

A Search for Alternative Electronic Order
in the
High Temperature Superconductor $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$
by Scanning Tunneling Microscopy

by

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Abstract

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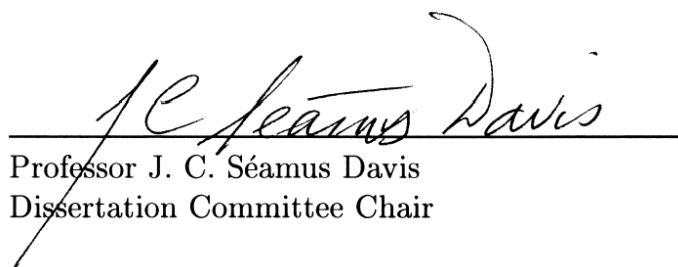
Professor J. C. Séamus Davis, Chair

High temperature superconductors were discovered in 1986, but despite a frantic pace of research, resulting in some 10^4 publications per year for the last 16 years, these materials remain poorly understood. Because their electronic structure is both inhomogeneous and highly correlated, a full understanding will require knowledge of quasiparticle properties both in real space and momentum space. These materials also exhibit a rich three-dimensional phase diagram parameterized by temperature, magnetic field, and carrier concentration. Despite numerous theoretical predictions for exotic phases, large regions of parameter space remain unexplored due to experimental limitations.

In this thesis, I will present the first application of Fourier-transform scanning tunneling spectroscopy (FT-STs) to a high temperature superconductor, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. For the first time, a single experiment can simultaneously probe the real space and momentum space properties of the quasiparticles. FT-STs shows that the quasiparticles in optimally doped BSCCO at 4.2 K and zero applied field can be described by a d -wave superconducting phase, without the need to invoke any exotic order parameters.

I will also present scanning tunneling microscopy (STM) studies of nanoscale features in BSCCO. With such a local probe, we may take advantage of spatial inhomogeneity to gain insight into phases inaccessible to bulk experiments. Crystal inhomogeneity allows the use of single atom defects to probe nanoscale domains of very underdoped BSCCO, sug-

gesting that the electronic structure there is very different from that in the superconducting state. Field inhomogeneity, because BSCCO is a type-II superconductor, allows the study of magnetic vortices, another kind of nanoscale domain where superconductivity is destroyed. Remarkably, in vortices I find evidence of a four-unit-cell periodic “checkerboard”-like electronic structure. This may be the first local glimpse into the structure of the mysterious “pseudogap” phase whose bulk properties are exhibited by all high temperature superconducting materials outside of the superconducting dome.



Professor J. C. Séamus Davis
Dissertation Committee Chair

To my husband,

Daniel Todd Larson

who can always find a way to make me laugh.

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Education

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Publications

- [1] “Relating atomic-scale electronic phenomena to wave-like quasiparticle states in superconducting $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$,” K. McElroy, R.W. Simmonds, J.E. Hoffman, D.-H. Lee, J. Orenstein, H. Eisaki, S. Uchida, J.C. Davis, *Nature* **422**, 592 (2003).
- [2] “Imaging quasiparticle interference in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$,” J.E. Hoffman, K. McElroy, D.-H. Lee, K.M. Lang, H. Eisaki, S. Uchida, J.C. Davis, *Science* **297**, 1148 (2002).
- [3] “A four unit cell periodic pattern of quasi-particle states surrounding vortex cores in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$,” J.E. Hoffman, E.W. Hudson, K.M. Lang, V. Madhavan, H. Eisaki, S. Uchida, J.C. Davis, *Science* **295**, 466 (2002).
- [4] “Imaging the granular structure of high- T_c superconductivity in underdoped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$,” K.M. Lang, V. Madhavan, J.E. Hoffman, E.W. Hudson, H. Eisaki, S. Uchida, J.C. Davis, *Nature* **415**, 412 (2002).

Invited Talks

- “Scanning Tunneling Spectroscopy of High Temperature Cuprate Superconductors.” Condensed Matter Seminar, Caltech Physics Department, 23 May 2003.
- “Wavefunction Imaging in High Temperature Cuprate Superconductors.” Condensed Matter Seminar, University of California, Los Angeles Physics Department, 21 May 2003.
- “Wavefunction Imaging in High Temperature Cuprate Superconductors.” Condensed Matter Seminar, University of California, Berkeley Physics Department, 28 April 2003.
- “Wavefunction Imaging in High Temperature Cuprate Superconductors.” Yale University Applied Physics Department, 17 April 2003.
- “Wavefunction Imaging in High Temperature Cuprate Superconductors.” Harvard University Physics Department, 3 April 2003.
- “Quasiparticle Interference in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.” Aspen Center for Physics, conference on Condensed Matter Physics: Complex Quantum Order, Aspen, Colorado, 11 February 2003.
- “Imaging Quasiparticle Interference in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.” International Conference on Physics and Chemistry of Molecular and Oxide Superconductors (MOS), Hsinchu, Taiwan, 14 August 2002.
- “Incommensurate Conductance Modulations from Quasiparticle Scattering in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.” Stanford University Applied Physics Department, 15 July 2002.
- “Checkerboards in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.” Stanford University Applied Physics Department, 28 May 2002.
- “Imaging Quasiparticle Interference in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.” Condensed Matter Seminar, M.I.T. Physics Department, 17 April 2002.
- “Introduction to the Scientific Community.” MATHCOUNTS National Competition, Washington, D.C., May 1998.
- “Networking for Student Success.” College Board National Forum, New York, NY, November 1996.

Research

- **UHV-compatible, Scanning Tunneling Microscope Construction, J.C. Davis Group, Physics Department, UC Berkeley, 2001-2003.** I have designed, purchased, assembled, debugged, and operated a cryogenic high-resolution STM system, which achieved atomic resolution on the cuprate superconductor $\text{Bi}_2\text{La}_x\text{Sr}_{2-x}\text{CuO}_{4+\delta}$.
- **Scanning Tunneling Microscopy of High- T_c Superconductors, J.C. Davis Group, Physics Department, UC Berkeley, 2000-2003.** I have used a 4 K scanning tunneling microscope with sub-Ångstrom resolution to probe the local density of states of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$. Specific studies have included: the effect of Ni and Zn impurities and their relation to local superconducting gap magnitude, electronic structure of magnetic vortices, and long-range quasiparticle interference patterns due to disorder scattering. I have applied the technique of Fourier-transform scanning tunneling spectroscopy for the first time to the cuprates, using an STM to provide simultaneous real-space and momentum-space information about the quasiparticles.
- **Branching Fractions in J/Ψ Production, Fermi National Laboratory, Summer 1999.** I wrote code to analyze over one million potential J/Ψ events to determine what fraction of the actual J/Ψ particles resulted from decay of a B -meson.
- **Femtosecond Laser Catalysis of Chemical Reactions on a Platinum Surface, E. Mazur Group, Physics Department, Harvard University, Summer 1996-Winter 1998.** Using a femtosecond laser in a UHV chamber I studied reactions of carbon, oxygen, methyl iodide, and benzene on a platinum surface.

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- Mentor, Society for Women in Physical Sciences, UC Berkeley, 1999-2000.
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