Comprehensive Study of the Model Mercury-Based Cuprate Superconductors
DE-SC0006858

Final Report
August 15, 2011 - August 14, 2017

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November 13, 2017

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Executive Summary

This is the Final Report on DE-SC0006858, which opened 15 August 2011 and closed 14 August 2017. The Principal Investigator is Martin Greven, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 555455 (email: greven@umn.edu). The Administrative Point of Contact is Patricia Jondahl, phone: 612-624-5599, email: awards@umn.edu. The DOE Program is the Office of Basic Energy Sciences, Program manager is Dr. P. Thiyagarajan, Neutron Scattering SC-22.2/ Germantown Bldg. (email: Thiyagarajan@science.doe.gov). The chief activity was the crystal growth, characterization, neutron and X-ray scattering study of the mercury-based cuprates, arguably the most desirable high-T_c superconductors for experimental study due to their record values of T_c and their relatively simple crystal structures. It is thought that the unusual magnetic and charge degrees of freedom of the copper-oxygen sheets that form the fundamental building block of all cuprate superconductors give rise to the high T_c and to many other unusual properties exhibited by the class of quantum materials. Neutron scattering experiments were performed to reveal the nature of the magnetic degrees of freedom of the copper-oxygen sheets, whereas X-ray scattering experiments and complementary charge-transport experiments were performed to reveal the nature of the charge degrees of freedom. In addition, collaborations were initiated with experts in the use of complementary experimental techniques. The primary products are (i) scientific articles published in peer-reviewed scientific journals, (ii) scientific presentations at national and international conferences, and (iii) education of postdoctoral researchers, PhD graduate students and undergraduate researchers by providing a research experience in crystal growth, characterization and scattering. Twenty scientific papers were published in peer-reviewed journals, thirty-one invited talks were presented at national or international conferences, or as colloquia or seminars, and three postdoctoral researchers, six PhD graduate students and nine undergraduate researchers were supported wholly or in part in the pursuit of the scientific topics of this award. This report summarizes the activity and productivity, lists highlights, publications and conference presentations, postdocs, students and collaborators. A balance of zero remained at the close of the grant.

Comprehensive Study of the Model Mercury-Based Cuprate Superconductors

1. Introduction and Summary

This is the Final Report on DE-SC0006858, which opened 15 August 2011 and closed 14 August 2017. The contract institution is the University of Minnesota, address: 200 Oak St. SE, Suite 450, Minneapolis, MN 55455-2070. The Principal Investigator is Martin Greven, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 555455 (phone: 612-624-7542, email: greven@umn.edu). The Administrative Point of Contact is Patricia Jondahl (phone: 612-624-5599, email: awards@umn.edu). The DOE Program is the Office of Basic Energy Sciences, U.S. Department of Energy, Germantown Building, 1000 Independence Ave., SW Washington, DC 20585. The program manager is Dr. P. Thiyagarajan, Neutron Scattering SC-22.2/ Germantown Bldg. (phone: 301-903-9706, email: Thiyagarajan@science.doe.gov).

The primary scientific goal was the crystal growth, characterization, neutron and X-ray scattering study of the mercury-based cuprates, arguably the most desirable high-transition-temperature (high-T_c) superconductors for experimental study due to their record values of T_c and their relatively simple crystal structures. It is thought that the unusual magnetic and charge degrees of freedom of the copper-oxygen sheets that form the fundamental building block of all cuprate superconductors give rise to the high T_c and to many other unusual properties exhibited by these quantum materials. Neutron scattering experiments were primarily performed at the Spallation Neutron Source (SNS) and High Flux Isotope Reactor (HFIR), both at ORNL, and at the Laboratoire Léon Brillouin (LLB) and Institute Laue Langevin (LLB), both in France, in all cases on world-class instruments. Synchrotron X-ray scattering experiments were performed both at DOE laboratories and international facilities. Detailed characterization included charge-transport measurements and the use of high magnetic fields at the National High Magnetic Field Laboratory (NHMFL) at LANL and the Laboratoire National des Champs Magnétiques Intenses (LNCMI) in Toulouse, France. A second scientific goal was to share well-characterized crystals with world leaders in the use of complementary experimental techniques in order to work toward a comprehensive understanding of high-T_c cuprate superconductivity.

The neutron, X-ray and transport data obtained were generally analyzed at the University of Minnesota by the PI and participating postdoctoral researchers and graduate students. The activity made possible by this award is summarized in Section 2.1. The scientific productivity in terms of scientific papers published, conference presentations given and graduate students involved is summarized in Section 2.2. Key scientific highlights of the project are presented in Section 2.3. Community service is noted in Section 3. The postdoctoral researchers, Ph.D. students and undergraduate research students are identified in Section 4. Collaborators are listed in Section 5. Expenditures and Cost Status is given in Section 6. DOE funds are highly leveraged by neutron and X-ray beam time, instrumentation, technical support and hospitality at scattering facilities where experiments are conducted and some data analysis is conducted. The report closes with a list of publications (Section 7) and invited presentations (Section 8).

2. Progress Report: 15 Aug 2011 to 14 Aug 2017

2.1 Activity

In this section we state the chief scientific activity of DOE funded research between the start date of 15 August 2011 and the close date of 14 August 2017. The chief scientific activity was the crystal growth, characterization, neutron and X-ray scattering study of the mercury-based cuprates, arguably the most desirable high-T_c superconductors for experimental study due to their record values of T_c, their relatively simple crystal structures, and minimal disorder effects. This research took advantage of the fact that the PI's group had previously developed a unique method to grow sizable, high-quality single crystals of $HgBa_2CuO_{4+\delta}$ (Hg1201) the first member of this most desirable family of superconductors, thereby enabling unique research activity. It is thought that the unusual properties of the cuprates (including their record transition temperatures at ambient pressure) result from the complex behavior of their magnetic and charge degrees of freedom (in particular of the copper-oxygen sheets that form the fundamental building block of all cuprate superconductors). Therefore the study of these degrees of freedom in the model compound Hg1201 is of utmost importance. Neutron scattering is a unique probe of the energy and momentum dependence of magnetic degrees of freedom, whereas synchrotron X-ray scattering uniquely probes the corresponding charge degrees of freedom. Sophisticated sample characterization via charge transport, including measurements in high magnetic fields, was found to be of utmost importance in this endeavor. Whenever possible, the scattering and high-field transport measurements were performed at facilities in the U.S. Extensive measurements were also made at international facilities. The chief goals were: (i) determination of the magnetic excitation spectrum of Hg1201; (ii) determination of charge-density-wave correlations (CDW) in competition with superconductivity in Hg1201; (iii) quantitative charge transport measurements of Hg1201; (iv) initiation of meaningful collaborations with experts in the use of complementary experimental probes. In project (i), we observed a novel magnetic mode and mapped out the antiferromagnetic (AF) response at several hole doping levels; rather than typically observed 'hourglass' AF response, we uncovered that the response in the model compound Hg1201 has a 'wine-glass' shape. Under (ii) and (iii), we established the doping and temperature dependence of the CDW correlations and build a connection with charge transport data in high magnetic fields at low temperature (quantum oscillations). We also obtained fresh insight into the normal-state transport behavior. Finally, under (iv), we established a considerable number of new collaborations leading to new insight.

The PI led a successful effort to seek funding for a new Center for Quantum Materials (CQM) at the University of Minnesota, which received funding coincident with the last year of DE-SC0006858. The latter was subsumed by the CQM award, and the high level of activity generated under DE-SC0006858 is benefitting the CQM.

2.2 Productivity

The productivity or deliverable of the project is chiefly (i) articles published in peer-reviewed scientific journals, (ii) scientific presentations at national and international

conferences and workshops as well as at research laboratories and universities, and (iii) education of postdoctoral researchers, Ph.D. graduate students and undergraduate researchers in materials physics, with emphasis on crystal growth, characterization and scattering. In order to demonstrate productivity, we provide:

Lists of (i) scientific publications (Section 7) and (ii) invited presentations (Section 8). Twenty scientific papers were published in peer-reviewed journals and thirty-one invited talks were presented. In addition, numerous preprints were completed, and ten invitations to speak at international conferences or workshops had to be declined due to time conflicts. The peer-reviewed results were published in some of the most prestigious journals, including Nature Physics, Nature Communications, Physical Review Letters, Physical Review X, Physical Review B, and the Proceedings of the National Academy of Sciences. The invited talks include the International Conference on Novel Superconductivity, several Gordon Research Conferences, the American Physical Society March Meeting, several Low-Energy Electrodynamics in Solids Conferences, Ames Lab/Iowa State University, Argonne National Lab, Harvard, Berkeley, the University of Illinois in Chicago and Urbana-Champaign, and many others.

(iii) Lists of postdoctoral researchers, PhD graduate students and undergraduate researchers that were supported are provided in Section 4. All the six graduate students participated in the National School on Neutron and X-Ray Scattering at Argonne's Advanced Photon Source and Oak Ridge's Spallation Neutron Source and High Flux Isotope Reactor facilities, and all of them used neutrons and/or X-rays in their research.

2.3 Scientific Highlights

Highlights of this DOE-supported research are:

1. One of the central issues in the cuprates is to clarify the interplay between magnetism and superconductivity. Following the prior discovery of a novel dispersionless magnetic mode, our inelastic neutron scattering work (*Nature Physics* 2012; 22 citations according to Web of Science) revealed a second such excitation in the pseudogap (PG) state of $HgBa_2CuO_{4+\delta}$ (Hg1201).
2. We observed Shubnikov-de-Haas oscillations in the pseudogap state of Hg1201, which demonstrated, for the first time, that the prior observation of such quantum oscillations (QO) in the structurally more complex Y-based cuprates indeed universally results from the underlying copper-oxygen planes (*Nature Physics* 2013; 60 citations). In subsequent QO measurements, we were able to provide quantitative evidence of the existence of only a single QO frequency in Hg1201 (*Nature Communications* 2014; 13 citations). In separate charge transport work, we speculated on a connection with the charge-density-wave (CDW) phenomenon (*Phys. Rev. X* 2013; 62 citations).
3. Following the prior discovery of CDW order in a different cuprate compound, we used synchrotron X-rays to discover that CDW correlations are prominent in Hg1201 as well. Moreover, in this work we were able to establish a connection between the CDW and QO phenomena (*Nature Communications* 2014; cited already 105 times).

4. We provided the first quantitative planar resistivity results for Hg1201 in the (PG) state and, from comparison with the published literature, we were able to identify the fundamental sheet resistance of the quintessential copper-oxygen planes of the cuprates. This work furthermore provided initial arguments for the possibility of Fermi-liquid-like behavior in the PG state of the cuprates (*Proc. Nat. Acad. Sci.* 2013; 49 citations).
5. This in turn motivated (i) subsequent collaborative optical spectroscopy work with the group of Dirk van der Marel that provided further evidence for the Fermi-liquid nature of the charge carriers in the PG part of the phase diagram (*Proc. Nat. Acad. Sci.* 2013; 62 citations) and our successful demonstration that Kohler scaling of the magnetoresistance, the property of a simple metal, is fundamentally obeyed in the cuprates (*Phys. Rev. Lett.* 2014; 26 citations). Remarkably then, the itinerant carriers in the mysterious PG state have to be thought of as conventional quasiparticles.
6. In this same part of the phase diagram, we established via neutron scattering that the antiferromagnetic excitations spectrum of Hg1201 becomes prominent below the PG temperature T* and that it has a 'wine-glass' rather than an 'hourglass' shape. Given that Hg1201 exhibits both particularly high structural symmetry and optimal T_c, a likely explanation of this observation is that disorder effects and/or lower structural symmetry mask the wine-glass-shaped response in other cuprates. Magnetic fluctuations are one of the leading candidates for the Cooper pairing required for superconductivity to occur in the cuprates, and thus this recent result is beginning to receive considerable interest from theoretical physicists (*Nature Communications* 2016 and *Phys. Rev. Lett.* 2016, with a respective 10 and 5 citations so far).
7. Most recently, we followed up on our original observation of CDW order in Hg1201 by studying its full doping and temperature dependence. This has allowed us, for the first time, to construct a rather detailed phase diagram of Hg1201 that includes characteristic temperatures from neutron scattering, X-ray scattering and charge transport (Figure 1). The combined neutron and X-ray measurements make clear that an strong increase in AF correlations precedes the CDW order upon cooling, consistent with theoretical scenarios that AF correlations drive both the CDW correlations and superconductivity (*Phys. Rev. Lett.* 2017).
8. Notable additional collaborative work includes: (i) the first quantitative photoemission measurements of Hg1201 with Zhi-Xun Shen (Stanford) and Inna M. Vishik (now at UC Davis (*Phys. Rev. B* 2014; 18 citations); (ii) the observation of a feedback-effect on the high-energy magnetic fluctuations in Hg1201 from electronic Raman scattering with Bernhard Keimer (MPI, Stuttgart, Germany) and Yuan Li (now at Peking University, China) (*Phys. Rev. Lett.* 2012; 15 citations); (iii) transient reflectivity results by Joseph Orenstein (LBL and UC Berkeley) that, as seen from Figure 1, are highly consistent with our synchrotron X-ray data for the onset of CDW order (*Scientific Reports*, 2016; 5 citations).
9. Importantly, the neutron scattering observations of a novel magnetic mode and of enhanced AF scattering below the PG temperature in Hg1201, along with charge transport results, motivated us to develop a simple inhomogeneous Mott-like (de)localization model wherein exactly one hole per copper-oxygen unit is gradually

delocalized with increasing doping and temperature. The model is percolative in nature, with parameters that are experimentally constrained. It comprehensively captures pivotal unconventional experimental results, including the temperature and doping dependence of the pseudogap phenomenon, the strange-metal linear temperature dependence of the planar resistivity, and the doping dependence of the superfluid density. The success and simplicity of the model demystify the cuprate phase diagram and point to a local superconducting pairing mechanism. This model will need to be further tested through future inelastic neutron scattering measurements of magnetic excitations to very high temperatures, and through similar X-ray scattering measurements of charge-transfer excitations. This work is described in one of five preprints listed in Section 7.

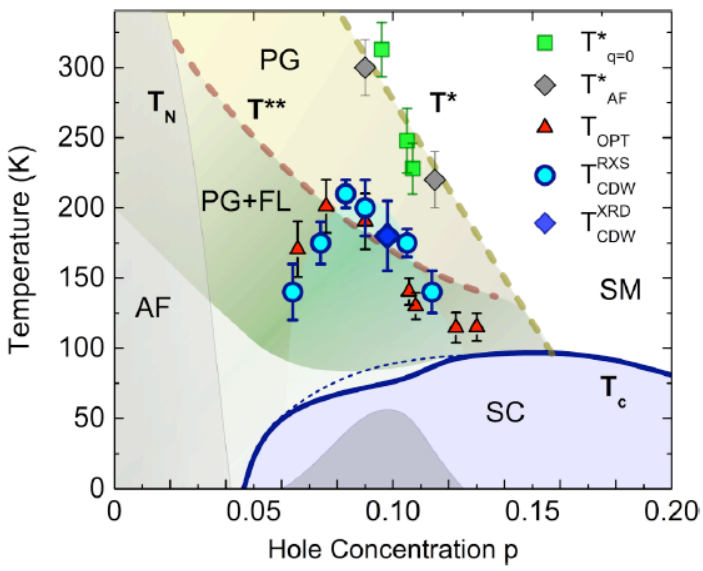

Figure 1: Temperature versus doping (hole concentration p) phase diagram of Hg1201, with characteristic temperatures from neutron scattering (pseudogap temperature T*; *Nature Physics* 2012 and prior DOE-sponsored work), X-ray scattering (charge-density-wave onset temperature T_{CDW}; *Nature Communications* 2014 and *Physical Review B* 2017), and collaborative transient reflectivity measurements T_{OPT} (*Scientific Reports* 2016). Below the characteristic temperature T**, within the pseudogap (PG) state, we established Fermi-liquid (FL) behavior (two manuscripts in the *Proceedings of the National Academy of Sciences* in 2013; *Physical Review Letters* 2014). Also indicated are the strange-metal (SM), superconducting (SC) and antiferromagnetic (AF) phases.

3. Service and Awards

Committee Membership:

• DOE-BES-MSE Triennial Review at Argonne National Laboratory (5/2017)

• Program Committee, Low Energy Electrodynamics in Solids Conference, Japan (5/2016)

- Executive Committee Member-at-Large, American Physical Society Division of Condensed Matter Physics (2015-2018)
- Program Committee, Materials and Mechanisms of Superconductivity conference, Geneva, Switzerland (8/2015)
- Program Committee, Low Energy Electrodynamics in Solids conference, Loire Valley, France (6/2014)
- International Advisory Committee, International Conference on the Materials and Mechanisms of Superconductivity (7/2012)

Panel, Proposal and Peer Reviews:

- National Science Foundation Materials Innovation Platforms (MIP) Reverse Site Visit Panel, Arlington, VA (8/2015)
- Oak Ridge National Laboratory Review Panel, DOE-BES Division of Materials Science and Engineering (4/2015)
- Oak-Ridge National Laboratory Science Review Panel (2010-2013)
- Proposal reviews for US National Science Foundation and Department of Energy (incl. service on review panels); NSERC (Canada); European Research Council (ERC), DFG (Germany); ISF (Israel); SNF (Switzerland); NIST Center for Neutron Research beam-time proposals; NWO (The Netherlands)
- Reviewer for Nature, Nature Physics, Nature Materials, Nature Communications, Physical Review B, Physical Review X, Physical Review Letters, Science, etc.

Conference/workshop Organization:

- Co-organizer (with A. Kamenev and M. Randeria), Workshop on Correlated Oxides and Oxide Interfaces, University of Minnesota (4/2014)

Honors/Awards:

In 2015, Martin Greven was elected Fellow of the American Association for the Advancement of Science (AAS). The citation reads: “For establishing a stellar record in growth and perfection of high quality crystals of oxide superconductors, enabling experiments leading to important advances in the field."

Honors/Awards (group members):

In 2015, former undergraduate research student Michael J. Veit (now in the Appled Physics Ph.D. program at Stanford University) won the prestigious LeRoy Apker Award of the American Physical Society for best undergraduate research in physics at a U.S. Ph.D. granting institution (http://www.aps.org/programs/honors/awards/apker.cfm). His research involved crystal growth and sophisticated characterization work. He presented his results in an invited talk at the 2015 APS March Meeting. This marked the first time that a University of Minnesota undergraduate won this award.

4. Students and Postdocs Supported

Postdoctoral researchers and senior research associates: Mun K. Chan (now scientific staff at NHMFL, LANL), Wojciech Tabis (Assistant Professor at the AGH University of

Science and Technology in Krakow, Poland, and also on the scientific staff at TU Vienna, Austria), Guichuan Yu (senior research associate, University of Minnesota).

Graduate students: Zachary Anderson, Sajna Hameed, Yangmu Li (now postdoctoral researcher in the neutron scattering group at Brookhaven National Laboratory), Yang Tang, Biqiong Yu. All the six graduate students participated in the National School on Neutron and X-Ray Scattering at ANL's Advanced Photon Source and ORNL's Spallation Neutron Source and High Flux Isotope Reactor facilities, and all of them used neutrons and/or X-rays in their research.

Undergraduate research students: Chelsey Dorow (now graduate student at UCSD), Ryan Frink (graduate student at Cornell), Jacob Freyermuth (researcher, University of Minnesota), Yang Ge (graduate student at Penn State), Vikram Nagarajan (graduate student at UC Berkeley), Sanjeev Mishra, Kaiwen Zhang (graduate student at UCSB), Michael Veit (graduate student at Stanford).

5. Research Collaborators

Principal neutron scattering collaborators: Douglas L. Abernathy, Andrew D. Christianson, and Masaaki Matsuda at ORNL; Dmitry Reznik at the University of Colorado, Boulder; Philippe Bourges and Yvan Sidis at LLB, France; Paul Steffens and Lucile Mangin-Thro at ILL, France; Masaki Fujita at Tohoku University, Japan.

Principal synchrotron X-ray scattering collaborators: Alan I. Goldman at Ames Lab/Iowa State University; Mathieu Le Tacon at Karlsruhe Institute of Technology, Germany; Eugen Weschke at Helmholtz-Zentrum Berlin, Germany; Giacomo Ghiringhelli at Politecnico di Milano, Italy.

Principal collaborator in charge-transport measurements: Neven Barišić, TU Vienna, Austria.

Principal collaborators in the use of complementary experimental techniques (based on crystals:

1. Juergen Haase (Leipzig, Germany): Nuclear magnetic resonance
2. William I. Halperin (Northwestern University): Nuclear magnetic resonance
3. David Hsieh (California Institute of Technology): Nonlinear optical measurements
4. Marc-Henri Julien (High Magnetic Field Laboratory, Grenoble, France): Nuclear magnetic resonance
5. Aharon Kapitulnik (Stanford University): Polar Kerr effect
6. Bernhard Keimer (MPI, Stuttgart, Germany) and Yuan Li (Peking University): Electronic Raman scattering
7. Dirk van der Marel (Université de Génève, Switzerland): Optical spectroscopy
8. Joseph Orenstein (University of California, Berkeley): Pump-probe optical measurements
9. Claudio Giannetti (Brescia, Italy): Time-resolved optical reflectivity

10. Miroslav Pozek (University of Zagreb, Croatia): Microwave and nonlinear charge transport
11. Cyril Proust (LNCMI, Toulouse, France): Ultrasound measurements in high magnetic fields
12. Ruslan Prozorov (Iowa State University and Ames National Laboratory): Superconducting penetration depth measurements
13. Dr. B. J. Ramshaw (now at Cornell University), Dr. A. Shekter (NHMFL, Florida), Dr. A. Migliori (LANL): Resonant ultrasound measurements in zero magnetic field
14. Dmitry Reznik (University of Colorado): time-resolved Raman Scattering
15. Robert J. Birgeneau (UC Berkeley), Inna M. Vishik (UC Davis) and Zhi-Xun Shen (Stanford University): Photoemission spectroscopy

6. Expenditures and Cost Status

The chief expenditures were support for graduate students and postdoctoral researchers, summer salary for the PI, as well as travel costs to conduct experiments at major neutron and synchrotron X-ray facilities and to attend national and international scientific meetings. All these funds are very highly leveraged by support from national and international neutron facilities, which fund experiments on a competitive proposal basis and provide essential technical support and often significant equipment support for experiments. A balance of zero remained at the close of the grant.

7. Publications, 2011 – 2017

Twenty (20) papers were published, including six (6) in either Nature or Nature Commun., five (5) in Phys. Rev. Lett., four (4) in Phys. Rev. B, and two (2) in Proc. Nat. Acad. Sci. USA. In addition, five (5) manuscripts have been submitted for publication.

Published, peer-reviewed manuscripts:

1. Yuan Li, G. Yu, M. K. Chan, V. Baldent, Yangmu Li, N. Barišić, X. Zhao, K. Hradil, R. A. Mole, Y. Sidis, P. Steffens, P. Bourges, and M. Greven, Two Ising-like collective magnetic excitations in a single-layer cuprate superconductor, Nature Phys. **8**, 404 (2012). http://dx.doi.org/10.1038/nphys2271

2. Yuan Li, M. Le Tacon, M. Bakr, D. Terrade, D. Manske, R. Hackl, L. Ji, M. K. Chan, N. Barišić, X. Zhao, M. Greven, and B. Keimer, Feedback effect on the high-energy magnetic fluctuations in the model high- temperature superconductor $HgBa_2CuO_{4+\delta}$ observed byelectronic Raman scattering, Phys. Rev. Lett. **108**, 227003 (2012). http://dx.doi.org/10.1103/PhysRevLett.108.227003

3. D.-D. Xia, G. Yu, Yuan Li, X. Zhao, and M. Greven, Temperature and field dependence of the anisotropy parameter for the high-temperature superconductor $HgBa_2CuO_{4+\delta}$, Super. Sci. Tech. **25**, 115010 (2012). http://dx.doi.org/10.1088/0953-2048/25/11/115010

4. S. I. Mirzaei, D. Stricker, J. N. Hancock, C. Berthod, A. Georges, E. van Heumen, M. K. Chan, X. Zhao, Yuan Li, M. Greven, N. Barišić, and D. van der Marel, Spectroscopic Evidence for Fermi liquid-like energy and temperature dependence of the relaxation rate in the pseudogap phase of the cuprates, Proc. Nat. Acad. Sci. US **110**, 5774 (2013). http://dx.doi.org/10.1073/pnas.1218846110

5. N. Doiron-Leyraud, S. Lepault, O. Cyr-Choiniere, B. Vignolle, F. Laliberte, J. Chang, N. Barišić, M. K. Chan, L. Ji, X. Zhao, Y. Li, M. Greven, C. Proust, L. Taillefer, Hall and Nernst coefficients of underdoped $HgBa_2CuO_{4+\delta}$. Fermi-surface reconstruction in an archetypal cuprate superconductor, Phys. Rev. X **3**, 021019 (2013). http://dx.doi.org/10.1103/PhysRevX.3.021019

6. N. Barišić, Yuan Li, G. Yu, X. Zhao, M. Dressel, A. Smontara, and M. Greven, Universal sheet resistance and revised phase diagram of the cuprate superconductors, Proc. Nat. Acad. Sci. U.S.A. **110**, 12235 (2013). 10.1073/pnas.1301989110

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8. A. M. Mounce, Sangwon Oh, Jeongseop A. Lee, W.P. Halperin, A.P. Reyes, P.L. Kuhns, M. K. Chan, C. Dorow, L. Ji, D. Xia, X. Zhao, and M. Greven, Absence of static orbital current magnetism at the apical oxygen site in $HgBa_2CuO_{4+\delta}$ from NMR, Phys. Rev. Lett. **111**, 187003 (2013). http://dx.doi.org/10.1103/PhysRevLett.111.187003

9. N. Barišić, S. Badoux, M. K. Chan, C. Dorow, W. Tabis, B. Vignolle, G. Yu, J. Beard, X. Zhao, C. Proust, and M. Greven, Universal quantum oscillations in the underdoped cuprate superconductors. Nature Physics **9**, 761 (2013). http://dx.doi.org/10.1038/nphys2792

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12. F. Cilento, S. Dal Conte, G. Coslovich, S. Peli, N. Nembrini, S. Mor, F. Ban_, G. Ferrini, H. Eisaki, M. K. Chan, C. Dorow, M. Veit, M. Greven, D. van der Marel, R. Comin, A. Damascelli, L. Rettig, U. Bovensiepen, M. Capone, C. Giannetti, and F. Parmigiani. Photoenhanced antinodal conductivity in the pseudogap state of high-Tc cuprates. Nature Commun. **5**, 4353 (2014). http://dx.doi.org/10.1038/ncomms5353

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18. M. K. Chan, N. Harrison, R. D. McDonald, B. J. Ramshaw, K. A. Modic, N. Barišić, and M. Greven, Single reconstructed Fermi surface pocket in an underdoped single-layer cuprate superconductor. Nature Commun. **7**, 12244 (2016). http://www.nature.com/articles/ncomms12244

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20. W. Tabis, B. Yu, I. Bialo, M. Bluschke, T. Kolodziej, A. Kozlowski, E. Blackburn, K. Sen, E. M. Forgan, M. v. Zimmermann, Y. Tang, E. Weschke, B. Vignolle, M. Hepting, H. Gretarsson, R. Sutarto, F. He, M. Le Tacon, N. Barišić, G. Yu, and M. Greven, Synchrotron x-ray scattering study of charge-density-wave order in $HgBa_2CuO_{4+\delta}$. Phys. Rev. B **96**, 134510 (2017). https://journals.aps.org/prb/abstract/10.1103/PhysRevB.96.134510

Preprints:

1. N. Barišić, M. K. Chan, M. J. Veit, C. J. Dorow, Y. Ge, Y. Tang, W. Tabis, G. Yu, X.

Zhao, and M. Greven**,** Evidence for a universal Fermi-liquid scattering rate throughout the phase diagram of the copper-oxide superconductors. https://arxiv.org/abs/1507.07885

2. D. Pelc, M. Vučković, M. Grbić, M. Požek, G. Yu, T. Sasagawa, M. Greven, N. Barišić, Emergence of superconductivity in the cuprates via a universal percolation process. https://arxiv.org/abs/1710.10219

3. P. Popčević, D. Pelc, Y. Tang, K. Velebit, Z. Anderson, V. Nagarajan, G. Yu, M. Požek, N. Barišić, and Martin Greven, Percolative nature of the dc paraconductivity in the cuprate superconductors. https://arxiv.org/abs/1710.10220

4. D. Pelc, P. Popčević, G. Yu, M. Požek, M. Greven, and N. Barišić, Unusual behavior of cuprates explained by heterogeneous charge localization. https://arxiv.org/abs/1710.10221

5. G. Yu, D.-D. Xia, D. Pelc, R.-H. He, N.-H. Kaneko, T. Sasagawa, Y. Li, X. Zhao, N. Barišić, A. Shekhter, and M. Greven, Universal superconducting precursor in the cuprates. https://arxiv.org/abs/1710.10957

8. Invited Presentations, 2011 – 2017

Thirty-one (31) invited talks given. In addition to the talks listed below, ten invitations to speak at international conference/workshops had to be declined due to a time conflict.

Invited conference/workshop talks and seminars/colloquia that were given:

1. International Conference on Novel Superconductivity, Tainan, Taiwan (8/2011)
2. 26th International Conference on Low-Temperature Physics, Beijing, China (8/2011)
3. Ames Lab/Iowa State (9/2011)
4. Massachusetts Institute of Technology (10/2011)
5. American Physical Society Meeting, Boston (2/2012)
6. 9th International Workshop on Polarized Neutrons in Condensed Matter Investigations, Paris, France (7/2012); talk given by former postdoc Mun K. Chan
7. Materials and Mechanisms of Superconductivity, Washington D.C. (7/2012)
8. 8th Annual Minnesota Nano Workshop (11/2012)
9. Argonne National Laboratory (2/2013)
10. Gordon Research Conference on Superconductivity, Les Diablerets, Switzerland (5/2013)
11. Spectroscopies in Novel Superconductors, Berkeley, California (6/2013)
12. International Symposium on Frontier of Superconductivity Research (III): Neutron Scattering on Unconventional Superconductors, Beijing, China (10/2013)
13. University of Colorado, Boulder, CA (11/2013)

14. Quantum Condensed Matter Workshop, Lawrence Berkeley National Laboratory, Berkeley, CA (12/2013)
15. Low-Energy Electrodynamics in Solids (LEES), Loire Valley, France (6/2014)
16. Fundamentals and Modern Aspects of Superconductivity, Kinken-Wakate School, Sendai, Japan (9/2014)
17. Institute for Materials Research workshop on Research Frontier of Transition-Metal Compounds, Sendai, Japan (10/2014)
18. Harvard University (11/2014)
19. Gordon Research Conference on Superconductivity, Hong Kong (5/2015)
20. Low-Energy Electrodynamics in Solids (LEES) conference, Moriyama, Japan (5/2016)
21. Laboratoire National des Champs Magnétiques Intenses, Toulouse, France (6/2015)
22. Boston College (9/2015)
23. Harvard University (9/2015)
24. University of Illinois, Chicago (9/2015)
25. Strong Correlations and the Normal State of the High-Temperature Superconductors Workshop, Dresden, Germany (talk given by collaborator and former postdoc Neven Barišić, TU Vienna, Austria; 5/2016)
26. From Solid State to Biophysics VIII, Dubrovnik, Croatia (talk given by collaborator and former postdoc Prof. Neven Barišić, TU Vienna, Austria; 6/2016)
27. University of Illinois, Urbana-Champaign (9/2016)
28. University of California, Berkeley (10/2016)
29. Laboratoire de Physique des Solides, Université Paris-Sud, France (11/2016)
30. Seoul National University, Seoul, S. Korea (5/2017)
31. Kavli Institute for Theoretical Physics (KITP) workshop on Order, Fluctuations, and Strong Correlations: New Platforms and Developments (8/2017)