we have performed transport measurements in microscale Sr2RuO4 single crystal thin films. In our previous reports, we revealed that the current-voltage (I − V) curves violate parity with respect to the zero bias current due to the excitation of the Majorana-Wyle fermions along the chiral edge current of single domain Sr2RuO4 [1, 2]. Hence, transport measurements in the Hall-bar geometry of Sr2RuO4 single crystal thin films are important if we are to clarify the Chern structure of topologically protected novel quantum states.
In this presentation, we report the observation of a Chern structure in Sr2RuO4 single crystal thin films by measuring the electric transport properties[3]. Specifically, we have discovered the following: first, in the absence of an external magnetic field, the surface transport in Sr2RuO4 thin films exhibited a fractional quantum Hall conductance in the superconducting state; second, the fractional magnetic-fieldinduced electric polarization was observed under zero bias current; and third, the fractional axion angle $\theta = \pi/3$ is determined by observing the topological magneto-electric effect in Sr2RuO4 thin films.

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Th-S45-CT2 / Geometry, band structure, and pairing range dependence of topological defects in a chiral p-wave superconductor

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Abstract
Numerous experiments point to the spin-triplet chiral p-wave (CPW) state as the strongest candidate for the pairing state of Sr2RuO4. Chiral superconducting phases are topological superconducting phases that are characterized by a Chern number. Depending on the band filling, the CPW state has a Chern number C=±1 for nearest-neighbor pairing, and ±1 or ∓3 for next-to-nearest-neighbor pairing.
An important consequence of the topology is that spatial topological defects, where the Chern number changes, host quasiparticle bound states whose energy eigenvalues cross the bulk energy gap, and such that their total spectral flow is given by the jump in the Chern number through the defect.
In a CPW state we expect persistent currents to flow along the topological defects (here, surfaces and domain walls), and to generate local magnetic fields. While edge states have been observed by tunneling spectroscopy in Sr2RuO4, attempts to observe edge and domain wall currents have failed so far. Yet Josephson spectroscopy measurements revealed robust unconventional behaviors that can be related to nontrivial phase shifts which are expected in the presence of chiral domain walls. Our aim is to shed light on those questions based on a microscopic study of the edge and domain wall bound states in the CPW state.
Using a tight-binding model of a square lattice for the dominant gamma-band of Sr2RuO4 and assuming the CPW state (for |C|=1 and 3), we solve numerically the self-consistent Bogolyubov-de Gennes equations. We study the geometry, band structure, and pairing range dependence of the edge and domain wall states and discuss the current pattern that they generate. Peculiarly we consider two geometries, with the defects taken along the (100)-direction (i.e. along straight axes), and with the defects taken along the (110)-direction (i.e. along zigzag axes).
It turns out that, for a given topology, the edge and domain wall states and currents strongly depend on the band filling and the orientation of the defects. Peculiarly, changing the geometry can qualitatively affect the bound state spectrum and reverse the current directions giving rise to unusual current patterns.
We also obtain the most stable domain wall configurations. This goes beyond previous studies that were based on the low-filling properties of the CPW. We briefly discuss the consequences for the Josephson effect with a CPW superconductor.
As a conclusion, our work has important consequences for the characterization of the edge currents in a CPW superconductor and should be taken into account with regard to the issue of the observation of edge currents in Sr2RuO4. Furthermore, our work changes the picture of the most stable domain walls in the CPW state and naturally explains some of the unconventional behaviors observed in Josephson interferometry experiments involving Sr2RuO4.

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Th-S46-CT3 / Camelback-shaped band reconciles heavy electron behavior with weak electronic Coulomb correlations in superconducting $TlNi_2Se_2$

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Abstract
Using high-resolution photoemission spectroscopy and rst-principles calculations, we characterize superconducting TlNi2Se2 as a material with weak electronic Coulomb correlations leading to a bandwidth renormalization of 1.4. We identify a camelback-shaped band, whose energetic position strongly depends on the selenium height. While this feature is universal in transition metal pnictides, in TlNi2Se2 it lies in the immediate vicinity of the Fermi level, giving rise to a pronounced van Hove singularity. The resulting heavy band mass resolves the apparent puzzle of a large normal-state specic heat coecient (Phys. Rev. Lett. 112, 207001) in this weakly correlated compound.

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Th-S46-CT2 / Hunting down pairing bosons in cuprate high temperature superconductors

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Abstract
Superconductivity is caused by pairing of electrons resulting from virtual exchange of bosons. In low-temperature superconductors Cooper pairing is mediated by phonons, but for high-temperature superconductors the pairing interaction is not yet confidently known. I will describe our recent experimental study [1] which sheds light on this problem by performing a new type of non-equilibrium boson generation-detection spectroscopy. In contrast to the conventional tunneling spectroscopy we probe not the single electron current into the sample, but directly hunt down the emission of nonequilibrium bosons that are responsible for Cooper pairing. When non-equilibrium electrons recombine into Cooper pairs, the binding energy is carried away by recombination bosons that are mediating in pairing. Identification of such bosons provides a direct clue about the pairing ``glue". We employ intrinsic Josephson junctions, built in the crystalline structure of a layered Bi2Sr2CaCu2O8+d cuprate for generation and detection of recombination bosons. We observe that bosons are well defined and carry clear spectroscopic information about the superconducting energy gap. Bosons decay at a ~micrometer distance, which together with a ~ps decay time yields the boson propagation speed of 106 m/s. This is more than two orders of magnitude larger than the phononic (sound) velocity and is close to the electronic Fermi velocity. This provides a direct and unambiguous evidence for involvement of an unconventional electron-electron pairing mechanism in cuprates.

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Th-S46-CT1 / Electron self-energies and their role in setting the Tc in cuprates

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Abstract
In all conventional superconductors the pairing strength alone sets the majority of the physical properties including the superconducting transition temperature TC. In the cuprate high temperature superconductors, no such link has yet been found between the pairing interactions and TC. Using a new variant of photoelectron spectroscopy termed the TDoS (Tomographic Density of States) method we measure both the pair-forming (Delta) and a self energy/pair-breaking term (Gamma_S) as a function of sample type and sample temperature, and we make the measurements over a wide range of doping and temperatures within and outside of the pseudogap/competing order regimes. In all cases we find that TC is approximately set by a crossover between the pair-forming strength Delta and 3 times the self-energy term Gamma_s. In addition to departing from conventional superconductivity in which the pairing alone sets TC, these results indicate the great importance of the near-nodal self-energy effects, which may be more significant than the competing order/pseudogap effects. Finding a way to control these self-energy/pair-breaking interactions is thus a possible new route towards even higher superconducting transition temperatures.

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Th-S47-CT1 / Spin-state crossover model for the magnetism and superconductivity of iron pnictides

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Abstract
We present a minimal model describing magnetic and superconducting behavior of iron pnictides. Our model emerges as an effective model of the multi-orbital Hubbard model in the regime of large Hund's coupling and large interorbital hopping.
Assuming a coexistence of strongly correlated orbitals hosting magnetic moments and more itinerant bands, we first formulate a model for the former separately [1]. The key ingredient here is a dynamical mixing of quasi-degenerate spin states of Fe2+ ions by intersite electron hoppings. Due to this mixing, the usual exchange interaction of the local moments is complemented by Hamiltonian terms describing their creation/annihilation in a form of singlet pairs, and the local moments are of non-saturated spin-length resulting in a large magnetoelastic coupling due to the spin-length fluctuations. The model phase diagram shows an interesting antiferromagnetic phase where the long-range ordered moment varies widely, but the effective spin-length and the bandwidth of magnon spectra are universal, resolving the puzzle of large but fluctuating Fe-moments. The tendency of the local moments to form singlet pairs manifests itself in signatures of a large biquadratic coupling in the magnon spectra.
Further, we add the itinerant part to the model and inspect the coupled system. The interplay of the local moments and the band fermions gives rise to the dynamic magnetic susceptibility showing a universal high-energy behavior while its low-energy part is affected by the changes in the bands induced by superconductivity or the reconstruction upon entering the antiferromagnetic phase. The origin of the linear temperature dependence of the static spin susceptibility in the paramagnetic phase is also explained. Finally, when addressing superconductivity, we find that, in addition to the commonly used spin-fluctuation mediated interpocket pairing, our model leads to a large intrapocket pairing.

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Th-S47-CT2 / Evidence for spin-fluctuation induced pairing in Ba0.6K0.4Fe2As2

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Abstract
Experimental evidence of coupling mecanisms in superconductors is hard to obtain. Only in conventional superconductors with electron-phonon coupling the isotope effect or the inversion of the tunneling spectra provides robust evidence of the type of Cooper pair formation. In unconventional systems such as the cuprates or the iron-based systems coupling mechanisms remain elusive. In the iron-based systems spin, orbital or charge fluctuations may contribute. For further insight the electronic Raman effect of optimally doped Ba0.6K0.4Fe2As2 was studied in detail. Experimental results and an analysis of the spectra will be presented.1,2 The analysis is based on LDA band structure calculations and the subsequent derivation of effective non-resonant Raman vertices. Experimentally a narrow, emergent mode appears in the B1g (dx2-y2) Raman spectra only below Tc, well into the superconducting state and at an energy below twice the energy gap on the electron Fermi surface sheets. The Raman spectra can be reproduced quantitatively with estimates for the magnitude and momentum space structure of the s pairing gap on different Fermi surface sheets, as well as the identification of the emergent sharp feature as a Bardasis-Schrieffer exciton, formed as a Cooper pair bound state in a subdominant dx2-y2 channel. The binding energy of the exciton relative to the gap edge shows that the coupling strength in this subdominant dx2-y2 channel is as strong as 60% of that in the dominant s channel. This result suggests that the transition temperature in Ba0.6K0.4Fe2As2 is reduced since the dx2-y2 potential breaks pairs in the s ground state. This effect could explain the reduction of Tc on the overdoped side if, as expected theoretically, the relative strength of the dx2-y2 channel further increases. In Fe-based superconductors which lack central hole bands dx2-y2 may be the dominant pairing symmetry and, since a competing state is missing then, Tc may become substantial again. This scenario is a strong case for spin-fluctuation induced superconductivity in the Fe-based superconductors. In addition, this experiment along with the analysis is the first clear observation of the Bardasis-Schrieffer mode predicted in 1961.3

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Th-S48-CT1 / Development of high current cables and high field magnets at CRPP-SC

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Abstract
The Superconductivity Section of the Center for Research in Plasma Physics (CRPP-SC), EPFL is active in Low Temperature and High Temperature Superconducting technology for fusion and other applications. Most of the activities of CRPP-SC deals with the development and operation of SULTAN and EDIPO, the only test facilities worldwide able to test short length, high current (up to 100 kA), forced flow superconductors in high magnetic fields (up to 11 T) over a broad temperature range; the SULTAN test facility has a long and reliable history (over 30 years) in testing conductors for the fusion program. In fact all conductors (NbTi and Nb3Sn) for ITER coils and superconductors for other fusion magnets (like Wendelstein 7-X, HT7U, etc.) and large magnets (high field hybrid) are tested and qualified in SULTAN.
CRPP-SC is also participating in the European R&D activities on superconducting cables (LTS and HTS) for DEMO, the Fusion facility, successor of ITER, which should demonstrate the generation of electricity. CRRP-SC is involved in the design and test of improved Nb3Sn conductors: the innovative winding layout is a graded, layer wound with Nb3Sn and NbTi, aiming at minimizing the size and the cost of the superconductor. In contrast with the conductor for ITER, a Nb3Sn "react&wind" flat cable has been considered with copper segregation and thick steel conduit assembled by longitudinal weld. The conductor designs included electromagnetic and thermal-hydraulic analysis. A full size prototype conductor was manufactured in 2014 and the test is planned in 2015. In parallel also a high current HTS cable is being developed: two prototype cables, about 2 meters long have been manufactured. Each cable is composed of 20 strands, each containing 16 tapes 4 mm wide. The current capacity is comparable to the Nb3Sn cable for ITER. The two cables will be assembled in a sample which can be measured either in SULTAN or EDIPO facility. Relying on the accumulated experience, two cables (using coated conductor tapes) were designed for a DEMO class (80 kA) magnet.
Small scale activities are mainly focused on the development of high field insert coil for laboratory magnet using HTS (REBCO coated conductors). Various coils were prepared with and without electrical insulation, and the whole manufacturing process, (winding, splicing and impregnation) was adapted to coated conductors. Simulations and experiments are used to investigate a protection method against quenches.

Th-S48-CT2 / REBCO coated conductors for high field magnets: electro-mechanical properties and turn end requirements

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Abstract
Rare-earth-barium-copper-oxide (REBCO) tapes are now available from several industrial manufacturers and are very promising conductors in high field applications. Their use is envisaged in in laboratory magnets, NMR spectrometers and particle accelerators due to their ability to sustain high current density even in the highest magnetic background fields. For these applications, the reversible and irreversible effects of mechanical strain on the superconductors' current carrying capabilities play a critical role in the machines' design.
Thanks to their hard metal substrate, REBCO coated conductors exhibit high tolerances to axial strains and stresses. However, their properties strongly vary from manufacturer to manufacturer depending on the fabrication process, the electrical stabilization, the substrate material and the thickness. At present, the electro-mechanical characterizations of REBCO coated conductors are typically done at 77 K, self-field while comprehensive and comparative electro-mechanical characterizations close to the operating conditions of high field applications are needed.
In this work, the current carrying capabilities' strain and stress dependence of REBCO coated conductors from various industrial manufactures are investigated and compared at 4.2 K, 19 T using a 4 turn Walter's spring (WASP) system. Particular attention is devoted to the design of high field solenoid inserts, where the areas of highest strain are the inner layers' turn ends. In order to allow high field magnets' designers to choose the ideal material for their specific boundary conditions, the WASP investigations are accompanied by winding tests of the different REBCO tapes to small diameters.

Th-S48-CT3 / Evaluation of 6 kVA 3-Phase Current Limiting Transformer Operating by Flux Transfer

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Abstract
We have developed and tested a 6 kVA 3-phase model of the flux-transfer type “current-limiting” transformer. In the model, the primary and the secondary coils are placed on two independent iron cores, and, then, the two iron cores are coupled with each other by using a closed loop of YBCO superconducting tapes. The potential application of the transformer is based on the principle of the magnetic flux stability in the closed loop. We measured that the short circuit current in this arrangement smaller than the operational current in about 3 to 4 periods. Hence, the decreased fault current is not good enough for the conventional protection. The superconducting wire used for the transformer windings as closed loops is found to be very suitable for the effective fault current limiting. In the artificial fault cases, the fault time can be more than 1 s and that the device can operate continuously without any damage. The recovery time is found to be dependent on the serial or parallel superconducting wire arrangements with different coupling mechanisms between iron cores. These results are to be reported as new and detailed analysis with all accounts will be presented.

Th-S49-CT2 / Evidence for precursor superconducting pairing above Tc in underdoped cuprates from an analysis of the in-plane infrared response

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Abstract
We performed calculations of the in-plane infrared response of underdoped cuprate superconductors to clarify the origin of a characteristic dip feature which occurs in the published experimental spectra of the real part of the in-plane conductivity below an onset temperature Tons considerably higher than Tc and known from earlier studies of the c-axis infrared conductivity [1,2]. We provide several arguments, based on a detailed comparison of our results with the published experimental data of Refs. [3] and [4], confirming that the dip feature and the related features of the memory function $M(\omega)=M1(\omega)+iM2(\omega)$ (a peak in the spectra of M1 and a kink in those of M2) are due to superconducting pairing correlations that develop below Tons. In particular, we show that
(i) the dip feature, the peak and the kink of the low-temperature experimental data can be almost quantitatively reproduced by calculations based on a model of a d-wave superconductor, and that the formation of the dip feature in the experimental data below Tons is analogous to that in the spectra computed using the same model, below Tc;
(ii) Calculations based on simple models, for which the dip in the temperature range from Tc to Tons is unrelated to superconducting pairing, predict a shift of the onset of the dip at the high-energy side upon entering the superconducting state, that is not observed in the experimental data;
(iii) The conductivity data in conjunction with the recent photoemission data obtained by Reber and coworkers [5] imply the persistence of the coherence factor characteristic of superconducting pairing correlations in a broad range of temperatures above Tc.

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Th-S49-CT1 / Finite temperature effective field theory for a two-band Fermi gas in the BCS-BEC crossover

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Abstract
A finite temperature effective field theory has been derived [1, 2], capable of describing both single-band and two-band Fermi superfluids in the whole temperature range below the critical temperature. The developed method is applicable for strong-coupling superfluid systems, especially the ultracold Fermi gases in the BCS-BEC crossover regime. The effective field functional is obtained from a derivative expansion of the exact action up to second order both in space and time. A complete summation of the whole series in powers of the order parameter has been performed in each term of the derivative expansion. As a result, we obtain an effective field theory (EFT) representing a straightforward extension of several limiting theories. The present method retrieves the GL equation near the critical temperature and the Gross-Pitaevskii (GP) equation in the BEC regime. Also we reproduce the homogeneous results obtained within the microscopic path-integral formalism through the whole BEC-BCS crossover. In the limit of small temperatures, we retrieve the ground state energy obtained from the microscopic path-integral theory for Fermi superfluids, and for temperatures near the critical temperature, we obtain the standard Ginzburg-Landau expressions. We discuss several applications of the developed finite-temperature EFT. The present formalism has been applied to reveal the presence of two healing length scales in two-bandgap superfluid Fermi gases. We investigate the finite-temperature vortices and dark solitons [3] in the BCS-BEC crossover comparing the results with the Bogoliubov – deGennes (BdG) theory. In comparison with BdG, the finite temperature EFT allows us to consider the spatially inhomogeneous Fermi gases at arbitrary temperatures and arbitrary coupling strength with greatly reduced computation time. In some cases, our EFT description yields exact analytic solutions. Finally, we analyze the ground state parameters and spectra of collective excitations for two-band superfluid Fermi gases through the entire BCS-BEC crossover. The obtained spectra of collective excitations at finite temperatures are in a fair agreement with experiment.
This work was supported by the Flemish Research Foundation (FWO-Vl), project nrs. G.0370.09N, G.0180.09N, G.0115.12N, G.0119.12N, G.0122.12N and by the Scientific Research Network of the Research Foundation-Flanders, WO.033.09N, and by the Research Council of Antwerp University, project DOCPRO 2014 - 29778.

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Th-S50-CT2 / Unique Coulomb enhancement of superconducting correlations in the frustrated quarter-filled band

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Introduction:

Whether or not electron-electron (e-e) Coulomb interactions enhance superconducting pair correlations in the weakly doped quasi-two-dimensional (quasi-2D) Mott-Hubbard insulator remains contoversial. There is broad agreement, however, that the superconducting state can be reached from a strongly correlated insulating state with nonzero spin gap. Hypothetical examples of such unconventional insulators are 1/2-filled band even-leg Hubbard ladders or 2D lattices composed of weakly coupled ladders, but how these toy theoretical models could be related to real materials is also not clear. In contrast, we have previously shown that there is very strong tendency in the 1/4-filled band with strong e-e interactions, in both 1D and 2D, for charge carriers to pair up as local spin-singlets separated by pairs of vacant sites [1,2]. We argue theoretically, and demonstrate from high precision numerical calculations within the extended Hubbard model that for sufficiently large geometric lattice frustration, e-e interactions strongly enhance the superconducting pair-pair correlations at or near 1/4-filling, even as they are suppressed at other fillings.

Methods and Results:

We have calculated pair-pair correlations with s- and d-wave symmetries within the extended Hubbard model for four different anisotropic triangular lattices: 4x4, 6x6, 10x6 and 10x10, for varied anisotropy and for the complete range of carrier concentrations. We use exact diagonalization (for 4x4), Path Integral Renormalization Group [3] and the Constrained Path Quantum Monte Carlo approach [4] to investigate these finite clusters. We show that pair correlations are enhanced by the Hubbard U only at or very close to 1/4-filling. The nearest neighbor interaction V can actually enhance the pair correlations further.

Conclusions:

The remarkable bandfilling specificity gives fresh insight to the mechanism of superconductivity in the organic charge-transfer solids (CTS), which in all cases are 1/4-filled. There exist an unusually large number of other unconventional superconductors that share this bandfilling and lattice frustration with the CTS, including the superconducting spinels and the layered cobaltate Na_xCoO_2 . yH2O. In all these cases superconductivity is proximate to a fluctuating order that resembles the spin-singlet insulator we found earlier theoretically [1,2]. Elsewhere we have pointed out that superconducting metal-intercalated phenacenes should be also described as 1/4-filled [5]. Our work thus provides a broad new theoretical framework within which many different classes of correlated-electron may be understood.

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Th-S50-CT1 / The SU(2) symmetry in cuprate superconductors

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Abstract

In this talk we review the recent theoretical approach to the theory of high temperature superconductors, which considers the SU(2) rotation between d-wave pairing and the charge sector as a main player in the physics of these compounds [1-4]. We first discuss the role of this symmetry in the physics of the pG phase, its relation with AFM fluctuations and the recently observed charge orders in the under doped regime. We show recent numerical findings suggesting that the splitting of the SU(2) symmetry is minimal for a wide range of parameters, and gets smaller and smaller as the coupling is increased [4]. We argue that the collective mode associated with this symmetry corresponds to the A1g resonance observed in Raman scattering at 41 meV around optimal doping.

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Th-S50-CT3 / Signature of high temperature superconductivity in electron doped Sr_2IrO_4

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Abstract

Sr2IrO4 was predicted to be a high temperature superconductor upon electron doping since it highly resembles the cuprates in crystal structure, electronic structure and magnetic coupling constants. Here we report a scanning tunneling microscopy/spectroscopy study of Sr2IrO4 with surface electron doping by depositing potassium atoms. At the 0.5-0.7 monolayer K coverage, we observed a sharp, V-shaped gap with about 95% loss of density of state (DOS) at EF and visible coherence peaks. The gap magnitude is 25-30 meV for 0.5-0.6 ML K coverage and it closes around 50 K. These behaviors exhibit clear signature of superconductivity. Furthermore, we found that with increased electron doping, the system gradually evolves from aninsulating state to a normal metallic state, via a pseudogap-like state and possible superconducting state. Our data suggest possible high temperature superconductivity in electron doped Sr2IrO4, and its remarkable analogy to the cuprates.

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Fr-S51-CT1 / Excitation of Josephson plasmon in stripe ordered La2-xBaxCuO4 compounds: A possibility to study intertwined order parameters

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Abstract

Cuprate superconductors arise out of a parent Mott Insulating state through chemical doping. The transition temperature is dome shaped as a function of doping with holes, however there is a severe anomaly at x=1/8 doping. This anomaly has been explained through dynamical layer decoupling due to the intertwining of the superconducting order parameter to other collective excitations (like charge/spin density wave orders) 1. However a direct demonstration of the existence of coupled order parameters is lacking.

Cuprates along the c-axis are generally understood as a stack of intrinsic Josephson junctions consisting of superconducting Cu-O planes separated by insulating layers. The tunneling of superconducting Cooper pairs between the planes characterizes the c-axis electrodynamics in the superconducting state, which manifests as a sharp resonance in reflectivity (called Josephson Plasma Resonance (JPR)) at terahertz (THz) frequencies. THz spectroscopy is thus a powerful tool to monitor the interlayer superconducting coupling in these compounds2. This JPR is an infrared-active mode and associated with the Josephson phase gradient between the Cu-O planes. Excitation of the Josephson plasmon (or a creation of phase gradient between the Cu-O planes) can be achieved by the application of a strong terahertz field on ultrafast time scale3. The time evolution of the plasmon dynamics can then be followed with another, delayed THz pulse, providing insights about the coupling of the Josephson phase to other collective excitations. To this end, we investigate the dynamical interlayer Josephson coupling in stripe ordered La2-xBaxCuO4 compounds (x= 9.5% and 11.5%) through time-domain THz spectroscopy following its excitation by a strong single-cycle THz pump pulse generated through optical rectification in LiNbO33.

Excitation of the Josephson plasmon induces coherent oscillations of the interlayer tunneling in both x=9.5% and x=11.5% doped samples. Two modes are observed for LBCO 9.5% (0.35 THz and 0.8 THz) while one for LBCO 11.5% (0.35 THz). This novel observation may be explained by the coupling of the Josephson phase to other density waves.

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Fr-S51-CT2 / First principles quantum Monte Carlo simulations of inhomogeneity in doped cuprates

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Abstract

One of the more challenging aspects of the cuprate superconductors is that traditional electronic structure techniques like standard density functional theories do not describe these materials accurately. The reason for this is that the description of electron correlation in the density functionals is not sufficiently accurate. Our goal in this work is to use large-scale computer simulations to accurately account for electron correlation from first principles; that is, starting from the bare Coulomb interaction to derive the emergent physics of these materials.

Our method of choice is fixed node diffusion quantum Monte Carlo (FN-DMC), which samples many-body configurations of electrons directly. This allows us to study electron correlations in silico. To stabilize this method, we use the fixed node approximation, which introduces a variational constraint in the solution. This method has the desirable property that, given a trial wave function, it can always find a solution closer to the ground state.

With simple nodal constraints, we have found that calculated values for the superexchange, gap, and phonon frequencies for the undoped cuprates are in excellent agreement with experiment[1]. In these systems, we also showed that the magnetic degrees of freedom are coupled strongly to the phonon degrees of freedom, which may help explain some experimental results.

This talk will focus on the doped cuprates. Using the fixed node as a constraint, we have investigated the interaction of doped holes with the local moments. The lowest energy wave functions are ones with inherent electronic inhomogeneities. I will discuss what this result means in terms of the 3-band Emery model for this system.

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Fr-S52-CT1 / Fully non-empirical study on superconductivity in compressed sulfur hydrides

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Abstract

Recently, it has been discovered that H2S exhibits superconductivity under high pressures at ~190K, which is the new record of the superconducting transition temperature (Tc) [1]. Since the observed Tc is subject to the hydrogen isotope effect, this superconducting phase has been supposed to be induced by the phonon-induced conventional mechanism [1]. In fact, there have been ab initio calculations which have predicted strong electron-phonon coupling [2]. However, there are still puzzles. First, the crystal structure realized in the experimental situation has not been specified. If we estimate Tc of H2S using the conventional McMillan formula [2, 3], the calculated value is too low compared with the experimentally observed value. It has also been proposed that H3S phase instead emerges under high pressures [4,5]. Second, anomalously large hydrogen isotope effect coefficient a~1.0 has been observed. To further investigate the above points, we need to address not only the electron-phonon interaction but also the electron-electron Coulomb interaction in the HxS systems. Accurate evaluation of the impact of the pair breaking Coulomb repulsion is vital because this governs the absolute value of Tc, as well as a [3].

We study various possible structural phases of H2S and H3S [6] using the density functional theory for superconductors [7, 8]. This theory enables us to calculate Tc without any empirical parameter and therefore evaluate the effect of the screened Coulomb interaction on Tc and a. In the pressure range P<~150GPa, the experimentally observed high Tc (>130 K) is accurately reproduced by assuming that H2S decomposes into R3m-H3S and S, which indicates the relevance of R3m-H3S phase (and irrelevance of H2S phases) in this pressure regime. For the higher pressures, the calculated Tcs for Im3m-H3S are systematically higher than those for R3m-H3S and the experimentally observed maximum value (190 K), which suggests the possibility of another higher-Tc phase. We also quantify the isotope effect from first principles and demonstrate that the isotope effect coefficient can be larger than the conventional value (0.5) when multiple structural phases energetically compete.

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Fr-S52-CT2 / High Tc in hydrogen sulfide under pressure as a property of the electron-phonon system

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Abstract
Eliashberg theory generalized for the account of the peculiar properties of the finite zone width electron-phonon (EP) system with the non constant electron density of states, the electron-hole nonequivalence, chemical potential renormalization with frequency is used for the study of the most general properties of the normal and superconducting properties of the electron-phonon system. The pairing within the full width of the electron zone was taken into account, not just on the Fermi surface. It is found that the finiteness of the electron zone width in the derived anew Eliashberg equations together with the abrupt fall of the density of states above the Fermi surface are the crucial factors for the high temperature superconductivity appearance. It is shown that all necessary conditions for the manifestation of the high superconducting transition temperature are ideally implemented in the hydrogen sulfide under high pressure. The results of the calculations of the electron and phonon properties of the most thermodynamically favorable phase of hydrogen sulfide under pressure are used. These results are applied to the calculation of the superconducting properties of hydrogen sulfide under pressure. It is shown that the high Tc value of the hydrogen sulfide under pressure [1] is reproduced with the EP interaction constant not substantially exceeding unity.

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Fr-S53-CT2 / Electron-phonon Coupling and the Superconducting Phase Diagram of the LaAlO3-SrTiO3 Interface

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Abstract
The superconductor at the LaAlO3-SrTiO3 interface provides a model system for the study of two-dimensional superconductivity in the dilute carrier density limit. Here we experimentally address the pairing mechanism in this superconductor. We extract the electron-phonon spectral function from tunneling spectra and conclude, without ruling out contributions of further pairing channels, that electron-phonon mediated pairing is strong enough to account for the superconducting critical temperatures. Furthermore, we discuss the electron-phonon coupling in relation to the superconducting phase diagram. The electron-phonon spectral function only depends on the carrier density in the underdoped region of the phase diagram. The tunneling measurements reveal that the increase of the chemical potential with increasing carrier density levels off and is zero in the overdoped region of the phase diagram. This indicates that the additionally induced carriers do not populate the band that hosts the superconducting state and the superconducting order parameter therefore is weakened by the additional Coulomb interactions.

Fr-S53-CT1 / Superconducting Coupling Properties of Bi-Interface LaAlO3/SrTiO3 Heterostructures

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Abstract
The discovery of a two-dimensional electron liquid (2DEL), formed at the interface between the two band insulators LaAlO3 (LAO) and SrTiO3 (STO), has generated significant interest partly because of the opportunity to realize oxide nanoscale devices. The 2DEL oxide interface has revealed intriguing electronic properties including tunable superconductivity and a rich phase diagram. This interface naturally provides a versatile system to artificially build stacks of multiple 2-dimenstional (2D) superconductors that would allow coupled 2D superconducting layers to be studied.

However, one main obstacle is the realization of a fully metallic interface between LAO and STO thin films. By adopting an extremely high STO growth temperature, metallic, down to the lowest temperature, and superconducting 2DEL at interfaces between LAO layers and artificially-grown STO thin films can be achieved. [1] Following this path, (001) bi-layer LAO/STO heterostructures with two LAO/STO interfaces are successfully fabricated. We demonstrate that the 2DELs can be generated at both interfaces between LAO and STO thin-film, and/or between LAO and STO substrate. By inserting one monolayer of SrO between LAO thin-film and the STO substrate to remove the conductivity at the bottom interface, we reveal the superconducting properties of the top LAO/STO thin-film interface. In-plane and out-of-plane critical field measurements on this 2DEL, residing in the sandwiched STO thin-film layer, confirm the quality of the STO and reveal properties that are different than the ones of the standard LAO/STO interface.

Recent developments also show strong experimental evidence of the presence of superconducting coupling in functional bi-interface LaAlO3/SrTiO3 heterostructures.

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Fr-S54-CT2 / Scaling laws for thermo-electric transport at quantum criticality

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Abstract
It has long been speculated that the unusual transport phenomena observed in the strange metal phase of unconventional superconductors are due to a quantum critical point. Transport properties at quantum critical points however are strongly constrained by dimensional analysis. They are typically governed by two critical exponents: the dynamical critical exponent z determining the relative scaling of spatial and temporal coordinates and the hyperscaling violating exponent theta. We will show that in general response to electromagnetic fields requires a third exponent, an anomalous dimension for the coupling to background fields. We show that this exponent is generically non-zero in critical points constructed via holographic toy models and discuss its potential relevance to the physics of cuprates. In particular, we will show that the anomalous temperature scaling of five distinct transport quantities in the strange metal regime of the cuprate superconductors can be reproduced with only two nontrivial critical exponents. The quantities are: (i) the electrical resistivity, (ii) the Hall angle, (iii) the Hall Lorenz ratio, (iv) the magnetoresistance and (v) the thermopower. Our results will be compared and contrasted to other potential explanations of strange metal transport based on holographic toy models.

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Part of the talk will be based on
[1] Conductivities for Hyperscaling Violating Geometries, Andreas Karch (Washington U., Seattle). May 12, 2014. 17 pp., Published in JHEP 1406 (2014) 140 DOI: 10.1007/JHEP06(2014)140, e-Print: arXiv:1405.2926 [hep-th]wheras the bulk of the talk will be based on a paper with Sean Hartnoll to appear on the preprint arxive mid January 2015

Fr-S54-CT1 / Top-down approaches to holographic superconductors

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Abstract
Gauge/gravity duality is a new approach originating from string theory which in a matrix large N limit maps strongly coupled systems to weakly coupled gravity theories. This opens up new possibilities for studying strongly coupled systems. We applied this approach to a magnetic impurity coupled to strongly correlated electrons. Our string theory approach allows to identify the microscopic degrees of freedom of the model, unlike other, `bottom-up' approaches in gauge/gravity duality. Screening corresponds to a large N condensation mechanism, in which a bilinear operator, product of an electron and a slave fermion, condenses. This corresponds to a RG flow from a UV to an IR fixed point. We consider quantum quenches in this system by adding perturbations to either the UV or IR fixed point. We find different scenarios depending on the parameters, ranging from fast quenches to a decay of the perturbation. We also calculate the entanglement entropy by studying the backreaction of a hypersurface on the geometry. We find that the entanglement entropy decreases with the size of the entangling domain, demonstrating the presence of screening.

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Fr-S55-CT2 / Possible triplet superconductivity and its main features in the quasi-one-dimensional conductor $Li_{0.9}Mo_6O_{17}$

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Abstract
We theoretically analyze unusual experimental data [1] and make a conclusion that they can be explained only if the quasi-one-dimensional conductor Li0.9Mo6O17 is a triplet superconductor which is non-sensitive to the spin-splitting mechanism of a destruction of superconductivity [2]. We also show that a triplet nodeless scenario better corresponds to the experimental data than a triplet nodal scenario of superconductivity [3]. We pay attention on the fact that superconductivity can restore in the above mentioned compound at pulsed feasibly high magnetic fields of the order of 100 T [4,5] and describe the main features of this reentrant phase [6].

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Fr-S55-CT1 / NMR Studies on the Superconducting State of an Organic Doped Mott Insulator with a Isotropic Triangular Lattice, κ-$(BEDT\text{-}TTF)_4Hg_{2.89}Br_8$

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Abstract
Strongly correlated electrons have a wide variety of phase diagrams, which include novel electronic phases such as unconventional superconducting states. It is well known that the organic conductors, κ-(BEDT-TTF)2X, are prototypes for investigating Mott physics for half-filled band systems. Since organic compounds are highly compressible, pressure is a powerful method to develop and explore novel electronic phases. Superconducting phases appear by pressure via the Mott transition from an antiferromagnetic insulator in an anisotropic triangular-lattice system, κ-(BEDT-TTF)2Cu[N(CN)2]Cl, but from a spin-liquid insulator in an nearly isotropic triangular-lattice one, κ-(BEDT-TTF)2Cu2(CN)3. The title compound that has an isotropic triangular lattice has a unique place in κ-phase family, because it is a doped Mott insulator due to the non-stoichiometry of Hg, which causes 11% hole doping to a half-filled band. According to the pressure-temperature phase diagram of this material [1], a superconducting dome with maximally enhanced superconductivity of 6 K and a marginal-Fermi liquid characters in transport properties appear around 0.5 GPa where mobile carriers increase critically, suggesting a possible quantum phase transition between strongly and weakly correlated regimes [1].

We investigate on the normal and superconducting states by means of 13C NMR at ambient pressure and under pressure. At ambient pressure, we observed a huge enhancement of 1/T1T and rather broadened lines in a normal state at low temperature. On the other hand, under a pressure where Tc reaches the maximum, 6 K, the line width becomes small and shift is temperature independent in normal state. While these behaviors are reminiscent of a simple metallic state, 1/T1T shows a remarkable increase with decreasing temperature, dissimilar to the behavior of the conventional metals. On approaching the superconducting transition, however, 1/T1T shows pseudo-gap behavior, which has not been observed in the undoped triangular-lattice system κ-(BEDT-TTF)2Cu2(CN)3 [2]. On entering into the superconducting state, there appears no coherence peak but a sudden drop in 1/T1T. At lower temperatures, 1/T1T exhibits a power-law temperature dependence suggestive of nodal superconductivity.

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POSTERS

A: Cold atoms

A004 / Structure factor of ultra-cold bosons in two-dimensional optical lattices

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Abstract
We study the structure factor of the interacting ultra-cold atoms in a square optical lattice. Using a combined Bogoliubov method and the quantum-rotor approach, the Bose-Hubbard Hamiltonian of strongly interacting bosons is mapped onto the U(1)-phase action [1, 2]. This allows to calculate the momentum and energy dependence of the single- and two-particle correlation functions. The former leads to the spectral function and latter to dynamical structure factor, which are both determined in the presence of the Mott insulator and superfluid phases. It appear that a sharp coherence peak emerges resulting from the long-range order manifesting superfluidity [3]. On the other hand, correlation effects lead to the appearance of a smearing of the excitation spectra of incoherent particles although the remnants of the Bogoliubov band are still present in the part linked to coherent particles.

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B : Cuprate superconductors

B001 / On the itinerant-local dualism in the high Tc cuprates: an RVB perspective

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Abstract
The persistence of magnon excitation in heavily doped cuprates as found in RIXS measurements poses a serious challenge to our understanding of the physics of these systems. The fact that the same group of electrons that constitute the coherent quasiparticle excitation near Fermi surface are also responsible for the local moment behavior at high energy invalidates the use of most existing theories. In this talk, we will introduce our variational theory of spin fluctuation on the RVB ground state and its application to the physics of cupartes. The exact form of the magnon dispersion is derived in the single mode approximation for the t-t'-J model. When the Gutzwiller projected BCS state is used as the variational ground state, a spin-wave-like dispersion of about 2.2J is uncovered along the $\Gamma=(0,0)$ to $M=(\pi,0)$ line. Both the mode energy and the integrated intensity of the spin fluctuation spectrum are found to be almost doping independent in large doping range, which agrees very well with the observations of recent RIXS measurements. We also calculated the full spin