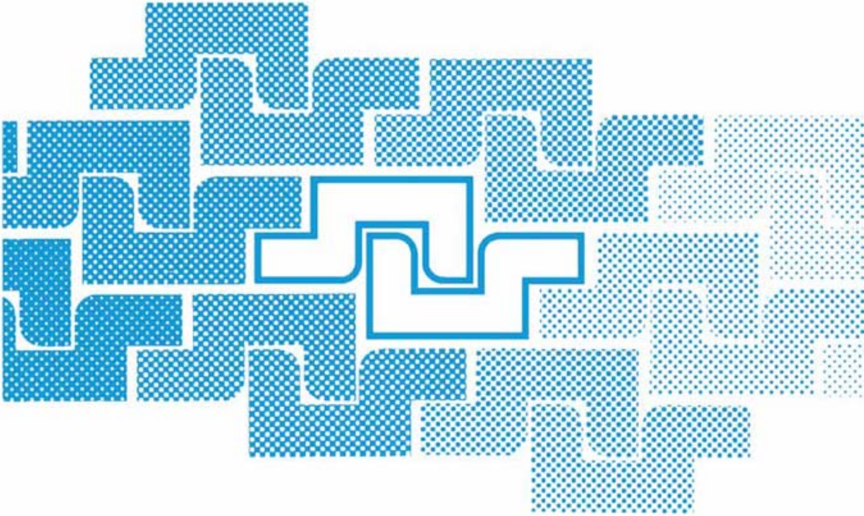

# New Challenges in Superconductivity: Experimental Advances and Emerging Theories

Edited by

J. Ashkenazi, Mikhail V. Eremin,
Joshua L. Cohn, Ilya Eremin, Dirk Manske,
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# Preface

This volume contains the proceedings of the 2004 University of Miami Workshop on Unconventional Superconductivity. The workshop was the fourth in a series of successful meetings on High-$T_C$ Superconductivity and related topics, which took place at the James L. Knight Physics Building on the University of Miami campus in Coral Gables, Florida, in January 1991, 1995, 1999, and 2004.

The workshop consisted of two consecutive events: 1. NATO Advanced Research Workshop (ARW) on New Challenges in Superconductivity: Experimental Advances and Emerging Theories, held on January 11-14, 2004; 2. Symposium on Emerging Mechanisms for High Temperature Superconductivity (SEMHTS), held on January 15-16, 2004.

It is hard to write a balanced preface to a volume like this one, yet at least we try to offer the reader a taste of what was happening in this workshop. There were close to a hundred scientists from around the world, albeit fewer Russians than we had originally hoped for. Nevertheless, the workshop was very lively and we trust that this is demonstrated in this volume.

The workshop included high-quality presentations on state of the art works, yet a key issue, discussed by many, was how homogeneous the cuprates are. STM data, as well as other reports, showed that the cuprate superconductors (SC's) studied were inhomogeneous, especially in the underdoped regime; while experiments, like ARPES and magnetoresistance have established the existence of a Fermi Surface (FS), at least above some doping level, in the cuprates.

This leaves us with the question of how would one understand the existence of an FS in a sample consisting of a 2 nm wide island of an SC embedded in (and eventually connected by) a bad exotic metal. Thus it is necessary to understand the meaning of the FS within the scale in which it exists. It seems to be established that a quasiparticle peak is the signature of the SC islands; yet there are different views on the meaning of this peak.

As usual, there have been almost as many interpretations and definitions of the pseudogap temperature T* as there were participants. Thus, there was hardly any convergence on this topic, especially that different thoughts exist concerning the normal state. Consequently there were at least five generic phase diagrams presented that imply different frameworks. Convincing data has been shown that a glassy state persists up to about $x=0.19$ in LSCO; yet that still did not clarify controversies concerning the existence of quantum critical points.

Most scientists consider d-wave symmetry to be confirmed in the cuprates; yet there were several reports that the situation may be more complicated. In general, experiments have shown more convergence than high-$T_C$ theories. There is definitely no consensus on the high-$T_C$ mechanism, although two broad groups exist: those around the extended "Big Tent" homogenous scheme, and those who assume an intrinsic inhomogeneous state. Another division could be viewed between those who consider the high-$T_C$ mechanism to be essentially of an electronic-magnetic origin (with no role played by the lattice), and those who assign an important role to the lattice.

There seems to be a consensus that $MgB_2$ and the fullerenes are simpler SC's than the cuprates, while work on ruthenocuprates and the coexistence of SC and ferromagnetism still provides new stimuli to research and understanding. Interest was drawn also by the new $Na_xCoO_2 \bullet yH_2O$ SC. Although this is a low-$T_C$ material, its physical properties have a similarity to those of the cuprates; thus research on this system seems to be important for the understanding of high $T_C$ SC.

In conclusion, the workshop showed that more outstanding experimental and theoretical work is necessary to elucidate high $T_C$ SC and related phenomena. Thus further challenges await all of us!

The Editors

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The University of Miami is acknowledged for providing its facilities.

The workshop participants and Advisory Committee are thanked for their contributions which made this event possible.

Acknowledged for their assistance are the University of Miami Physics Department staff members: Nancy Brady, Judy Mallery, Riquie Mathews, Marco Monti, and Leonardo Rodriquez; the graduate students: Corneliu Chiorescu, Simona Khizroev, and Hengsog Zhang; and the faculty members: George Alexandrakis, Thomas Curtright, and others.

The assistance of Nina Travel is also acknowledged.

# LATTICE DYNAMICS AND ELECTRON PAIRING IN HIGH TEMPERATURE SUPERCONDUCTORS

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Abstract: Angle resolved photoemission spectroscopy combined with isotope substitution ($^{16}O$   $^{18}O$) sample preparation method is used to probe the effect of the lattice degrees of freedom on the electron dynamics of optimally doped $Bi_2Sr_2CaC_2O_{8+\delta}$ high temperature superconductors, as a function of momentum and temperature. Our data show that the lattice dynamics strongly renormalizes the electron dispersion and the photoemission line shapes. The renormalization is enhanced near the anti-nodal region and in the superconducting state, i.e. as the superconducting gap opens up. This unusual behavior is direct evidence that the electron-phonon interaction is correlated with the electron pairing in the high temperature superconductivity.

Key words: Electron-lattice interaction, phonons, Spin Peierls, Angle Resolved Photoemission spectroscopy, Isotope Substitution

## 1. INTRODUCTION

One of the ongoing debates in the field of high temperature superconductors is whether the lattice degrees of freedom are responsible for some of the unusual electronic properties of the cuprates. While many experiments have pointed out that the lattice is heavily involved in several properties of the cuprate superconductors [1], the lack of experiments probing directly the electronic response to the lattice has kept the debate open. In addition, the absence of a pronounced conventional isotope effect

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[2] on the critical temperature ($T_c$) [3, 4] has reinforced the belief that the magnetic interaction is the main player instead. However, the meaning of this small isotope coefficient of $T_c$ is unclear since even for conventional superconductors screening can induce small and/or negative value of the isotope coefficient [5]. Indeed, there are several experiments suggesting the presence of a strong electron-phonon interaction in the cuprates, for example the observation of a phonon "kink" in the quasiparticle dispersion measured by photoemission spectroscopy [6], the presence of a very large isotope effect on the pseudogap formation temperature [7,8] and the magnetic susceptibility [9], and the observation of an anomalous isotope effect on the in-plane far-infrared optical conductivity [10].

## 2. ISOTOPE EFFECT ON THE ELECTRON DYNAMICS

To probe directly the response of the electronic degrees of freedom to the lattice degrees of freedom we propose a novel experiment where Angle Resolved Photoemission Spectroscopy (ARPES) is combined with oxygen isotope substitution on high temperature superconductors. This allows monitoring how changes in the lattice induce changes in the electronic structure. While ARPES in fact is the only technique that probes the electronic structure in a momentum resolved manner, isotope substitution control the lattice degrees of freedom.

ARPES data were collected at beamline 10.0.1 of the Advance Light Source using a SCIENTA 2000 analyzer on optimally doped oxygen isotope substituted $Bi_2Sr_2CaC_2O_{8+\delta}$ (Bi2212) ($T_c$=92K) superconductors. Upon isotope substitution ($^{16}O \rightarrow {}^{18}O$), $T_c$ changes to 91K. The details of isotope substitution are described elsewhere [11]. The energy resolution was of 15 meV FWHM and the angular resolution of 0.15 degree, corresponding to momentum resolution better than 0.01 $\pi/a$. The vacuum during the measurement was better than $5 \times 10^{-11}$ Torr. The photon energy was 33 eV. Data were collected for scans parallel to the nodal cut ΓY, (0, 0) to (π, π), of the Brillouin zone, at two different temperatures, below (25K) and above (100K) $T_c$. Each cut is assigned a cut number, which is the angle offset from the nodal direction. For example, cut 0 will mean a nodal cut, and cut 6 will mean a cut 6 degrees displaced from the nodal cut.

In Figure 1 we show the raw ARPES data as image plots, for several cuts in the momentum space, from the nodal ΓY (panel a0 and b0) to half way towards the M point (π, 0) (panels a6 and b6), for the two isotope substituted samples. The color scale represents the photoelectron intensity versus the momentum and binding energy, with maximum in black and minimum in white. The reversibility of the isotope effect upon the isotope re-substitution ($^{18}$O→$^{16}$O) has been shown elsewhere [11].

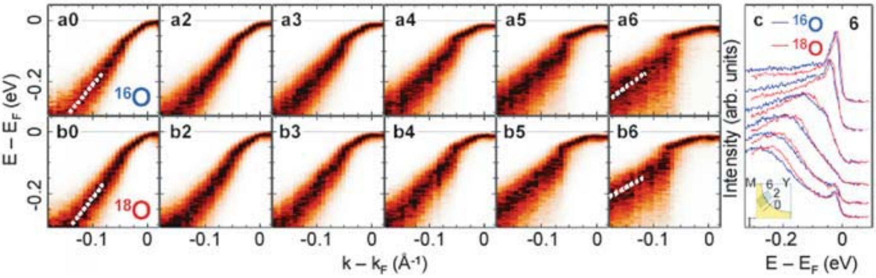

*Figure 1.* Low temperature (25 K) ARPES data of optimally doped Bi$_2$Sr$_2$CaC$_2$O$_{8+\delta}$ high temperature superconductors with oxygen isotope $^{16}$O (panels a) and $^{18}$O (panels b). These maps are normalized so that the intensity of each EDC goes from 0 to 1 (see text for details). The panels are labeled with a cut number, i.e. angle offset from the nodal cut. Inset of panel c shows the cut numbers. In panel c, isotope dependence of a few selected EDC's are shown for cut 6. The top pair corresponds to k=k$_F$, i.e. momentum value on the normal state Fermi surface, shown as a curve in the inset.

The intensity maps shown in Figure 1 were normalized (i.e. shifted and scaled in intensity) in such a way that each energy distribution curve (EDC) at each momentum value has intensity range from 0 to 1. This new way of presenting the data allows an easy overview of main differences between the two isotopes, because the information regarding the energy-momentum dispersion relation and the line widths can be already "read off" from the images, without actually applying EDC fit procedures, which are not so straightforward in general. Because of this reason, we will refer to these maps as "pro-EDC maps."

In particular, the maps in Figure 1 make it very easy to see the dichotomy of two dispersing branches, sharp low energy branch (sharp peaks) and broad high-energy branch (broad humps). Note that throughout this paper we use the terms energy and binding energy interchangeably. Following the Fermi liquid terminology, we refer to the low energy branch as coherent branch, while we refer to the high-energy branch as incoherent branch. Also, we will loosely refer to the sharp peak near Fermi level (E$_F$; defined as zero throughout the paper) as "coherent quasi-particle" peak.

In these pro-EDC maps, the kink phenomenon [6] is visualized as the crossover from the low energy quasi-particle branch to the high-energy incoherent branch. This crossover region is the region of low intensity (indicated by white dashed line, and blue and red arrows), where the two dispersions mix and give rise to a double peak structure, commonly referred to as a "peak-dip-hump" structure, of EDC's [6,12-14]. In this terminology,