TT 30 Superconductivity: Twenty Years High-T_c Cuprates - Recent Progress

Time: Thursday 14:00–18:45 Room: HSZ 02

TT 30.1 Thu 14:00 HSZ 02

Electron-phonon coupling reflecting dynamic charge inhomogeneity in copper-oxide superconductors — •Dmitri Reznik[1], L. Pintschovious[1], M Ito[2], S. Iikubo[2], M. Sato[2], H. Goka[3], M. Fujita[3], K. Yamada[3], G. Gu[4], and J.M. Tranquada[4] — [1]Forschungszentrum Karlsruhe, Institut für Festkörperphysik, P.O.B. 3640, D-76021 Karlsruhe, Germany — [2]Department of Physics, Division of Materials Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan — [3]Institute for Material Research, Tohoku University, Katahira, Aoba-ku, Sendai, 980-8577, Japan — [4]Physics Department, Brookhaven National Laboratory, Upton, New York 11973

The attempt to understand cuprate superconductors is complicated by the presence of multiple strong interactions. While many believe that antiferromagnetism is important for the superconductivity, there has been resurgent interest in electron-lattice coupling. The conventional superconductor MgB2 has a very strong electron-lattice coupling predicted by standard theory. We show that there is a similarly strong anomaly in the Cu-O bond-stretching phonon in cuprate superconductors however, this behavior is completely absent in conventional calculations. Instead, the anomaly is strongest in compounds that exhibit static stripe order.It occurs at a wave vector corresponding to the charge order. The results suggest that this giant electron-phonon anomaly, which is absent in undoped and over-doped non-superconductors, is associated with charge inhomogeneity. It follows that electron-phonon coupling may be important to understanding superconductivity although its contribution to the mechanism is likely indirect.

TT 30.2 Thu 14:15 HSZ 02

Origin of dynamic stripe correlations in the charge response of cuprates — •Peter Horsch and Giniyat Khaliullin — Max-Planck-Institut FKF, 70569 Stuttgart, Germany

We discuss the dynamical density fluctuation spectra of cuprates starting from the $t-J$ model in the slave-boson $1/N$ framework [1]. Our theory provides the generic density response of a doped Mott-insulator and reveals novel low-energy structure on the energy scale $J+\delta t$ due to the correlated motion of holes in a RVB spin liquid. This low-energy response implies an anomalous renormalization of several phonon modes [2,3]. In particular our approach explains the peculiar doping dependence of breathing and bond-stretching phonons as observed by neutron scattering [4]. Here we further extend the discussion and analyse the connection between incommensurabilities in the spin-response and dynamic stripe correlations in the charge response of cuprates. Finally we address the question why collinear charge stripes are favored in LSCO compounds.

[1] G. Khaliullin and P. Horsch, Phys. Rev. B 54, R9600 (1996).
[2] G. Khaliullin and P. Horsch, Physica C 282-287, 1751 (1997).
[3] P. Horsch and G. Khaliullin, Physica B 359-361, 620 (2005).
[4] L. Pintschovius, phys. stat. sol. (b) 242, 30 (2005).

TT 30.3 Thu 14:30 HSZ 02

Charge and spin ordering phenomena in HTSC — •Leonardo Tassini, Wolfgang Prestel, Rudi Hackl, Michael Lambacher, and Andreas Erb — Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

We present a detailed study of the underdoped range of the phase diagram of various single crystals of $La_{2-x}Sr_xCuO_4$ (LSCO) and of $Y_{1-x}Ca_xBa_2Cu_3O_6$ (YBCO) using electronic Raman scattering. We conclude from the experimental data that there is a clear indication of a charge and/or spin modulation (stripes) in the two-dimensional CuO_2 planes manifesting themselves as additional Drude-like peaks at low energies and temperatures. The additional response in LSCO is in the B_{2g} and B_{1g} symmetry at doping levels of x = 0.02 and x = 0.10, respectively, and in the B_{2g} symmetry for all YBCO samples studied. The selection rules allow us to determine the orientation of the stripes to be along the diagonal of the CuO_2 plane in YBCO and in LSCO at x = 0.02, and along the principle axes in LSCO at x = 0.10. The stripes fluctuate, and the correlation length is of the order of the electronic mean free path. In LSCO temperature is the only scale of the response at different doping levels demonstrating the importance of quantum critical behaviour.

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TT 30.4 Thu 14:45 HSZ 02

Dispersion and geometry of spin excitations in the normal and superconducting state of twin-free YBCO(6.6) — •Vladimir Hinkov[1], Bernhard Keimer[1], P. Bourges[2], S. Pailhes[2], Y. Sidis[2], A. Ivanov[3], and CT. Lin[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [2]Laboratoire Leon Brillouin, CEA-CNRS, France — [3]Institut Laue-Langevin, Grenoble, France

There is a strong debate about the normal state (NS) and the *pseudogap* (PG) state in the high-Tc cuprates. For now, our understanding of their magnetism suffers from the lack of information about the regimes above Tc. We present an inelastic neutron scattering study (see also V. Hinkov et al, Nature 430, 650 (2004)), of the in-plane (a-b) anisotropy of spin-excitations between 26meV and 60meV in twin-free, underdoped YBCO(6.6), T_c =61 K. We identify three fundamentally different temperature regimes: the superconducting regime exhibits incommensurate peaks both along a and b with a X-shaped dispersion. Intensity shows a-b-anisotropy below the resonance peak and no anisotropy above. Heating to 70 K (PG-state), the dispersion changes to Y-shape, with a flat top, steeply dispersing signal below the resonance, which is 50% broader along a. Finally, at 290 K (NS), intensity is depleted below the resonance and is only visible at higher energies. We discuss the implication of our findings on different theoretical models proposed for the PG-regime: the stripe-model, spin-ladder models, preformed Cooper-pairs, competing order parameter. We compare our results with other techniques such as ARPES and STM, and with other systems such as the Haldane-compound YBaNiO(5).

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TT 30.5 Thu 15:00 HSZ 02

Theory for Inelastic Neutron Scattering in Orthorhombic High-T_c Superconductors — •Andreas Schnyder[1], Dirk Manske[2], Christopher Mudry[1], and Manfred Sigrist[2] — [1]Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland — [2]Institut für Theoretische Physik, ETH Zürich, Hönggerberg, CH-8093 Zürich, Switzerland

Extending our earlier fermiology-based studies on the magnetic susceptibility we analyze the in-plane anisotropy of the spin response in hole-doped high-T_c cuprates [1]. Employing the two-dimensional one-band Hubbard model and a generalized RPA-type theory we consider anisotropic hopping matrix elements ($t_x \neq t_y$) and a mixing of d- and s-wave symmetry of the superconducting order parameter in order to describe orthorhombic superconductors. We compare our calculations with available inelastic neutron scattering data on untwinned YBCO and find good agreement [2]. Furthermore, we predict a strongly anisotropic in-plane dispersion of the resonance peak and contrast our results to theories based on stripe formation.

[1] A. P. Schnyder, D. Manske, C. Mudry, and M. Sigrist, cond-mat/0510790.
[2] V. Hinkov, S. Pailhes, P. Bourges, Y. Sidis, A. Ivanov, A. Kulakov, C. T. Lin, D. P. Chen, C. Bernhard, and B. Keimer, Nature **430**, 650 (2004).

TT 30.6 Thu 15:15 HSZ 02

Spin excitations in fluctuating stripe phases — •Matthias Vojta[1], Thomas Vojta[2], and Ribhu Kaul[1,3] — [1]Universität Karlsruhe, Germany — [2]University of Missouri, Rolla, USA — [3]Duke University, Durham, USA

Using a phenomenological lattice model of coupled spin and charge modes, we determine the spin susceptibility in the presence of fluctuating stripe charge order. We assume the charge fluctuations to be slow compared to those of the spins, and combine Monte Carlo simulations for the charge order parameter with exact diagonalization of the spin sector. Our calculations unify the spin dynamics of both static and fluctuating stripe phases and support the notion of a universal spin excitation spectrum in doped cuprate superconductors.

TT 30.7 Thu 15:30 HSZ 02

Resonant spin excitations in the *id*-density wave state: probe for the pseudogap scenario in underdoped cuprates — •Jan-Peter Ismer[1], Ilya Eremin[1,2], and Dirk K. Morr[3] — [1]Max-Planck Institut für Physik komplexer Systeme, D-01187 Dresden, Germany — [2]Institut für Mathematische und Theoretische Physik, Technische Universität Carolo-Wilhelmina zu Braunschweig, D-38106 Braunschweig, Germany — [3]Department of Physics, University of Illinois at Chicago, Chicago, IL 60607, USA

Inelastic neutron scattering (INS) experiments probing dynamical spin susceptibility in the pseudogap phase of the high-T_c cuprates are addressed in the framework of the ordered d-density wave(DDW) state. In particular, we analyze the formation of the resonance peak at the antiferromagnetic wave vector $\mathbf{Q}_{AF} = (\pi, \pi)$ and its dispersion in three different ordered states: d-wave superconductor (DSC), DDW state, and coexisting DDW and DSC states. In particular, we find that the resonance excitations in the DDW-state exists in a narrow region around (π, π) forming nearly no dispersion due to peculiar structure of the Fermi surface. At the same time, in the combined DDW+DSC-state the resonance peak dispersion is determined mainly by the superconducting gap, although both phases interfere around (π, π) yielding a non-monotonic intensity cusp of the resonance peak dispersion. A comparison with existing INS experiments shows certain constraints on the application of the DDW-scenario for the pseudogap in underdoped cuprates.

TT 30.8 Thu 15:45 HSZ 02

Nuclear Magnetic Resonance Studies of Rare Earth co-doped Lanthanum Cuprates — •Hans-Joachim Grafe[1,2], Nicholas J. Curro[2], Markus Hücker[3], and Bernd Büchner[1] — [1]IFW Dresden, Germany — [2]Los Alamos National Laboratory, NM , USA — [3]Physics Department, Brookhaven National Laboratory, Upton NY, USA

^{17}O and ^{63}Cu Nuclear Magnetic Resonance (NMR) results in stripe ordered $La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ will be presented. At low temperatures the local electric field gradient (EFG) as well as the absolute intensity of the NMR signal of the planar O site exhibit a dramatic decrease. We interpret these results as microscopic evidence for a spatially inhomogeneous charge distribution, where the NMR signal from O sites in the domain walls of the spin density modulation are wiped out due to large hyperfine fields, and the remaining signal arises from the intervening Mott insulating regions. At similar temperatures the Cu NMR signal experiences a complete wipe out, suggesting that the oxygens are wiped out by the same mechanism that renders the Cu invisible, namely slowly fluctuating Cu electronic spins. Despite of this static magnetic and charge order, the Knight shift exhibits the same pseudogap-like temperature dependence as in superconducting $La_{2-x}Sr_xCuO_4$.

TT 30.9 Thu 16:00 HSZ 02

Exploring the phase diagram of $Bi_{2-y}Pb_ySr_{2-x}La_xCuO_{6+\delta}$ — •L. Dudy[1], B. Müller[1], A. Krapf[1], H. Dwelk[1], C. Janowitz[1], R. Manzke[1], and H. Höchst[2] — [1]Institut f. Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin — [2]Synchrotron Radiation Center, Stoughton, WI, U.S.A

Using angular resolved photoemission we are able to study the temperature dependence of the electronic structure of $Bi_{2-y}Pb_ySr_{2-x}La_xCuO_{6+\delta}$ (Pb-Bi2201) with high accuracy. The lead- ($0 \leq y \leq 0.4$) and lanthanum- ($0.2 \leq x \leq 0.8$) content was varied continously over a large range by controlling the crystal growth parameters. While lead doping raises the superconducting critical temperature (T_c) from $T_c^{max} \simeq 29K$ in lead-free samples to $T_c^{max} \simeq 35K$, the pseudogap temperature is slightly lowered in the hole-underdoped regime with increasing lead-content. We discuss the superconducting transition temperature and the pseudogap temperature in dependence of x and y. In agreement with Sato et al. [1] we find that the maximum gap magnitude near the antinodal point (Δ_{max}) for y=0.4 is much smaller (about four times) than in the two-layer compound of $Bi_2Sr_2CaCu_2O_8$ (Bi2212) at the same doping level. When measuring $\Delta_{max}(T)$ no significant change in this gap function was found within the experimental resolution when lowering the temperature through T_c .

[1] T. Sato et al. , Journal of Physics and Chemistry of Solids 62 (2001) 157-161

— 15 min. break —

TT 30.10 Thu 16:30 HSZ 02

Temperature dependent hole distribution in $Sr_{14-x}Ca_xCu_{24}O_{41}$ — •C. Hess[1], T. Kim[1], M. Knupfer[1], G. Behr[1], B. Büchner[1], N. Nücker[2], S. Schuppler[2], P. Nagel[2], U. Ammerahl[3], and A. Revcolevschi[3] — [1]IFW Dresden, Institute for Solid State Research, Germany — [2]FZ Karlsruhe, Institut für Festkörperphysik — [3]Laboratoire de Physico-Chimie des Solides, Université Paris-Sud, France

We studied the effect of charge order in the spin ladder material $Sr_{14-x}Ca_xCu_{24}O_{41}$ by means of polarization dependent Near-edge x-ray absorption fine structure measurements at the oxygen K-edge (O1s-NEXAFS). Stoichiometry gives a total hole count per formula unit of 6, and the holes are located mainly in the chains although some fraction does dope the ladders as well. At low doping levels a charge ordering transition, which affects the physical properties of both the doped spin chains and spin ladders, is present. We therefore investigated the temperature dependence of the spectra in order to look for a possible redistribution of holes between the different sites (chains and ladders) in the structure, especially at the charge-order transition. From the low temperature spectra we can clearly exclude that the ladder-doping becomes zero as suggested by other experiments. Nevertheless we observe a strong temperature dependence of the spectra.

TT 30.11 Thu 16:45 HSZ 02

Dopant-modulated pair interaction in cuprate superconductors — •Tamara Nunner[1], Brian Andersen[2], Ashot Melikyan[2], and Peter Hirschfeld[2] — [1]Institut fuer theoretische Physik, FU Berlin, Arnimallee 14, 14195 Berlin — [2]Department of Physics, University of Florida, Gainesville, FL 32611 (USA)

High-resolution STM experiments on superconducting BSCCO-2212 have revealed the existence of nanoscale inhomogeneities in the electronic structure at biases near the superconducting energy gap. Very recently, a strong correlation between this nanoscale electronic disorder and the locations of the oxygen dopant atoms has been identified by McElroy *et al.* [1]. We suggest that the primary effect of the oxygen dopant atoms is to modulate the pair interaction locally [2]. Based on single impurity T-matrix and many-impurity Bogoliubov-de Gennes calculations we show that a dopant modulated pair interaction can reproduce most of the correlations observed in recent STM experiments: nanoscale inhomogeneity of the coherence peak position, homogeneity of the local density of states at low bias, low charge disorder, negative correlation between the height of the coherence peaks and the gap magnitude and a positive correlation between the gap magnitude and the locations of the oxygen dopant atoms.

[1] K. McElroy, J. Lee, J. A. Slezak, D.-H. Lee, H. Eisaki, S. Uchida, and J.C. Davis, Science **309**, 1048 (2005).
[2] T.S. Nunner, B.M. Andersen, A. Melikyan, and P.J. Hirschfeld, Phys. Rev. Lett. **95**, 177003 (2005).

TT 30.12 Thu 17:00 HSZ 02

Optical spectral weight shifts and sum rules in cuprates: role of strong correlation — •Alessandro Toschi[1], Massimo Capone[2,3], and Claudio Castellani[3] — [1]Max-Planck Institut für Festkörperforschung, Heisenbergstr. 1,*D-70569 Stuttgart, Germany — [2]Istituto dei Sistemi Complessi del CNR, Via dei Taurini 19, I-00185*Roma, Italy — [3]Dipartimento di Fisica Università di Roma "La Sapienza"piazzale Aldo Moro 5,*I-00185 Roma, Italy

We show that many unusual features recently observed in the optical spectroscopy experiments on the high-temperature superconducting cuprates can be simply understood as arising from the vicinity to the Mott transition, without invoking more involved and exotic mechanisms. More specifically we compare calculations based on the Dynamical Mean Field Theory of the Hubbard model with the infrared spectral weight $W(\Omega, T)$ of $La_{2-x}Sr_xCuO_4$ and other cuprates. We find that most of the anomalies observed in the T- and the doping dependence of $W(\Omega, T)$ with respect to normal metals can be ascribed to strong correlation effects. Moreover the variation of weight at the superconducting transition in optimally and underdoped cuprates, that can be interpreted as a gain in kinetic energy, is accounted for by a strong-coupling (almost bosonic) superconductivity, while the overdoped materials behave more like standard superconductors.

[1] A.T., M. Capone, M. Ortolani, P. Calvani, S. Lupi, and C. Castellani, Phys. Rev. Lett. **95**, 097002 (2005)
[2] A.T., M. Capone and C. Castellani, cond-mat/0509188, to appear on Phys. Rev. B

TT 30.13 Thu 17:15 HSZ 02

Doping dependent tunneling behavior in electron-doped cuprates — •Yoshiharu Krockenberger[1], Andreas Winkler[1], Akio Tsukada[2], Michio Naito[3], Dirk Manske[4], and Lambert Alff[1] — [1]TU Darmstadt — [2]NTT, Atsugi, Japan — [3]TUAT, Tokyo, Japan — [4]MPI-FKF Stuttgart

Recently in the electron doped cuprates a pseudogap of the order of the superconducting gap has been observed by tunneling experiments [1]. In order to investigate the phase diagram in more detail, we have studied a series of $Pr_{2-x}Ce_xCuO_{4+y}$ thin film junctions within the whole doping region between $0 < x < 0.2$. Our results support the idea that the phase diagram of the electron doped cuprates is governed by a competition of superconductivity and other types of order. It is an open question how an ordered state at low doping can coexist with antiferromagnetic order.

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[1] L. Alff *et al.*, Nature **422**, 698 (2003).

TT 30.14 Thu 17:30 HSZ 02

Quasiparticle transport characteristics of thin film $La_{2-x}Ce_xCuO_4$ bicrystal junction SQUIDs — •Michael Wagenknecht[1], Boris Chesca[1], Martin Mueller[1], Dieter Koelle[1], Reinhold Kleiner[1], Akio Tsukada[2], and Michio Naito[3] — [1]Physikalisches Institut - Experimentalphysik II, Universitaet Tuebingen, Auf der Morgenstelle 14, 72076 Tuebingen — [2]NTT Basic Research Laboratories, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243, Japan — [3]Department of Applied Physics, Tokyo University of Agriculture and Technology (TUAT) 2-24-16 Naka-cho, Koganei, Tokyo 184-8588, Japan

While it is widely recognized that hole doped cuprates have predominantly d-wave symmetry of the superconducting order parameter, for electron doped cuprates the issue remains controversial. Here we present quasiparticle transport measurements of electron doped $La_{2-x}Ce_xCuO_4$ thin film bicrystal Josephson junction SQUIDs. The 900 nm thin films were deposited by molecular beam epitaxy on $SrTiO_3$ 24° and 30° [001]-tilt bicrystal substrates and have a Ce doping of $x \sim 0.08$ and a $T_c \sim 30$ K. At 4.2 K we observe in some SQUIDs a pronounced zero-bias anomaly in the quasiparticle differential conductance in magnetic fields up to 7 T, consistent with the formation of Andreev bound states at the junction interface. These results are strongly supportive of a d-wave symmetry, in accordance with previous work [1]. In addition we will discuss the subgap structures as well as some resonances at energies above the superconducting gap, which we repeatedly observed in quasiparticle transport measurements.

[1] B. Chesca et al., Phys. Rev. B **71**, 104504 (2005).

TT 30.15 Thu 17:45 HSZ 02

Symmetry and shape of the gap function in the hole- and electron-doped superconductors: the functional renormalization-group analysis — •Andrey Katanin[1,2] and Arno Kampf[3] — [1]Max-Planck-Institut für Festkörperforschung, D-70569, Stuttgart, Germany — [2]Institute of Metal Physics, 620219 Ekaterinburg, Russia — [3]Theoretische Physik III, Elektronische Korrelationen und Magnetismus, Institut für Physik, Universität Augsburg, D-86135 Augsburg, Germany

The problem of symmetry of superconducting pairing and the form of the gap function in the hole- and electron-doped superconductors are considered within the temperature-cutoff functional renormalization group approach combined with the Bethe-Salpeter equations. The momentum dependence of the order parameter for antiferromagnetic and superconducting instabilities in these compounds is analyzed. In the superconducting channel we find significant deviations from the conventional d-wave form of the gap functions. For hole-doped case a higher angular momentum component arises besides the standard $d_{x^2-y^2}$-wave component, which flattens the angular dependence of the gap. In the electron-doped case the gap function in the antiferromagnetic (particle-hole) channel has its maxima at the hot spots, or at the diagonal of the Brillouin zone in their absence. The wavefunction in the singlet superconducting channel is non-monotonic in the vicinity of the $(\pi, 0)$ and $(0, \pi)$ points in striking similarity with recent experimental data. The instability in the triplet superconducting channel is much weaker than in the singlet one and has f-wave like form of the gap function.

TT 30.16 Thu 18:00 HSZ 02

From d- to p-wave pairing in the t-t' Hubbard model at zero temperature — •K. Held and R. Arita — Max-Planck Institut für Festkörperphysik, Stuttgart

The Hubbard model is commonly considered to be relevant for unconventional superconductors like cuprates and ruthenates. For a more thorough insight into the physics of this model (is it explaining superconductivity?), the dynamical cluster approximation (DCA) combined with quantum Monte Carlo (QMC) [1] is a promising approach. DCA(QMC) is however restricted to rather high temperatures T. A prediction of superconducting phases at low-T is hence problematic. As a new path to low T, a projective QMC algorithm for impurity problems was recently developed [2], allowing for the solution of the dynamical mean field approximation (DMFT) equations in the $T \to 0$ limit.

We extend this projective QMC algorithm to DCA [3], and apply it for studying pair susceptibilities of the two-dimensional Hubbard-model with next-nearest neighbor hopping. In particular, we identify which pairing symmetry is dominant in the U-n parameter space (U: repulsive Coulomb interaction; n: electron density). We find that p_{x+y}- ($d_{x^2-y^2}$-) wave is dominant among triplet (singlet) pairings -at least for $0.3 < n < 0.8$ and $U <= 4t$. The crossover between $d_{x^2-y^2}$-wave and p_{x+y}-wave occurs around $n \sim 0.4$.

[1] M.H. Hettler *et al.*, Phys. Rev. B **58** R7475 (1998).
[2] M. Feldbacher, K. Held, and F. F. Assaad, Phys. Rev. Lett. **93**, 136405 (2004).
[3] K. Held and R. Arita, cond-mat/0508639.

TT 30.17 Thu 18:15 HSZ 02

Superconductivity and Antiferromagnetism in the 2d-Hubbard model – An RG and MF approach — •Julius Reiss, Daniel Rohe, and Walter Metzner — MPI-FKF,Heisenbergstrasse 1, 70569 Stuttgart

The functional renormalisation technique in the wick-ordered scheme is used to derive an low energy model, which is treated with an extended mean-field calculation to get insight into the symmetry-broken phase of the 2–dimensional Hubbard model. d-wave superconductivity (SC) and s-wave antiferromagnetism (AF) and coexistence of both is found. The issue of the reliability of low energy models for order parameters, which show first order transitions, like the AF, is discussed.

TT 30.18 Thu 18:30 HSZ 02

Kondo screening in unconventional superconductors: The role of anomalous propagators — •Lars Fritz and Matthias Vojta — Theorie der Kondensierten Materie, Universitaet Karlsruhe

The Kondo effect in superconductors is frequently investigated using the local quasiparticle density of states as sole bath characteristics, i.e., the presence of anomalous propagators is ignored. We show that this is exact for a number of experimentally relevant situations, including point-like impurities in d-wave superconductors.