SUNSET 2017

School on Unconventional Superconductivity : Experiment and Theory

August 7th-19th, 2017 - IESC, Cargèse, Corsica, France

The school aims at bringing together Ph.D. students, young scientists and experts from all over the world to learn about new concepts in the field of unconventional superconductivity in a coherent and unified framework.

Topics

-- Multiband/multiorbital phenomena

-- Topological superconductivity; influence of spin-orbit coupling

-- Centrosymmetry & time reversal symmetry broken systems

-- Strong interactions and BCS-BEC crossover

-- Superconductivity in Artificial structures

-- Coexistence & competition with other phases

-- Novel aspects of disorder

Organizers

Veronique Brouet (U. Paris Sud)

Peter Hirschfeld (U. Florida)

Indranil Paul (U. Paris Diderot)

Ilya Vekhter (Louisiana State U.)

ICAM-I2CAM Institute for Complex Adaptive Matter

PALM Laboratoire d'Excellence Physique : Atomes Lumière Matière

More information and applications on :

https://www.phys.ufl.edu/sunset17/index.shtml

Invited speakers

Henri Alloul
Lara Benfatto
Jean-Pascal Brison
Stuart Brown
Tristan Cren
Ilya Eremin
Matthias Eschrig
Antoine Georges
Laura Greene
Peter Hirschfeld
Aharon Kapitulnik
Thilo Kopp
Jerome Lesueur
Nadya Mason
Mike Norman
Catherine Pépin
Alain Sacuto
Douglas Scalapino
Takasada Shibauchi
Pascal Simon
Louis Taillefer
Roser Valenti
Inna Vishik

SUMMARY

SUNSET'17 : Cargèse, 7-19 Août 2017					
Week 1					
Time	Tuesday, Aug. 8	Wednesday, Aug. 9	Thursday, Aug. 10	Friday, Aug. 11	Saturday, Aug. 12
8:45-9:00	Opening remarks				
9:00-10:00	Scalapino I	Scalapino II	Scalapino III	Kopp I	Alloul
10:00-11:00	Georges I	Taillefer II	Eremin II	Lesueur I	Kopp II
11:00-11:30	Break	Break	Break	Break	Break
11:30-12:30	Taillefer I	Georges II	Brison I	Georges III	Lesueur II
12:30- 2:30	Lunch	Lunch	Lunch	Lunch	Lunch
2:30-3:30	Benfatto I	Eremin I	Benfatto III	Brison II	Contributed
3:30-5:30	Break	Break	Break	Break	Break
5:30-6:30	Mason	Benfatto II	Posters	Valenti	
6:30-7:15	wiki organization	wiki	Posters	wiki	

Week 2					
Time	Monday, Aug. 14	Tuesday, Aug. 15	Wednesday, Aug. 16	Thursday, Aug. 17	Friday, Aug. 18
9:00-10:00	Shibauchi I	Brown I	Brown II	Kapitulnik II	Eschrig II
10:00-11:00	Greene	Shibauchi II	Kapitulnik I	Eschrig I	Vishik
11:00-11:30	Break	Break	Break	Break	Break
11:30-12:30	Simon I	Simon II	Shibauchi III	Contributed	Round table
12:30- 2:30	Lunch	Lunch	Lunch	Lunch	Lunch
2:30-3:30	Hirschfeld I	Hirschfeld II	Pepin II	Cren II	
3:30-5:30	Break	Break	Break	Break	
5:30-6:30	Posters	Pepin I	Cren I	Sacuto	
6:30-7:15	Posters	wiki	wiki	wiki	

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POSTERS, SESSION 1

1 - 30

1) ADACHI Kyosuke

Department of Physics, Kyoto University

Superconducting-fluctuation effects in strong-coupling regime

FeSe, one of the iron-based superconductors, has multi-band structure with small Fermi energies. Interestingly, in one of these bands, the magnitude of the superconducting gap is comparable to the Fermi energy. This suggests an exciting scenario (i) in which the attractive interaction among the electrons in FeSe is in the strong-coupling, or the BCS-BEC-crossover, regime [1]. In contrast, it is indicated as another scenario (ii) that the multi-band structure and the smallness of the Fermi energies are essential, while the unconventional strong interaction is unnecessary for the sizable superconducting gap [2].

To consider which of the scenarios (i) and (ii) is more relevant to FeSe, we focus on the superconducting-fluctuation (SCF) phenomena, which are caused by metastable Cooper pairs [3]. Regarding SCF effects, it has been observed on FeSe that the diamagnetic responses are much larger than those in the Gaussian-fluctuation approximation (GFA) and emerge far above the superconducting-transition temperature [4]. Therefore, it is important to investigate whether a model corresponding to each scenario can or cannot reproduce the SCF-induced large diamagnetism.

We first study the scenario (i) where electrons interact with a strong attractive interaction [5]. The short coherence length characteristic of the strong-coupling regime makes the interaction between SCFs significant. We find that this feature can lead to the large diamagnetic responses compared to those in the GFA, which are qualitatively consistent with the experiments on FeSe. Our results show that the SCF-induced specific heat will also become larger than that in the GFA. In addition, we find that the lowest-Landau-level scaling of thermodynamic quantities in high magnetic fields, which has been observed experimentally in cuprates [6] and theoretically in the weak-coupling regime, can break down in the strong-coupling regime. The investigation of SCF effects based on the scenario (ii) is ongoing.

[1] S. Kasahara et al, Proc. Natl. Acad. Sci. U.S.A. 111, 16309 (2014).

[2] A. V. Chubukov, I. Eremin, and D. V. Efremov, Phys. Rev. B 93, 174516 (2016).

[3] A. Larkin and A. Varlamov, "Theory of Fluctuations in Superconductors" (Clarendon Press, Oxford, 2005).

[4] S. Kasahara et al, Nat. Commun. 7, 12843 (2016).

[5] K. Adachi and R. Ikeda (in preparation).

[6] U. Welp et al., Phys. Rev. Lett. 67, 3180 (1991).

Citations

1. K. Adachi and R. Ikeda, "Fluctuation diamagnetism in two-band superconductors", Phys. Rev. B 93, 134503 (2016).
2. K. Adachi and R. Ikeda, "Possible Field–Temperature Phase Diagrams of Two-Band Superconductors with Paramagnetic Pair-Breaking", J. Phys. Soc. Jpn. 84, 064712 (2015).

2) ALSPAUGH David

Louisiana State University

Proximity-induced superconductivity in topological heterostructures

We revisit the nature and properties of topological superconductivity induced by the proximity effect in the surface states of topological insulators taking into account the presence of interface potentials. We consider proximity-induced pairing due to coupling to both singlet and triplet superconductors, and show that the resulting order parameter sensitively depends on the symmetries broken by the interface barriers. In particular, we analyze how the spin structure of the triplet order parameter affects the induced topological surface superconductivity. We obtain the surface density of states, compute the conductance for lateral heterostructures on top of the topological insulator, and discuss how Andreev spectroscopy can be used to determine the salient features of the interface superconducting order.

3) AUVRAY Nicolas

Université Paris Diderot

A la recherche de la nature du pseudogap dans le composé Nd-LSCO

Abstract not available

4) BAUER Carsten

Institute for Theoretical Physics, University of Cologne

Quantum criticality in metals

In many systems of strongly correlated electrons, it is believed that quantum critical points play a crucial role in determining the physics over certain regions of phase space. While quantum critical phenomena in insulators are relatively well understood, their metallic counterparts pose a substantial theoretical challenge since order parameter fluctuations can interact with gapless fermionic excitations on the Fermi surface. This interplay, however, allows for a competition of orders in the vicinity of a metallic quantum critical point including the formation of unconventional superconductivity when driving the metallic system through a phase transition.

Fortunately, for certain classes of metallic quantum critical points this rich physics can be studied by determinant quantum Monte Carlo simulations, without suffering from the notorious fermion ”sign problem”. I will present numerically exact studies of the antiferromagnetic quantum critical point in two spatial dimensions displaying unconventional superconductivity with d-wave symmetry and a "strange metal" phase with non-Fermi liquid correlations. Furthermore, I will discuss novel Machine Learning techniques to improve on the scalability of the determinant quantum Monte Carlo simulations.

5) BHATTACHARYYA Shinibali

University of Florida

Evaluation of orbitally resolved quasiparticle weight renormalization factors in Fe-based superconductors.

We study the dynamical quasiparticle scattering by spin and charge fluctuations in Fe-based pnictides within a multi-orbital tight-binding model with on-site interactions. The leading contribution to the scattering is calculated from the second-order self-energy diagram with the polarization operator calculated in the random-phase approximation. We find one-particle renormalization factors for orbital weights on each Fermi surface, from the first order frequency derivative of the real part of the dynamic self energy at the Fermi level. The orbitally resolved renormalization factor Z modifies the spin-fluctuation pairing through suppression of pair scattering processes in the corresponding orbital channel, resulting in orbital-selective Cooper pairing of electrons. We use the modified spin-fluctuation pairing interaction to compare our results with experimentally observed anisotropic gap structures of certain Fe-pnictides, to establish the validity of current phenomenological theories of orbitally selective spin fluctuation pairing.

6) BÔKER Jakob

Ruhr-Universität Bochum/Theoretische Physik III

s+is superconductivity with incipient bands: doping dependence and STM signatures

Motivated by the recent observations of small Fermi energies and comparatively large superconducting gaps, present on bands located below the Fermi energy (incipient bands) in iron-based superconductors, we analyse the doping evolution of superconductivity in a four-band model in the BCS-BEC crossover regime for the iron pnictides. Similar to the BCS case we find that with hole doping the phase difference between superconducting order parameters of the hole bands changes from 0 to pi through an intermediate s+is state breaking time-reversal symmetry. However, in the BCS-BEC crossover phase this transition occurs in the region where electron bands are already above the Fermi level and that the chemical potential renormalization leads to significant broadening of the $s+is$ region. This makes the observation of this phase easier in experiment. We further present the qualitative features of the s+is state that can be observed in scanning tunnelling microscopy (STM) experiments.

Citations

1. s+is Superconductivity with incipient bands: doping dependence and STM signatures. Jakob Böker*, Pavel A. Volkov*, Konstantin B. Efetov*, and Ilya Eremin* - *Institut fur Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum, Germany

7) **BRISTOW Matthew**

University of Oxford, Physics, Condensed Matter Physics

Exploring superconducting phase diagrams of single crystals of FeSe1-xSx and CaKFe4As4

CaKFe4As4 belongs to a new class of 1144 iron-based superconductors showing superconductivity at 35K without the need for doping, similar to a system close to the optimally doped regime. CaKFe4As4 has very large upper critical fields in excess of 60 T, making it potential candidate for practical applications. I will present a series of transport, magnetization and torque studies up to 16T to characterize the superconducting state of CaKFe4As4. In particular, I will discuss the superconducting phase diagram, the mixed state, its anisotropy and the nature of the vortex pinning in these new materials. These studies will be compared to the superconducting behaviour of the low Tc superconductors FeSe1-xSx, in which superconductivity is tuned as a function of the sulphur substitution. The upper critical field will be discussed in terms of both one band and two-band models.

8) CHAKRABORTY Debmalya

Institut de Physique Théorique, CEA, Saclay, France

Effect of impurities in strongly correlated d-wave superconductors: Disorder vs Strong electronic correlations

The strong repulsive electron-electron interactions are known to be significant for the high-temperature superconductors as they turn the undoped compound into an insulator. This is quite different from the metallic non-superconducting state of a standard isotropic superconductor. Disorder, on the other hand, is inherent to most real systems, especially high-temperature superconductors. We analyze the complex interplay of the strong correlations and impurities within an inhomogeneous mean field theory augmented with Gutzwiller approximation. We show that while strong correlations make superconductivity in this system immune to weak disorder, superconductivity is destroyed efficiently when disorder strength is comparable to the effective bandwidth. The initial robustness of superconductivity to weak disorder is attributed to the strong repulsive correlation that smears out charge inhomogeneities by reorganizing the hopping on the bonds of underlying lattice. In weak disorder limit, strong interactions are treated non-perturbatively using Schrieffer-Wolff transformation to obtain a low energy effective Hamiltonian and disorder potential is added to this description afterwards, which fails to account for the fact that if the potential difference across a bond is much larger than the hopping scale, it is energetically unfavorably for the electron to hop across that bond. Thus for strong disorder, we consider appropriate extension of Schrieffer-Wolff transformation which builds in the absence of hopping across bonds with large potential difference across them, and thus includes the Anderson mechanism of localization in a more direct way. The suppression of charge motion in regions of strong potential fluctuation leads to formation of Mott insulating patches, which anchor a larger non-superconducting region around them. The system thus breaks into islands of Mott insulating and superconducting regions, with Anderson insulating regions occurring along the boundary of these regions. Thus, electronic correlation and disorder, when both are strong, aid each other in destroying superconductivity, in contrast to their competition at weak disorder. We highlight our findings in the perspective of experimental signatures of substitutional impurities in cuprates.

Citations

1. Fate of Disorder-induced inhomogenieties in strongly correlated d-wave superconductors, Debmalya Chakraborty and Amit Ghosal, **New J. Phys. 16 (2014) 103018**
2. Effects of strong disorder in strongly correlated superconductors, Debmalya Chakraborty, Rajdeep Sensarma and Amit Ghosal, **Phys. Rev. B 95, 014516 (2017)**

9) **CHEN Xiao**

Department of Physics, University of Florida

Effect of nonmagnetic impurities on s± superconductivity in the presence of incipient bands

Several Fe chalcogenide superconductors without hole pockets at the Fermi level display high temperature superconductivity, in apparent contradiction to naive spin fluctuation pairing arguments. Recently, scanning tunneling microscopy measurements have measured the influence of impurities on some of these materials, and claimed that non-magnetic impurities do not create in-gap states, leading to the conclusion that the gap must be s++, i.e. conventional s wave with no gap sign change. Here we present various ways sign-changing gaps can be consistent with the absence of such bound states. In particular, we calculate the bound states for an s± system with a hole pocket below the Fermi level, and show that the nonmagnetic impurity bound state energy generically tracks the gap edge in the system, thereby rendering it unobservable. A failure to observe a bound state in the case of a nonmagnetic impurity can therefore not be used as an argument to exclude sign-changing pairing states.

Citations

1. X. Chen, V. Mishra, S. Maiti, and P. J. Hirschfeld, Phys. Rev. B 94, 054524 (2016).
2. X. Chen, S. Maiti, A. Linscheid, and P. J. Hirschfeld, Phys. Rev. B 92, 224514 (2015).

10) **CHONG Yi Xue**

LASSP, Physics Department, Cornell University

Visualizing Orbital-Selective Mottness and Cooper Pairing in FeSe

FeSe is the focus of intense research interest because of its unusual non-magnetic nematic state and because it forms the basis for achieving the highest critical temperatures of any iron-based superconductor. However, its Cooper pairing mechanism was unknown because an accurate knowledge of the momentum-space structure of superconducting energy gaps $(\vec{\boldsymbol{k}})$ on the different electron-bands $(\vec{\boldsymbol{k}})$ did not exist.

We used Bogoliubov quasiparticle interference (BQPI) imaging to determine the coherent Fermi surface geometry of the □□and □□bands of FeSe, and to measure their superconducting energy gaps $(\vec{\boldsymbol{k}})$ and $(\vec{\boldsymbol{k}})$. We showed both gaps are extremely anisotropic but nodeless, and are aligned along orthogonal crystal axes. Moreover, by implementing a novel phase-resolved single-impurity QPI technique, we demonstrated the sign change between $(\vec{\boldsymbol{k}})$ and $(\vec{\boldsymbol{k}})$. Based on a model in which the quasiparticle weight for states with dzy character exceed those with dzx which in turn exceed dxy, we show that this complex configuration of $\mathbf{\Delta\alpha}(\vec{\boldsymbol{k}})$ and $\mathbf{\Delta\varepsilon}(\vec{\boldsymbol{k}})$ is due to orbital-selective Cooper pairing of electrons in dyz orbitals.

Orbital selective Mottness, in which electrons of one orbital type exhibit Fermi liquid weak-interaction characteristics but those of another orbital exhibit quasi-localized strong-interaction phenomenology is the likely explanation. To test this hypothesis we predict the normal state QPI characteristics for the known band structure of FeSe but now using different quasiparticle weights for states with dzy, dzx and dxy character. The measured normal state QPI of FeSe in the energy range +-100meV are found to be in excellent agreement with the predictions from orbital selective decoherence in FeSe, based on same quasiparticle weights that are required to cause the observed orbital selective Cooper pairing. The challenge now is to understand the microscopic cause and strength of the orbital selective decoherence and how it influences the superconducting and nematic phases of FeSe.

Authors: Y. Chong, A. Kostin, P. Sprau, JC. Davis

Citation:

1. Sprau et. al, ArXiv e-prints (2016), 1611.02134

11) COOK Ashley

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Topological gapped edge states in fractional quantum Hall-superc

We propose and implement a numerical setup for studying edge states of fractional quantum Hall droplets with a superconducting instability. We focus on a time-reversal symmetric bilayer fractional quantum Hall system of Laughlin ν=1/3 states. The fully gapped edges carry a topological parafermionic degree of freedom that can encode quantum information protected against local perturbations. We numerically simulate such a system using exact diagonalization by restricting the calculation to the Laughlin quasihole subspace. We study the quantization of the total charge on each edge and show that the ground states are permuted by spin flux insertion and the parafermionic Josephson effect evidencing their topological nature and the Cooper pairing of fractionalized quasiparticles.

Citations

1. S. Ok, M. Legner, T. Neupert, A. M. Cook, arXiv:1703.03804
2. B. Yuan, J. P. Clancy, A. M. Cook, C. M. Thompson, J. Greedan, G. Cao, B.-C. Jeon, T.-W. Noh, M. H. Upton, D. Casa, T. Gog, A. Paramekanti, Y.-J. Kim, arXiv:1701.06584
3. A. M. Cook, B. M. Fregoso, F. de Juan, S. Coh, J. E. Moore, Nature Communications 8, 14176 (2017)
4. A. M. Cook, Phys. Rev. B 94, 205135 (2016)

12) **CSIRE Gabor**

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First principles based proximity effect of superconducting heterostructures

We investigate the proximity effect in superconductor-normal metal heterostructures based on first principles calculations with treating the pairing potential as an adjustable parameter. The superconducting order parameter (anomalous density) is obtained from the Greenfunction by solving the Kohn-Sham-Bogoliubov-de Gennes equations with the Screened Korringa-Kohn-Rostoker method. The results are interpreted for an Au/Nb (001) system. The layer resolved anomalous spectral function is also obtained which is closely related to the superconducting order parameter. We show that the proximity effect can be understood via the anomalous spectral function.

Citations

1. Gábor Csire, Balázs Újfalussy, József Cserti, Balázs Győrffy, Multiple scattering theory for superconducting heterostructures, Phys. Rev. B **91**, 165142 (2015)
2. Gábor Csire, József Cserti, Istvan Tüttő, Balázs Újfalussy, Prediction of superconducting transition temperatures of heterostructures based on the quasiparticle spectrum, Phys. Rev. B **94**, 104511 (2016)
3. Gábor Csire, Stephan Schönecker, Balázs Újfalussy, First-principles approach to thin uperconducting slabs and heterostructures, Phys. Rev. B **94**, 104502 (Rapid Communication) (2016)
4. Gábor Csire, József Cserti, Balázs Újfalussy,First principles based proximity effect of superconductor -- normal metal heterostructures, Journal of Physics: Condensed Matter **28**, 495701 (2016)

13) **CUI Tianbai**

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Rare region effects on the Ising-nematic quantum phase transition

The phase diagrams of several correlated electronic systems display an unusual type of electronic liquid-crystalline order, called Ising-nematic, in which the electronic degrees of freedom spontaneously break the tetragonal symmetry of the system. Here, we investigate theoretically the impact of rare regions, characteristic of disordered systems with random dilution, on the Ising-nematic quantum phase transition promoted by the partial melting of a density-wave phase. Although long-range Ising-nematic order takes place in droplets of all sizes, the onset of the transition and the character of the transition (i.e. second-order or first-order) depend on the size of the droplet. After averaging over the droplets, we find that the first-order quantum Ising-nematic transition of the clean system is smeared and behaves

essentially as a second-order transition. We attribute this behavior to an effective dimensional crossover, and discuss the experimental implications of our findings.

Citations

1. Tianbai Cui, Rafael Fernandes, Rare region effects on the Ising-nematic quantum phase transition (in preparation).
2. Tianbai Cui, Michael Schuett, Peter Orth, Rafael Fernandes, Quench dynamics of iron-based superconductors (in preparation).

14) DALDOCE PEREIRA Diego Oliver

Instituto de Física – Universidade Federal do Rio de Janeiro

Topological aspects of the superconductor Haldane model

Topological phase transitions are associated with changing of topological numbers. In the Haldane model, the electronic bands have a nontrivial topology characterized by the impossibility of defining uniquely the phase of the wave function over the entire Brillouin zone. In this work, we consider a chiral p-wave superconductor modelled by Haldane Hamiltonian with an on-site attractive interaction. By applying the BCS theory to this model, we analyze its characteristics and the phase transitions as a function of the different parameters of the Haldane model. In addition, we present some aspects of the topological nature of the appearing gap.

Citations

1. Yuxuan Wang, Gil Young Cho, Taylor L. Hughes, and Eduardo Fradkin. Phys. Rev. B 93, 134512 (2016)
2. Gang Xu, Biao Lian, Peizhe Tang, Xiao-Liang Qi, and Shou-Cheng Zhang. Phys. Rev. Lett. 117, 047001 (2016)

15) DROUIN-TOUCHETTE Victor

Rutgers University

Composite order in superfluids

The study of liquid crystals provides unusual insight into composite superfluids. In collaboration with Peter P. Orth from Iowa State University, Premala Chandra and Piers Coleman from Rutgers University and Tom Lubensky from University of Pennsylvania, a coupled XY model of a six-fold invariant field with a two-fold field is studied. This model could be physically realized in liquid crystals by the benzene ring orientational order of 54COOBC. The phase diagram is investigated through scaling arguments and cluster Monte-Carlo methods. We show that the Berezynskii-Kosterlitz-Thouless quasi-long-range phase persists at low temperature with finite coupling, but that the fields lock at a certain critical temperature, experiencing a relative 3-state Potts order. The phase diagram was surveyed both analytically, with an renormalization group treatment, and computationally, where the critical exponents and scaling relations have been obtained. We found a strange regime in which the Potts locking predates the BKT transition, and studied how one order influences the other. This interplay of BKT and Potts order in coupled systems provides valuable information on the emergence of an hidden order in superfluids and superconducting films. It is also valuable for the field of cold atoms, where such a model could be engineered.

Citations

1. K. Binder, Journal of Statistical Physics 24, 69 (1981)
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16) **FERREIRA DE OLIVEIRA Jaime**

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Elemental Tellurium is a semiconductor, which crystallizes in the trigonal structural phase. It exhibits strong spin-orbit coupling and has a relatively small band gap (~330 meV) at ambient pressure. Under the application of modest hydrostatic pressure, the spin orbit coupling increases, while the band gap narrows. DFT studies predict a complete closing of the band gap at ~16kbar, as well as the possible formation of a topologically insulating1 or Weyl metal phase2. However, experimental findings are at odds with theory and, instead, the band gap narrows and reaches a minimum value at 25kbar3, after which it starts widening again. We study under pressure and low temperatures monocrystalline Tellurium sample. Preliminary results suggest that the material undergoes a phase transition to a non-trivial insulating phase below 10K under the application of 6 kbar.

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17) FRACHET Mehdi

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Sound velocity investigation of static charge order in YBCO in high magnetic field

Unconventional superconductivity is one of the main challenge of condensed matter physics. Among such superconductors cuprates focus a lot of attention. Indeed they exhibit higher critical temperature than any other know superconductors.

The recent discovery of a **long-range charge density wave** (3D CDW) by Nuclear Magnetic Resonance (NMR), above a **treshold magnetic field *Hco***, in YBCO [1] has raised new prospect regarding the study of high-Tc cuprates superconductors. *Is this 3D CDW a generic feature of cuprates superconductors? What is the link between superconductivity and CDW?*

Here we report an experimental investigation of this 3D CDW as a function of hole doping *p* in YBCO using sound velocity, a **thermodynamic probe** able to resolve the most subtle phase transition [2].

Sound velocity measurements are performed via an **ultrasound pulse-echo technique**. During its propagation through the sample the acoustic wave acquires a phase. The evolution of this phase allows us to perform **very sensitive measurements of sound velocity variation**.

Two kinds of measurements have been performed: magnetic field sweep at a given temperature and temperature sweep at a given magnetic field. These measurements which have been done on ten different YBCO samples, with $0.07 < p < 0.15$, show that **3D CDW and superconductivity compete** with each other and ask new questions regarding the **link between Fermi-surface reconstruction and charge density wave.**

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18) GOLOSOV Denis

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A Description of Phases with Induced Hybridisation at Finite Temperatures

In an extended Falicov-Kimball model, an excitonic insulator phase can be stabilised at zero temperature. With increasing temperature, the excitonic order parameter (interaction-induced hybridisation on-site, characterised by the absolute value and phase) eventually becomes disordered, which involves fluctuations of both its phase and (at higher T) its absolute value. In order to build an adequate mean field description, it is important to clarify the nature of degrees of freedom associated with the phase and absolute value of the induced hybridisation, and the associated phase space volume. We show that the appropriate description, as well as the phase-space integration measure, is provided by the SU (4) parametrisation on-site. This allows to describe both the lower-temperature regime where phase fluctuations destroy the long-range order, and the higher temperature crossover corresponding to an asymptotic vanishing of the absolute value of the hybridisation. This picture is also relevant in other contexts, including the Kondo lattice model.

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19) HAN Xinloong

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Robust d-wave pairing symmetry in multi-orbital cobalt high temperature superconductors

The pairing symmetry of the newly proposed cobalt high temperature (high-Tc) superconductors formed by vertex shared cation-anion tetrahedral complexes is studied by the methods of mean field, random phase approximation (RPA) and functional renormalization group (FRG) analysis. The results of all these methods show that the dx2−y2 pairing symmetry is robustly favored near half filling. The

RPA and FRG methods, which are valid in weak interaction regions, predict that the superconducting state is also strongly orbital selective, namely the dx2−y2 orbital that has the largest density near half filling among the three t2g orbitals dominates superconducting pairing. These results suggest that the new materials, if synthesized, can provide indisputable test to high-Tc pairing mechanism and the validity of different theoretical methods.

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20) HECKER Matthias

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Lattice effects on the superfluid stiffness

The underdoped regime of the copper oxide superconductors with its rich set of physical features has been intensely debated over years, while the overdoped side, perceived as simple and said to follow a BCS behavior, has been mostly disregarded.

In a recent experiment on the overdoped side of $La{2-x}Sr_xCuO_4$, yet, a stark contrast between the BCS prediction on the superfluid stiffness and the measurement outcome has been observed.

We investigate whether the discrepancy in the superfluid stiffness can be rooted in the underlying lattice and the concomitant electronic dispersion relation.

In particular, we work out the impact of fluctuation corrections to the superfluid stiffness in a Galilei-non-invariant system.

21) HILE Cornelia

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Correlation-induced effective attractive interaction in multi-orbital Hubbard models

An adequate description in terms of effective low-energy models, which take into account the material dependence of complex systems such as the cuprates, represents a long-standing challenge for their theoretical description. We here analyse the screening of the interaction for the Emery model by using the constrained RPA. The generated momentum and frequency dependence exhibits a non-trivial behavior. In particular, we determine the doping and the t_pp-hopping parameter dependence which encodes the material dependence. Most interestingly, we find an effective attractive nearest-neighbour interaction which cannot be captured by a description in terms of a simple one-band model.

22) HUBER Sebastian

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Spectral function of a quantum dimer model for the pseudogap

We study a quanum dimer model [1, 2], which describes several key properties of the pseudogap phase of hole-doped cuprates at low hole density p. The configurations of the system are built from two species of dimers: Fermionic dimers that carry spin S = 1/2 and charge +e embedded in a resonating valence bond background of neutral bosonic spin singlet dimers.

The electron dispersion relation and quasiparticle residue are calculated in a Lanczos algorithm with twisted boundary conditions up to a system size of 8x8. In a semianalytic approach we use these results to study in a single mode approximation the electron spectral function. We then compute the electron spectral function using full exact diagonalization on a lattice of size 6x6 with twisted boundary conditions and find clear signature of the so-called pseudogap at the antinode [3].

In a second part we show the implementation of a dynamical cluster approximation [4] for a cluster of size 2x2 in order to calculate spectral properties of the quantum dimer model with higher resolution. The cluster impurity problem is solved using the numerical renormalization group technique. We first motivate an effective cluster model consisting of an impurity cluster of interacting dimers coupled to a bath of free fermions. The method includes the application of a logarithmic discretization scheme on the effective cluster model and its mapping on a four channel Wilson chain. The subsequent iterative diagonalization is performed using SU(2) and U(1) symmetry of the quantum dimer model.

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23) **ISHII Tomohiro**

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Tuning the Magnetic Quantum Criticality of Artificial Kondo Superlattices $CeRhIn_5/YbRhIn_5$

In the strongly correlated electron systems, non-Fermi liquid behavior, associated with the quantum fluctuations near a quantum critical point (QCP), has been one of the central issues. The heavy fermion systems are particularly suitable for this study, because the ground state can be tuned readily by control parameters other than temperature, such as magnetic field, pressure, or chemical substitution. In these heavy-fermion systems, a plethora of fascinating properties have been reported in the vicinity of a QCP.

Recently, a state-of-the-art molecular beam epitaxy (MBE) technique has been developed to fabricate an artificial Kondo superlattice, a superlattice with alyernating layers of $CeCoIn_5$ and $YbCoIn_5$ that are a few atomic layers thick. These artificially engineered materials provide a new platform to study the properties of two-dimensional 2D Kondo lattices, in contrast to the three-dimensional bulk materials [1][2].

Here, to study effects of reduced dimensions and the interfaces on antiferromagneticquantum criticality, we have fabricated superlattices of $CeRhIn_5(n)/YbRhIn_5(7)$, formed by alternating n layers of heavy fermion anti ferromagnetic $CeRhIn_5$ and 7 layers of normal metal $YbRhIn_5$. As n is reduced, the Kondo coherence temperature is suppressed due to the reduction of effective Kondo screening. The Neel temperature is gradually suppressed with $1/n$ and the quasiparticle mass is strongly enhanced, implying dimensional control toward a QCP. Magnetotransport measurements revealed that a quantum critical point is reached for n = 3 superlattice by applying small magnetic fields. Remarkably, the anisotropy of the quantum critical fields is opposite to the expectations from the magnetic susceptibility in bulk $CeRhIn_5$, suggesting that the Rashba spin-orbit interaction arising from the spatial inversion symmetry breaking at the interface plays a key role for tuning the quantum criticality in the two-dimensional Kondo lattice.

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24) KLUG Markus

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Interplay between iCDW order and Electronic Excitations in FeSe

The origin of the nematic transition at 90K in FeSe and its underlying mechanism including its relevance for superconductivity remain unknown. Recently, the possibility of an imaginary charge density wave order (iCDW), which breaks translational and time reversal symmetry, was proposed [1]. On this poster, the implications of iCDW long-range order for several experimental observables are investigated. This includes the response functions measured in inelastic neutron scattering and electronic Raman scattering. The emergence of a spin and charge gap as well as the possibility of new collective modes are discussed.

In case of strong spin orbit coupling, which seems to be an essential ingredient of FeSe, iCDW order may induce a spin density wave order (SDW), which has the same symmetry breaking characteristics. The implications of this effect for the electronic spectrum, which is experimentally accessible in ARPES measurements, are investigated and expressions for energy shifts at high symmetry points of the Brillouin Zone are derived. Finally, a possible induction of magnetic fields due to bond currents associated with static iCDW order is checked, which could serve as a unique experimental signature.

It is pointed out that as iCDW may induce SDW, so would SDW induce iCDW order. Thus, the obtained results provide new experimental signatures also applicable to electronic systems such as Ba(FeAs)2 where SDW order is the leading instability.

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Quantum chaos and out-of-time order correlation functions in graphene

Out-of-time order correlation functions of type $C=\langle A(t)B(0)A(t)B(0) \rangle_\beta$ are believed to be a reasonable measure of quantum chaos which manifests in an exponential growth of C with a certain Lyapunov exponent determined by the microscopic model under considerations. Recently, it was conjectured hat this Lyapunov exponent is be bounded by $\lambda^{-1} \leq 2\pi/\hbar\beta$ [1].

In this work we investigate the out-of-time order correlation functions in graphene subject to the long range Coulomb interaction. To this end we develop a formalism to capture the relevant effects which determines the dominant time dependence of C. We demonstrate that the critical Dirac fluid graphene is a good candidate for saturating the bound mentioned above.

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25) KROHP Fredrik Nicolai

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Triplet pairing superconductivity from the Hubbard Model

Mixed gradient terms in Ginzburg-Landau free energies are interesting since they have previously have been found to determine the core structure of vortices in multicomponent superconductors and lead to a 4fi phase difference in the components which is common in p-wave triplet pairing. So far these terms have been included in the GL free energy by group theoretical methods by considering the symmetry of the Hamiltonian and assuming the energy of the dominant mode to be significantly higher than competing eigenmodes. This approach precludes gaining an understanding of the origin of the superconductivity in these systems as well as the details of the coefficients in the theory. From a generalized negative U version of the Hubbard-model we use the functional integral formalism to derive such mixed gradient terms. This is done by a Hubbard-Stratonovich transformation in the pairing channel of the interaction term that results in an effective path integral over an order parameter with several components. Since this is an effective bosonic theory we can use the method of stationary phase to derive a mean field value of the order parameter and consider fluctuations about it. For a system close to the transition point, the mean fields of the order-parameter vanish and we can consider the fields as small fluctuations about it. Thus we expand the logarithm appearing in the effective action to second order in the fluctuating fields and further expand in small momenta to derive mixed gradient terms.

26) LABAT Dimitri

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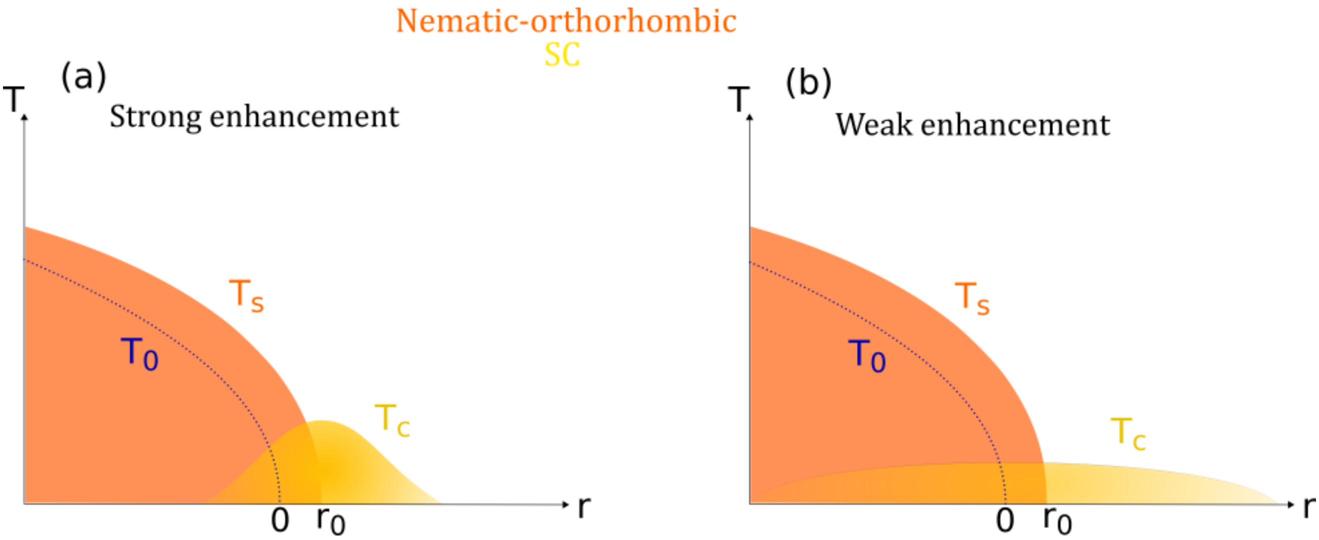
Enhancement of superconductivity near the lattice-coupled nematic quantum critical point in Iron-based superconductors

In the context of the Cu- and Fe-based high temperature superconductors (FeSC) theoretical studies1 have conjectured that the superconducting Tc increases significantly in the vicinity of a nematic quantum critical point (QCP). Such studies are based on electron-only models that ignore coupling between the electrons and the lattice strain that is invariably present. In this work we study the effect of this coupling. The effective static electronic interaction becomes gapped in all directions of the Brillouin zone with the exception two high-symmetry axes; along any other direction, the noncritical elastic constants cutoff the nematic fluctuations2. This lattice-generated cutoff allows us to analyze the problem within BCS theory right up to the QCP. Making use of the BCS-like linear gap equation, we show that there is a crossover between a regime of weak enhancement of the superconducting Tc, where the noncritical pairing interaction is dominant, and a regime of strong enhancement dominated by the nematic pairing interaction, provided that the nemato-elastic energy scale is sufficiently weak. These regimes are interpreted to cause the SC dome to be flat-shaped (fig. (b)) or peak-shaped (fig.(a)), respectively. The former is the case for FeSC, which exhibit strong nemato-elastic coupling3.



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27) LAKEHAL Massil

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Theoretical modeling of light induced transient magnetism in the iron arsenides

The recent development of ultra-fast lasers offers a new, out-of-equilibrium way to investigate the interplay of different degrees of freedom in a correlated system. In particular, a recent pump-probe study [1] on the iron arsenide BaFe2As2 has claimed that a transient magnetic phase is established over few picoseconds if the system is pumped from a paramagnetic phase. This transient magnetic phase has been shown to be intimately linked with the coherent excitation of the As A1g phonon by the laser pump. Motivated by this experimental observation, we develop a theoretical model that describes this out-of-equilibrium magnetic order at a microscopic level, and we make contact with equilibrium physics.

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28) LERICHE Raphaël

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Two-dimensional topological superconductivity in Pb/Co/Si(111)

Majorana particles are fermions which are their own antiparticles. They were first introduced in 1937 by Italian physicist Ettore Majorana. Such particles are likely to appear as quasiparticle excitations in topological superconductors.

A topological superconductor is a superconducting material with a non-trivial topological order. Several theoretical proposals suggest that topological superconductivity should be induced in superconductors with strong Rashba spin-orbit coupling in addition to Zeeman splitting.

The main goal of my PhD thesis is to engineer and study superconducting systems with 2D features and local magnetic structures using scanning tunneling microscopy/spectroscopy (STM/STS) under ultrahigh vacuum (UHV) and very low temperatures (300 mK).

In my poster, I will present recent results obtained in Pb/Co/Si (111) system. This system consists in a superconducting single atomic plane of Pb grown on a Si (111) substrate with magnetic clusters of Co buried underneath the Pb monolayer. Recent observations suggest that a strong Rashba spin-orbit coupling is present in the Pb monolayers such that in the areas above the Co magnetic clusters, both Zeeman splitting and Rashba spin-orbit coupling are at play. All the ingredients are gathered to realize topological superconductivity and we observed what we interpret as signatures of dispersive Majorana edge states.

Citations

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29) LI Yu

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Nodeless s-wave symmetry in the heavy-fermion superconductor $CeCu_2Si_2$

The superconductivity in heavy-fermion compound $CeCu_2Si_2$ is believed to be a nodal d-wave symmetry which induced by the magnetic fluctuations for the early years. But recently, many experiments with high quality samples have shown nodeless superconducting behaviors, which are still poorly understood theoretically. In here, we study the superconducting pairing symmetries with spin fluctuation mechanism in a multiband strong-coupling approach. By considering a phenomenological form of the susceptibility to capture the quantum critical spin fluctuations, we find nodeless s-wave (A_{1g}) solutions ($s^{\pm}$- or s^{++}-wave) are possible when the interband coupling dominated. It is the first theoretical evidence showing the nodeless behavior consistent with the experimental findings. And this semi-phenomenological theory have intrinsic difference from the scenario of the Fermi surface nesting, which may give a new hint on the theoretic mechanism of the spin fluctuation-mediated superconductivity

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Title and abstract not available

POSTERS, SESSION 2

31 - 61

31) LIU Xi

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Plain s-wave superconductivity in single-layer FeSe on SrTiO3 probed by scanning tunnelling microscopy

Single-layer FeSe film on SrTiO3(001) has recently come to the fore as an interfacial superconducting system, with a transition temperature that is significantly enhanced with respect to bulk FeSe. The mechanism for this enhancement, and indeed for the superconductivity itself, is therefore of great interest. Although the film has a simple Fermi surface topology, its pairing symmetry is unclear. By using low-temperature scanning tunnelling microscopy, we have systematically investigated the superconductivity of single-layer FeSe/SrTiO3 films, and report a fully gapped tunnelling spectrum and magnetic vortex lattice in the film. Quasi-particle interference patterns reveal scatterings between and within the electron pockets, and put constraints on possible pairing symmetries. By introducing impurity atoms onto the sample, we show that magnetic impurities such as Cr and Mn can locally suppress the superconductivity, but non-magnetic impurities (Zn, Ag and K) do not. Our results indicate that single-layer FeSe/SrTiO3 has a plain s-wave pairing symmetry, with an order parameter that has the same phase on all Fermi surface sections.

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32) LIZAIRE Maude

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Search for the pseudogap cr itical point in the cuprate superconductor Bi2201

Recent measurements of the resistivity and Hall coefficient in cuprates at high magnetic fields have revealed a new signature of the critical point p* where the pseudogap phase ends at T=0 in the

absence of superconductivity: the carrier density drops abruptly from n = 1+p above p* to n = p below [1,2].

Here we report on our search for such a signature in the cuprate superconductor Bi2201, whose pseudogap critical point was located through NMR [3] and ARPES [4] studies. We report the first results of our measurements of transport coefficients in overdoped samples of Bi2201 in magnetic fields large enough to access the normal state at T tending to 0.

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[4] T. Kondo *et al*, Nat. Phys. **7**, 21 (2011).

33) LOCHNER Felix

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Structural Properties of the New Iron-based Superconductor CaKFe4As4

The iron-based superconductor CaKFe4As4 is one of the most famous representatives of the new 1144 family of iron pnictides. Because of the combination of alcali and alcaline-earth metals CaKFe4As4 is hole-doped and reaches a transition temperature of Tc=35 K [1]. We calculate the electronic structure and internal parameters for CaKFe4As4 using density functional theory (DFT) and compare them with the corresponding 122 compounds CaFe2As2 and KFe2As2. Based on the DFT results, we furthermore introduce a tight-binding Hamiltonian to investigate the symmetry of the system and the electronic correlations. Herby we focus on the orbital-resolved electronic band-structure employing the leading angular harmonics approximation (LAHA) and determine in this way the structure of the superconducting gap. In contrast to other iron-based superconductors we find that the dz2-orbital shows a strong nesting and a strong contribution to the RPA-susceptibility. These insights could explain the high Tc values of this material.

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34) LORET Bastien

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Hallmark of the pseudogap in the superconducting state of cuprat.

Using Raman scaterring on underdoped Hg-1223 (Tc = 122K) at the antinodes, we observed that the superconducting pair-breaking peak is associated with a dip on its higher-energy side, disappearing together at Tc. This result reveals a key aspect of the unconventional pairing mechanism: spectral weight lost in the dip is transferred to the pair-breaking peak at lower energies. This conclusion is supported by cellular dynamical mean-field theory (CDMFT) on the Hubbard model, which is able to reproduce all the main features of the B1g Raman response and explain the peak-dip behavior in terms of a nontrivial relationship between the superconducting gap and the pseudogap.

Then we detected this hallmark of pseudogap in the superconducting state of various hole-doped cuprates showing its universality. In Bi-2212, we tracked this peak-dip feature as a function of doping p. The pseudogap reduces on the overdoped side, but it survives well above the optimal doping, and experimentally disappears above p = 0.22, the same doping level where the normal-state pseudogap collapses at a Lifshitz transition. This suggests that the pseudogap end-point in the T - p phase diagram is a vertical line.

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Broadening of the Berezinskii-Kosterlitz-Thouless transition by correlated disorder

The Berezinskii-Kosterlitz-Thouless (BKT) transition in two-dimensional superconductors is usually expected to be protected against disorder. However, its typical signatures in real system, like e.g. the superfluid-density jump, are often at odd with this expectation.

Understanding the role of the microscopic electronic disorder on the BKT transition within SC fermionic models is an incredible task, due mainly to the small size of systems accessible numerically. Alternatively, one can address the question directly within a proper phase-only model. A natural option is an XY model with random couplings, which mimics the random Josephson-like coupling between coarse-grained neighboring SC islands. By means of Monte Carlo simulations, we have shown that as long as the random coupling are spatially uncorrelated the Harris criterium guarantees that disorder is irrelevant, however the presence of spatially correlated disorder modifies the nucleation mechanism for vortex-antivortex pairs affecting the BKT transition. In particular, this leads to a considerable smearing of the universal superfluid-density jump as compared to the paradigmatic clean case, in agreement with experimental observations.

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36) MARTINEZ Vladimir

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Search for C-Axis Josephson Plasma in $La_{2-x}Ba_xCuO_4$

Reflectance spectra of superconducting $La_{2-x}Ba_xCuO_4$ on the ab-plane and c-axis in a widespread frequency range from 20-35000 cm^{-1}, doping from $0 \leq x \leq 0.155$ and temperatures above and below Tc have been studied. Strong doping dependence was found on the ab-plane, it was found that with increased doping there was a shift in the charge transfer band causing an increase in the low frequency optical conductivity [1]. On the c-axis however, insulating behavior was observed where others have seen a Josephson plasma edge. It was found in [1] that the Josephson plasma edge position was significantly affected by the superfluid oscillator strength, with decreasing oscillator strength the plasma edge shifted towards lower frequencies. The measurements made by [1] showed an absence of this plasma edge, although it has been seen in [2], this implies that there are scattering mechanisms that are causing a decrease in the superfluid density along the c-axis. These samples were polished with fine sand paper, which could have caused damage to the sample causing the absence of the plasma edge. Attempts to restore the Josephson plasma by annealing the sample will be made and measurements in the far and mid-infrared regions will be studied. Polarized reflectance at near normal incidence from 20-6000 cm^{-1} are made using a Bruker 113v Fourier Spectrometer. The samples are single crystals of $La_{2-x}Ba_xCuO_4$ grown by J. M. Tranquada and Genda Gu at Brookhaven National Laboratory using the traveling solvent floating zone method [3].

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Magnon-mediated interactions in the parent cuprates

After three decades of intensive research the pairing mechanism responsible for the formation of Cooper pairs in the high Tc cuprates is still not fully understood. One route towards a better theoretical understanding of the magnetic interactions leading to pairing is to study the propagation of two extra holes in the antiferromagnetic Mott insulating phase of the parent cuprates. While it is often assumed that the holes will form Zhang-Rice singlets and are well described by a single band t-J model, recent work by Ebrahimnejad et al. [1,2] and Lau et al. [3] shows that the quasiparticle properties of three-band cuprate models are qualitatively different from that of the t-J model. I present results obtained for the two-hole spectral function using the model introduced by Lau et al. and discuss the effect of magnon-mediated interactions in this model.

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38) MOSHE Aviv

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Multi-level Kondo effect and enhanced critical temperature in nanoscale granular Al.

We investigated the Kondo effect in two types of granular aluminum ($Al\text{-}Al_2O_3$) thin films, having an enhanced critical temperature up to three times more than bulk Al. The mentioned types of samples are obtained by sample preparation on liquid nitrogen cooled substrates or on room temperature substrates, where lower deposition temperature results in higher maximum Tc and smaller average grain size. In both types, upon decreasing the coupling between the grains Tc is first rising, up to a maximum Tc value where the coupling between the grains is "optimal", reducing the coupling between the grains further, Tc decreases until it vanishes at very low coupling. The degree of coupling is controlled by evaporation of clean Al in controlled partial O_2 pressure[1].

In both types, samples with maximum Tc shows almost no change in the normal state conductance curves as a function of temperature. In 2nm grain samples (liquid nitrogen deposition temperature), the normal state conductance shows non-monotonous temperature dependence. Upon cooling the conductance first rises, reaches a broad maximum, then decreases and finally increases again at low temperatures toward the superconducting transition[1]. 3 nm grain samples show a similar behavior but with one highly noticeable difference, the negative curvature, $d^2R/dT^2<0$ at high temperatures of the resistivity plot is very weak in contrast to 2nm grain samples where the negative curvature is clearly visible.

We will discuss these results in comparison with the theory of Florens et al[2], predicting that in a regime where the discrete level width exceeds the level separation, a multi-level Kondo effect is expected for quantum dots, showing a non-monotonous temperature dependence of the conductance. This interpretation of the experimental conductance data is in line with the previously reported presence of magnetic moments in these films[3].

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Development of a modular thermodynamic and thermal transport probe below 1K.

Precise measurement of the thermodynamic and thermal transport properties of superconducting materials has played a vital role in the development of our understanding of unconventional superconductivity. The temperature dependence of the specific heat at low temperatures can provide information about the overall symmetry of the superconducting gap in reciprocal space, elucidating possible electron pairing mechanisms. A key requirement is the ability to reliably perform these measurements at the lowest of temperatures and in high magnetic fields. A new multifunctional and modular platform for measurements of heat capacity and thermal transport at temperatures below 1K has been developed and is undergoing testing. The modular design allows the measurement of the specific heat of relatively small (<10mg) samples on a variety of cryogenic systems down to temperatures below 100 mK. The possibility of varying the orientation of samples has been included in the design, allowing variation of the direction of the applied magnetic field to measure any anisotropy of the specific heat and of other physical properties. Once completed, these extended experimental capabilities will be used to investigate a number of topical systems in the field of correlated electron systems, primarily in investigating the nature of the superconducting gap in YFe_2Ge_2 and the topological insulator SmB_6.

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Maximizing superconducting coupling strength in heavy-fermion hybrid superlattices of $CeCoIn_5/CeRhIn_5$

The interplay of magnetism and superconductivity is one of the central issues in condensed matter physics. In contrast to conventional superconductors mediated by phonons, it is believed that superconducting pairing is mediated by magnetic fluctuations in unconventional superconductors, such as cuprates and heavy-fermion compounds.

Heavy fermion $CeTIn_5$ (T = Co, Rh) compounds provide suitable platforms for the study of the interplay of magnetism and superconductivity because the ground states can be tuned readily by control parameters other than temperature, such as magnetic field, pressure, or chemical substitution [1]. An intriguing issue concerns how the superconductivity is modified when these fluctuations are directly injected through the interface.

Recently, a state-of-the-art molecular beam epitaxy (MBE) technique has been developed for fabricating multilayers of Ce-based heavy fermion materials [2, 3]. It has been shown that superconducting heavy quasiparticle as well as magnetism can be confined in a two-dimensional lattice with unit cell thick. This technique enables us to create an artificial interface of different materials such as a *d*-wave superconductor and an antiferromagnet.

Here, by using MBE, we fabricate hybrid superlattices consisting of alternating layers of *d*-wave superconductor $CeCoIn_5$ and spin-density-wave (SDW) metal $CeRhIn_5$. In these hybrid superlattices, we found the presence of both superconducting and SDW phases. At ambient pressure, the superconductivity is strongly Pauli limited. On the other hand, with approaching to the quantum critical point of $CeRhIn_5$ layers under applied pressure, the superconductivity is no longer Pauli limited. These results provide evidence of maximizing superconducting coupling strength in a superlattice structure built of superconducting layers and quantum critical layers.

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Competing order parameter symmetries in the extended attractive hubbard model

Superconductivity is a fascinating example of correlated quantum behavior driven by an effective attractive interaction between electrons. It is now well-known that in conventional BCS superconductors the effective attractive interaction is mediated via phonons, and leads to a spin-singlet pairing with s-wave symmetry [1]. Since the discovery of cuprates, heavy-fermion superconductors and iron-pnictides, it has become clear that phonons are not the only possible mediator for the attractive interaction [2-4]. In fact, the most important question that arises along with the discovery of any new superconducting material is: "what is the pairing glue?”. A first step towards answering this question is to understand the symmetries of the superconducting order parameter. Despite a large body of existing work on superconductors with different order parameters, a systematic exploration of the competition between different order parameter symmetries has been lacking [5-9].

In this work we make an effort to fill this gap by studying the competition between different superconducting order parameter symmetries in an electronic system with attractive interactions. As a generic model system we consider an attractive extended Hubbard Hamiltonian defined on a two-dimensional square lattice. In addition to the chemical potential μ, the model consists of two parameters: the on-site attraction strength U, and the inter-site attraction strength V. The model is well known to lead to an s-wave superconducting state for V=0 and a d-wave superconducting state for U=0. We employ a mean-field decoupling in the pairing channel, allowing for both singlet and triplet states, to write down the Bogoliubov-de Gennes mean-field Hamiltonian [10]. The model is then investigated for the existence of various possible superconducting order parameters using a combination of restricted (momentum-space) and unrestricted (real-space) self-consistent approaches. The parameter space of U, V and μ is explored and the competition between s-wave and d-wave superconducting phases is captured in the form of comprehensive U-V-n phase diagrams. Our main results include the possibility of coexistence of s-wave and d-wave superconducting orders in the intermediate density regime.

Evolution of quasiparticle dispersion from a s-wave to d-wave superconducting state is shown below. We uncover an interesting possibility of an s-wave wave order for U=0. The implications for experimentally observable quantities such as the local density of states are discussed. Finally we compare our results with those obtained via the recently proposed static auxiliary-field Monte-Carlo method [11]. The temperature and magnetic field dependence is also discussed.

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Strong correlations and the search for high-Tc superconductivity in chromium pnictides and chalcogenides

In 2010, Ishida and Liebsch published an article explaining that iron superconductors (with 6 electrons in 5 *d* orbitals) could be seen as electron-doped Mott systems from half-filling (with corresponds to 5 electrons in 5 *d* orbitals). In this 'doped-Mott scenario' we proposed [1] to search high-Tc superconductivity for the chromium analogues (with 6 electrons in 5 *d* orbitals) of iron pnictides, which would be the hole-doped Mott system. First, I will present some important results about the correlations in LaFeAsO by using the slave-spin formalism. Then, I will link these results with the ones obtained for the chromium pnictide, LaCrAsO. Finally, I will present the most favorable superconducting order parameter for the electron-doped LaCrAsO by using multiorbital RPA approach, as it seems to work on the iron counterpart.

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Title and abstract not available

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Strongly Enhanced Temperature Dependence of the chemical potential in FeSe

To understand high-temperature superconductivity and nematic ordering in the iron-based superconductors, it is necessary to obtain an accurate description and understanding of their electronic structure. FeSe is a prime candidate to study the unusual effects of superconductivity and nematicity in these systems, as it has a highly tunable superconducting transition temperature, ranging from 8 K in bulk to possibly over 100 K in monolayers on $SrTiO_3$ and, unlike most other iron-based superconductors, experiences a nematic phase transition below 90 K without any accompanying antiferromagnetic transition. Given the theoretical interest in understanding these phenomena, an accurate model of the electronic structure in the tetragonal phase is highly desirable.

To overcome the known limitations of ab-initio modelling in FeSe, we present a new set of hopping parameters for a 10-orbital tight binding model fitted directly to our latest high-resolution angle resolved photoemission spectroscopy (ARPES) data for the high temperature tetragonal phase of FeSe at 100 K [1]. These parameters quantitatively describe the experimentally observed quasiparticle band dispersions, including the recently observed 20 meV separation at the M/A point [2] as well as spin orbit coupling effects, providing a quantitatively accurate description for the low-energy dispersions observed in FeSe.

Using this parameter set we predict a surprisingly large 10 meV rigid shift of the chemical potential as a function of temperature between 100 K and 300 K. We have performed ARPES experiments on FeSe to confirm this prediction and observed an enhanced 25 meV rigid shift to the chemical potential in the same temperature range, resulting in several temperature induced Lifshitz transitions. This unexpectedly strong chemical potential shift has important implications for future theoretical models of superconductivity and of nematic ordering in FeSe.

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45) SATO Ryo

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Competition between d-wave Superconducting and Antiferromagnetic Orders in Cuprate

In the phase diagram of cuprate superconductors, various phases appear as the doping rate δ and temperature are varied. In low temperatures, the marked phases are antiferromagnetism (AF) at and near half filling (δ~0) and d-wave superconductivity (d-SC) around the optimum doping (δ~0.15). Although both phases are caused by spin correlation, they appear separately as δ is varied and do not coexist in most cuprates, except for the multi-layered systems. Thus, the interplay between AF and d-SC has been an intriguing and central subject in the research of cuprates.

In this presentation, we discuss this subject, applying a variational Monte Carlo (VMC) method to the two-dimensional Hubbard (t-t'-U) and t-J (t-t'-J) models (t': diagonal hopping integral). The principal aim is to consider in what conditions the two orders are coexistent or exclusive, construct a phase diagram in some model parameter spaces, and compare the two models. The VMC method is powerful to study strongly correlated systems because it treats local correlation factors exactly. In this method, the most important operation is to construct appropriate trial wave functions. We use pure AF, pure d-SC and a mixed (AF+d-SC) wave functions of Jastrow type, into which we introduce band-renormalization effects (BRE). In particular, we take account of BRE in the AF part for the first time.

We have estimated the areas of the two orders by varying the model parameters (t'/t, δ) and fixing U/t or J/t at typical values of cuprates. In the Hubbard model with U/t=12, almost all underdoped regime is occupied by AF orders, which becomes extremely stable by preserving the nesting condition through BRE. The d-SC is restricted to a narrow range of t'/t (~0) and always coexists with AF. Moreover, the state in this range is found to be unstable toward phase separation. The pure d-SC is allowed only in the overdoped regime of δ~0.20. By analyzing the pure states, we can reasonably interpret the present result. This result is clearly not consistent with experiments, but is common to recent results obtained by other schemes with high-accuracy calculations. In the t-J model with J/t=0.3, the features are basically similar to those of the Hubbard model. However, d-SC becomes the leading order for |t'/t|~ 0; such tendency is not found in the Hubbard model. Hence, d-SC is somewhat more favorable in the t-J model (J/t=0.3) than in the Hubbard model (U/t=12). Anyway, it is an important and urgent problem in theory to clarify why AF becomes so stable, or d-SC is not so stable.

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46) SATO Yuki

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Thermodynamic evidence for nematic phase transition at the onset of pseudogap in cuprates

One of the most important issues to understand the physics of superconductivity in cuprates is the origin and nature of the pseudogap (PG) state, where anomalous electronic states, including Fermi arc, charge density wave and d-wave superconductivity emerge. An intriguing open question is whether the PG state is a distinct thermodynamic phase characterized by broken symmetry. Some experiments in the PG state such as Nernst effect [1], transport [2], scanning tunneling microscopy[3] and polarized neutron diffraction[4] have revealed electronic nematicity with broken C_4 symmetry. However, no thermodynamic evidence for nematic phase transition has reported so far.

We use highly precise in-plane torque magnetometry, which is a thermodynamic probe particularly sensitive to a phase transition with broken rotational symmetry. In clean single crystals of

$YBa_2Cu_3O_x$ and $HgBa_2CuO_y$, in-plane magnetic anisotropy develops below T^* after exhibiting a distinct kink, which strongly implies the second order phase transition at the onset temperature of PG state. Our results suggest that PG state is a distinct thermodynamic phase with spontaneously broken C_4 symmetry, and more interestingly implies a potential link between the nematic fluctuation and strange metallic behaviour in the normal state, out of which high-Tc superconductivity appers.

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47) SCHWARZ Lukas

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Nonequilibrium dynamics in superconductors

We study ultrafast nonequilibrium phenomena in superconductors simulating pump-probe experiments. Thereby, a short laser pulse excites the superconductor nonadiabatically, which leads to oscillations in the quasiparticle distribution and consequently in the energy gap value. Such an excitation is equivalent to the Higgs mode in nonequilibrium of the symmetry-broken free energy potential represented by a Mexican hat.

The gap oscillation itself is not directly measurable, therefore, a second succeeding probe pulse is used to scan the state of the system at variable time delay. For such situations we perform calculations of the optical conductivity that also reveals characteristic intensity oscillations as a function of the time delay.

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48) **SEMENIUK Konstantin**

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Unconventional Superconductivity in the Layered Iron Germanide YFe_2Ge_2

YFe_2Ge_2 is a paramagnetic d-electron system which stands out due to the high Sommerfeld ratio of its specific heat capacity of 100 mJ/(mol K^2) and non Fermi-liquid $T^{3/2}$ power law temperature dependence of the electrical resistivity. The material was found to be superconducting below about 1.8 K [1].

Advances in YFe_2Ge_2 crystal growth allowed us to obtain high quality samples with residual resistivity ratios of the order of 200. Recent measurements of magnetisation and heat capacity provide further evidence for superconductivity, and the correlation between the transition temperature and the sample quality, the enhanced Sommerfeld coefficient and the anomalous T-dependence of the resistivity indicate that superconductivity in YFe_2Ge_2 is unconventional [2]. We report the results of detailed electrical resistivity measurements on YFe_2Ge_2 as a function of temperature, magnetic field and hydrostatic pressure, which provide further insight into the nature of superconducting and normal states of the material.

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49) **SERRIER BRINON GARCIA Lise**

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Stick-slip Phenomena and Memory Effects in Moving Vortex Matter

In a superconductor, the attractive interaction between the conduction electrons leads the system to condensate below a critical temperature of few Kelvin. Any applied magnetic field is expelled by the diamagnetic response of the superconducting condensate and thus until a critical value over which it penetrates the material collapsing into quanta of flux called vortices. Each vortex is constituted by a nanometric core where superconductivity is destroyed, while superconducting currents circulate around. They repel to each other by means of the magnetic flux lines and supercurrents and organized in lattices. Vortices are not generated spontaneously into the condensate but they penetrate by the edges, moving to reach the accurate locations. Vortex dynamics is consequently inherent to any magnetic field or supercurrent state affectations.

Furthermore, the defects intrinsically present in natural or artificial materials substantially modify the elastic properties and the mobility of vortex lattices. The theoretical efforts done on the topic were intense in the 90's but they were performed quasi exclusively on high-Tc superconductors and the experiments used global or indirect techniques only, consequently revealing specific of a few vortex dynamics with discrepancy. However, some researchers recently succeeded in moving vortices one by one like Auslaender et al. did using a magnetic tip to evidence anisotropic vortex displacements related to chains of oxygen vacancy and gap anisotropy in the cuprate YBaCuO. In the more conventional superconductor $NbSe_2$, scanning tunneling microscopy (STM) was used to directly image moving vortex lattices, confirming the peak effect analysis as a melting transition from an elastic phase to a plastic phase. These experiments are ones of the few carried with individually-probed vortex techniques necessary to validate the microscopic theories.

Recently, we have developed a new operating mode of the conventional STM technique to observe periodic vortex core trajectories with spatial and temporal resolution. A periodic motion is probed using an extended version of the so-called "Lazy fisherman method", in which a fisherman (STM tip) waits at a fixed position for a fish (vortex) to pass by. This method synchronized to the external excitation gives access to *the individual trajectory in real-time* and is applicable to virtually any scanning probe microscopy.

Here, we use this new technique to explore the vortex dynamics in interplay with the natural weak pinning landscape in $NbSe_2$. We provide the first direct observation of the *linear and collective motion of a Bragg vortex glass* in the so-called Campbell regime. Increasing the drives, the trajectories present striking nonlinear trajectories with a pinning-depinning process unrelated to local defects. Performing three-dimensional Langevin dynamics simulations, we demonstrate that the specific nonlinearity of the second regime is a *stick-slip motion* related to the collective pinning and the periodicity of the lattice. We additionally explore the impact of initial conditions at the transition between the two regimes and reveal an enhancement of the long-range correlations with the ac magnetic field cooling procedure. Finally, we explore the roughness of the pinning potential, causing creep phenomena at huge timescale.

The success of this work opens new possibilities to solve issues such as the dynamical channels related to the wave density charge in $NbSe_2$ or the memory effects observed in high-Tc superconductors.

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Compressibility divergence in Hund's Models

Hund's exchange coupling strongly influences the properties of correlated electron materials. Among the most important effects, there is a suppression (enhancement) of charge-fluctuations at (away from) half filling, changing the critical parameters of the Mott transition, as well as lowering the overall coherence.

Calculations based on the Slave-Spin method recently suggested a hitherto undiscovered instability of the Fermi-liquid, resulting in a divergence of the electronic compressibility. Motivated by these observations, we conducted a detailed finite temperature investigation on the influence of doping in 2- and 3-band Hubbard models with Hund's coupling, within Dynamical Mean Field Theory.

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Interaction between superconductor-ferromagnet thin films

Ferromagnetism and superconductivity have long been considered as antagonist phenomena. When the magnetic state of the ferromagnet is inhomogeneous, magnetic domains and domain walls can guide the vortices and spatially confine the superconductivity in an adjacent superconducting layer [1]. Additionally new physical phenomena like the proximity effect occur at the interface between a superconductor and an inhomogeneous ferromagnet.

On the application point of view, superconductor-ferromagnet thin films may lead to great improvements in spintronics [2]. Due to the perpendicular magnetic anisotropy and a periodic magnetic field distribution at the surface of FePd thin films, this structure can be used in bit-patterned media.

Our goal is to obtain an understanding of the proximity effect occurring between ferromagnetic thin films and superconducting layers. We want to investigate the effect of different magnetic domain structures of the ferromagnet onto a superconducting toplayer and vice versa, as well as the influence on the superconducting critical temperature.

As prototype system we use ferromagnetic FePd thin films with a toplayer of Nb as superconductor grown by Molecular-Beam-Epitaxy (MBE). To gain epitaxial growth the FePd is deposited on a buffer layer of Pd and Cr on a MgO substrate [3]. Deposited at 230°C, FePd grows in the L10-ordered phase with a magneto-crystalline anisotropy perpendicular to the surface plane with stripe-shaped domains. A chirality in the lateral domain structure on the surface has been evidenced by scattering of circularly polarized soft X-rays [4].

To investigate in particular the depth profile of the magnetic domain structure we use polarized Grazing-Incidence-Small-Angle-Neutron-Scattering (GISANS). The characterization of the macroscopic magnetization is performed with superconducting quantum interference detector (SQUID)-measurements. Furthermore the crystallography and layer thicknesses are measured with X-ray scattering, whereas the composition of the FePd compound layers are characterized with Rutherford Backscattering (RBS).

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Noise correlation spectroscopy for non-equilibrium measurements of low energy Raman modes of electronic and vibrational origin

In this contribution I will introduce the idea of performing noise correlation spectroscopy (NCS) experiments with ultrashort light pulses, in order to address the dynamical response of low energy Raman active modes in complex materials.

The central idea of NCS is to use stimulated Raman processes to imprint in the ultrashort light pulses correlation between different spectral components. In appropriate conditions, stimulated Raman processes can amplify the intrinsic noise which characterizes ultrashort light pulses at frequencies whose difference is resonant to the phonon mode.

By repeated measurements of the noise correlation between different spectral component introduced by the interaction between ultrashort light pulses and a sample, we will be able to retrieve the Raman response of materials.

We are confident that NCS will provide a useful tool to address the Raman modes in real materials. We stress that should NCS become viable, it will provide the possibility of measuring the Raman response in matter on a timescale solely limited by the pulse duration.

This would open new perspectives for non-equilibrium studies of electronic and vibrational degrees of freedom in complex materials.

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53) SVANIDZE Eteri

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Investigating the Role of Disorder, Electron Concentration, and Lattice Compression in Uranium-based Heavy Fermion Systems

Uranium intermetallic compounds exhibit a wide range of exotic properties -- unconventional superconductivity and quantum criticality, complex magnetic configurations, as well as heavy fermion and non-Fermi liquid behaviors. Moreover, while all of these phenomena are related to the degree of localization of the 5f electronic states, the complete understanding of underlying mechanisms is still lacking, explaining the unceasing interest in heavy fermion systems. One of the avenues in the search for heavy fermions has focused on compounds with high coordination number of U and, therefore, low concentration of U atoms. One such example is given by U2Zn17 - a heavy fermion antiferromagnet which exhibits a Sommerfeld coefficient g = 0.4 J/mol K2. In the presented work, the value of g was doubled by substituting all of Zn atoms by Cu and Ga, resulting in U2Cu17-xGax. This drastic effect is accompanied by non-Fermi liquid behavior. We analyze the relation between crystal structure, magnetic, and electronic properties of the U2Cu17-xGax compounds.

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Single gap superconductivity in Nb-doped $SrTiO_3$

Stochiometric $SrTiO_3$ exhibits three unoccupied electronic bands originating from the Ti t_{2g} orbitals. Upon doping with Nb or oxygen reduction charge carriers can be introduced, filling the electronic bands successively [1]. As a function of charge carrier density (which is one of the lowest among all superconductors) a superconducting dome is observed with a maximum transition temperature Tc≈0.3K. Therefore doped $SrTiO_3$ is considered as an ideal system to investigate multiband superconductivity [2]. Despite a long-running interest in the superconducting properties of doped $SrTiO_3$, many aspects concerning its possible multiband superconductivity remain enigmatic.

We performed microwave measurements on five Nb-doped $SrTiO_3$samples with charge carrier concentrations in a range of $n=0.3\times10^{20}$ cm^{-3} to 2.3×10^{20} cm^{-3} across the superconducting dome using stripline resonators [3]. Mounted in a dilution refrigerator, this technique allowed us to cover a frequency and temperature range from 2-23GHz and 0.07-0.4K respectively, smoothly crossing from $\hbar\omega << T_c k_B$ to $\hbar\omega >> T_c k_B$. We determined the frequency and temperature dependence of the complex optical conductivity $\sigma(\omega,T)$. This GHz conductivity gives us information on both the quasiparticles and the superconducting condensate, and we determine the temperature dependence of the superfluid density and the energy gap 2Δ. Despite significant deviations from single-gap behavior being expected for doped $SrTiO_3$, our data can be described with a single gap with a coupling ratio of $2\Delta_0 / k_B T_c \approx 3.5$ for all carrier concentrations. Therefore we conclude that doped $SrTiO_3$ is a single-gap superconductor that can be described by standard BCS theory although not being within the Migdal limit [4]. With additional microwave measurements in magnetic field we show that at least two bands contribute to superconductivity, and from the microwave spectra we conclude that only one superconducting gap exists throughout these two bands due to substantial electronic scattering.

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Neutron resonance peak dispersion in Ce1-xYbxCoIn5

The resonance peak observed in neutron scattering experiments of cuprate, iron pnictide, and heavy fermion superconductors has attracted much attention, especially due to its possible relation to the unconventional superconductivity of these compounds. The resonance is often attributed to a spin-exciton state that is a consequence of a sign-changing superconducting order parameter. Using the band structure extracted by quasiparticle inteference measurements of CeCoIn5, a theoretical calculation of the resonance dispersion in the random phase approximation yields a downward dispersion typical of the spin-exciton scenario. This result is inconsistent with the experimentally observed robust upward dispersion in Ce1-xYbxCoIn5 [Y. Song, et al. Nat. Comm. (2016)]. This suggests the resonance may be a magnon-like excitation that becomes undamped in the superconducting state.

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NMR study of charge order in YBCO under pressure

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Cuprate superconductors and most notably $YBa_2Cu_3O_y$ (YBCO) were the first materials with a sufficiently high Tc to be cooled with liquid nitrogen. By applying hydrostatic pressure the superconducting Tc can be enhanced even further. Common belief was that this enhancement essentially goes back to a pressure induced change of doping. Recently, charge density wave order (CDW order), an electronic phase with a rich phenomenology that competes with superconductivity was discovered by NMR in underdoped YBCO and subsequently in other cuprate families (1). It has been speculated that pressure tunes this competition by suppressing CDW order (2).

CDW order plays an essential role for the Fermi surface. In YBCO, which is a hole-doped cuprate, a hole-like Fermi surface is expected that is growing with increasing doping. Surprisingly, quantum oscillations that go back to small electron pockets were measured in underdoped YBCO, so the hole-like Fermi surface must have undergone a Fermi surface reconstruction (FSR). The most prominent candidate for the FSR is CDW order which is short-ranged and essentially bi-axial in a wide temperature and field range but becomes enhanced uniaxially above a threshold magnetic field. The application of very high pressure should eventually suppress charge order and thus affect FSR. Measurements at moderately high pressures showed that quantum oscillations persist.

Using NMR we are able to study both the short-ranged bi-axial as well as the long ranged uni-axial CDW order under high hydrostatic pressure in an underdoped sample of YBCO. Our results shed light on the competition between charge order and superconductivity as well as on the origin of the FSR.

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Impact of disorder on the superconducting transition temperature near a Lifshitz transition.

Multi-band superconductivity is realized in various conventional and unconventional superconductors, such as MgB2, iron pnictides and SrTiO3 (STO). One interesting problem related to multi-band superconductivity is the evolution of its superconducting transition temperature (Tc) with the chemical potential. Particularly in the case of a Lifshitz transition - A Lifshitz transition (LT) happens when the topology of the Fermi Surface changes as function of the chemical potential and, in the context of multi-band superconductivity, when a second Fermi Surface appears once the chemical potential reaches a critical value - Tc shows a strong enhancement when the second band starts to fill. However, recent experiments in STO show that Tc is actually suppressed once the second Fermi Surface emerges. In this work, we investigate the behavior of the critical temperature across a LT in the presence quenched disorder. We show that, when the superconducting gap have different signs on the two bands, inter-band scattering leads to a strong suppression of Tc near the LT, giving rise to a local minimum in the SC dome.

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Charge and current orders in the cuprates: implications from spin-fermion model with overlapping hot spots.

Experiments carried over the last years on the underdoped cuprates suggest the presence of a variety of symmetry-breaking phenomena in the pseudogap phase. Charge-density waves, breaking of C_4 rotational symmetry, as well as time-reversal symmetry breaking have all been observed in several cuprate families. Unification of these phenomena thus poses a crucial theoretical challenge. We address this issue in the framework of the spin-fermion model, where the low-energy fermions interact through the exchange of antiferromagnetic fluctuation quanta, paramagnons. Unlike previous studies, we do not restrict the Fermi surface to the vicinities of 8 'hot spots' and take the full regions around (0, π) and (π,0) into account instead.

Studying particle-hole instabilities we obtain a rich phase diagram. For sufficiently small $|\varepsilon(\pi,0)-E_F|$ and Fermi surface curvature we find the leading instability to be a C_4-breaking d-wave Pomeranchuk Fermi surface deformation. On the other hand, we show that Fermi surface curvature in the antinodal regions promotes a state formed by current loops organized in an antiferromagnetic structure (the d-density wave state), breaking time-reversal symmetry. We present analytical results for a simplified model with an instantaneous interaction, as well as numerical analysis of the equations obtained in the full spin-fermion model.

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Anomalous correlation effects and unique phase diagram of electron-doped FeSe revealed by ARPES

FeSe layer-based superconductors exhibit exotic and distinctive properties. The undoped FeSe shows nematicity and superconductivity, while the heavily electron-doped KxFe2-ySe2 and single-layer FeSe/SrTiO3 possess high superconducting transition temperatures that pose theoretical challenges. However, a comprehensive study on the doping dependence of an FeSe layer-based superconductor is still lacking due to the lack of a clean means of doping control. Through angle-resolved photoemission spectroscopy studies on K-dosed thick FeSe films and FeSe0.93S0.07 bulk crystals, here we reveal the internal connections between these two types of FeSe-based superconductors, and obtain superconductivity below ~46 K in an FeSe layer under electron doping without interfacial effects. Moreover, we discover an exotic phase diagram of FeSe with electron doping, including a nematic phase, a superconducting dome, a correlation-driven insulating phase and a metallic phase. Such an anomalous phase diagram unveils the remarkable complexity, and highlights the importance of correlations in FeSe layer-based superconductors.

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Broken Time reversal symmetry in unconventional superconductors probed by μSR

Currently my research interest is studying broken time reversal symmetry (TRS) in several superconducting systems using muon spin relaxation/rotation technique (μSR). The detection of a spontaneous internal magnetic field, Bs, is strong experimental evidence for broken TRS.

The presence of broken TRS indicates unconventional pairing and the existence of twofold or higher degeneracy of the superconducting order parameter. The origin of TRS breaking in the superconducting state of the filled skutterudite PrPt4Ge12 is not clear. Zero applied field μSR experiments in the (Pr,Ce)Pt4Ge12 alloy series reveal that Pr-Pr intersite interactions are important for the broken TRS, but pair-breaking by Ce doping suppresses superconductivity quickly. The superconducting transition temperature Tc's in Pr1-xLaxPt4Ge12 are very close. We carried out the non-pair-breaking doping study in Pr1-xLaxPt4Ge12 and discovered a second-order like suppression of broken TRS with doping content x. We also find that the onset temperature of Bs is not concurrent with the Tc in PrPt4Ge12. Such behavior is also present in (Pr,Ce)Pt4Ge12.

The origin of the pseudogap region below a temperature T* is at the heart of the mysteries of high-Tc cuprate superconductors. Study of the TRS symmetry in the pseudogap phase provides clues to elucidate high-Tc superconductivity. Broken time-reversal and inversion symmetry due to intra-unit-cell (IUC) magnetic order is reported by several symmetry-sensitive experiments except μSR or NMR. Recently our longitudinal applied field μSR experiments discovered a slowly fluctuating magnetic order below Tmag in single crystals of YBa2Cu3Oy, with Tmag ≈ T*. We also observed the critical slowing down of fluctuations at Tmag expected near TRS breaking transitions. These results are strong evidence for fluctuating IUC magnetic order in the pseudogap phase.

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The Proximity d + id′ Chiral Superconductivity

We will use both analysis and numerical methods to obtain a d+id′ topological superconductivity (SC) in a two layered systems, which exhibit different kinds of d-wave orders. The free energy is expended by t^4 analytically, where t is the tunneling constant between these two layers, and a (cosΔθ)^2 term is found, in which Δθ is the relative phase of these two SCs. So the relative phase of two SCs can be π/2, which implies a d + id′ SC. We also use a simple lattice model to verify our conclusions, and find that the d+id pairing symmetry is robust in the phase diagram. At last we derive a effective model of one layer to calculate the winding number and edge state to verify the topology nature of this d+id′ SC.

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