



NOVEMBER 4-5, 2016

FRONTIERS OF QUANTUM MATERIALS



RICE UNIVERSITY • HOUSTON, TEXAS



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Presentation Guidance

Scope

Quantum Materials is an emerging field of research that encompasses a broad range of studies in strongly correlated systems and applied materials physics. The breadth of the field calls for interactions among the different sub-communities. This workshop aims to bring together top experts from a variety of areas to highlight the recent achievements in each area, and to provide a forum for cross-talk among the subjects.

The workshop will revolve around the following focus areas in the overarching field of Quantum Materials:

- Unconventional Superconductivity
- Quantum Criticality
- Ultracold Matter
- Low Dimensional Systems
- Energy Materials

Oral sessions

All oral sessions will be held in BRC Room 280.

Poster Sessions

The poster sessions will be held in the BRC Event/Exhibition Hall, Room 120

WIRELESS INTERNET ACCESS

Wireless access is available through the wireless network 'Rice Visitor.' Simply select this network, agree to the terms and conditions, and you should have full access, including electronic journals supported by the Rice library.



Workshop on Frontiers of Quantum Materials

Thursday, November 3, 2016

Arrival

6:00 – 8:00 pm Welcome Reception for Speakers and RCQM PIs

Friday, November 4, 2016

BRC 2nd Floor Lecture Hall, Room 280

Welcome Session

8:30 – 8:45 am Opening Remarks

Session I – Quantum Criticality

Chair: Qimiao Si

8:45 – 9:15 am Meigan Aronson (Texas A&M)
Quantum Criticality in the Quasi-two-Dimensional Ferromagnet YFe_2Al_{10}

9:15 – 9:45 am Silke Paschen (TU Vienna/Rice U.)
Quantum Criticality in a Heavy Fermion System with Quadrupolar Order

9:45 – 10:15 am Subir Sachdev (Harvard U.)
Quantum Matter Without Quasiparticles: SYK Models, Black Holes, and the Cuprate Strange Metal

10:15 – 10:45 am Coffee Break

Session II – Broader Aspects

Chair: Isabell Thomann and Thejaswi Tumkur

10:45 – 11:15 am Hongjie Dai (Stanford U.)
Nanosciences for Renewable Energy

11:15 – 11:45 am Jason Ho (Ohio State)
New Developments in Cold Atoms Research

11:45 am – Noon Zhiqiang Mao (Tulane U.)
Contributed: Enhanced Electron Coherence in Atomically Thin Nb_3SiTe_6

Noon – 12:15 pm Yunxiang Liao (Rice U.)
Contributed: Many-Body Delocalization: Keldysh Sigma Model Approach

12:15 – 12:30 pm Blitz Poster Preview
1 minute per poster



Workshop on Frontiers of Quantum Materials

12:30 – 2:30 pm **Lunch and Poster Session**
BRC Event/Exhibition Hall, Room 120

Session III – Low Dimensional Systems

Chair: Doug Natelson

2:30 – 3:00 pm Allan MacDonald (UT Austin)
Moiré Patterns in Two-Dimensional Materials

3:00 – 3:30 pm David Hsieh (Caltech)
Revealing Hidden Order in the Pseudogap Region Using Nonlinear Optics

3:30 – 4:00 pm Cory Dean (Columbia U.)
Designer 2D Electronics

4:00 – 4:30 pm **Coffee Break**

Session IV – Energy Materials

Chair: P. Ajayan

4:30 – 5:00 pm Giulia Galli (U. Chicago)
Materials Discovery and Scientific Design by Computation: What Does it Take?

5:00 – 5:30 pm Aditya Mohite (Los Alamos)
The Emergence of Hybrid Perovskites for Low-Cost, High-Efficiency Optoelectronics

5:30 – 6:00 pm Pramod Reddy (U. Michigan)
Radiative Heat Transfer at the Nanoscale

6:00 pm **Banquet**
BRC Event/Exhibition Hall, Room 120

Saturday, November 5, 2016

BRC 2nd Floor Lecture Hall, Room 280

Session V – Ultracold Matter

Chair: Randy Hulet

8:45 – 9:15 am Kathy Levin (U. Chicago)
Atomic Fermi Gases as a Proxy Laboratory for Quantum Condensed Matter

9:15 – 9:45 am Immanuel Bloch (Max Planck, Garching)
Controlling and Exploring Quantum Matter Using Ultracold Atoms in Optical Lattices



Workshop on Frontiers of Quantum Materials

9:45 – 10:00 am Francisco Camargo (Rice U.)
Contributed: *Rydberg Polarons in a Bose Gas*

10:00 – 10:30 am Coffee Break

Session VI – Broader Aspects

Chair: Pengcheng Dai

10:30 – 11:00 am Gabriel Aeppli (Stanford U.)
Control and Readout of Quantum States in Solids

11:00 – 11:30 am Boris Spivak (U. Washington, Seattle)
Macroscopic Character of Composite High Temperature Superconducting Wires and Enhancement of Superconductivity by Magnetic Field

11:30 am – Noon Rong Yu (Renmin U.)
Antiferroquadrupolar and Ising-Nematic Orders of a Frustrated Bilinear-Biquadratic Heisenberg Model and Implications for the Magnetism of FeSe

Noon – 12:15 pm Blitz Poster Preview
1 minute per poster

12:15 – 2:00 pm Lunch and Poster Session
BRC Event/Exhibition Hall, Room 120

Session VII – Unconventional Superconductivity

Chair: Elihu Abrahams

2:00 – 2:30 pm Frank Steglich (Max Planck, Dresden)
Interplay Between Heavy-Fermion Quantum Criticality and Unconventional Superconductivity

2:30 – 3:00 pm Zhi-Xun Shen (Stanford U.)
Cooperative Interactions and Enhanced Superconductivity in FeSe

3:00 – 3:30 pm Gabriel Kotliar (Rutgers U.)
Theory of Iron Pnictides and Chalcogenides

3:30 – 3:45 pm Yu Song (Rice U.)
Contributed: *Antiferromagnetic order and excitations in insulating $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$*

3:45 – 4:00 pm Girsh Blumberg (Rutgers U.)
Contributed: *Critical Nematic Fluctuations in Iron Pnictide Superconductors*

4:00 – 4:15 pm Summary and Outlook
Allan MacDonald



Invited Speakers

Unconventional Superconductivity

Gabriel Kotliar	Rutgers University
Zhi-Xun Shen	Stanford University
Frank Steglich	Max Planck, Dresden

Quantum Criticality

Meigan Aronson	Texas A&M
Silke Paschen	TU Vienna
Subir Sachdev	Harvard University

Ultracold Matter

Immanuel Bloch	Max Planck, Garching
Jason Ho	Ohio State
Kathryn Levin	University of Chicago

Energy Materials

Hongjie Dai	Stanford University
Aditya Mohite	Los Alamos
Pramod Reddy	University of Michigan

Low Dimensional Systems

Allan MacDonald	UT Austin
David Hsieh	Caltech
Cory Dean	Columbia University

Broader Aspects

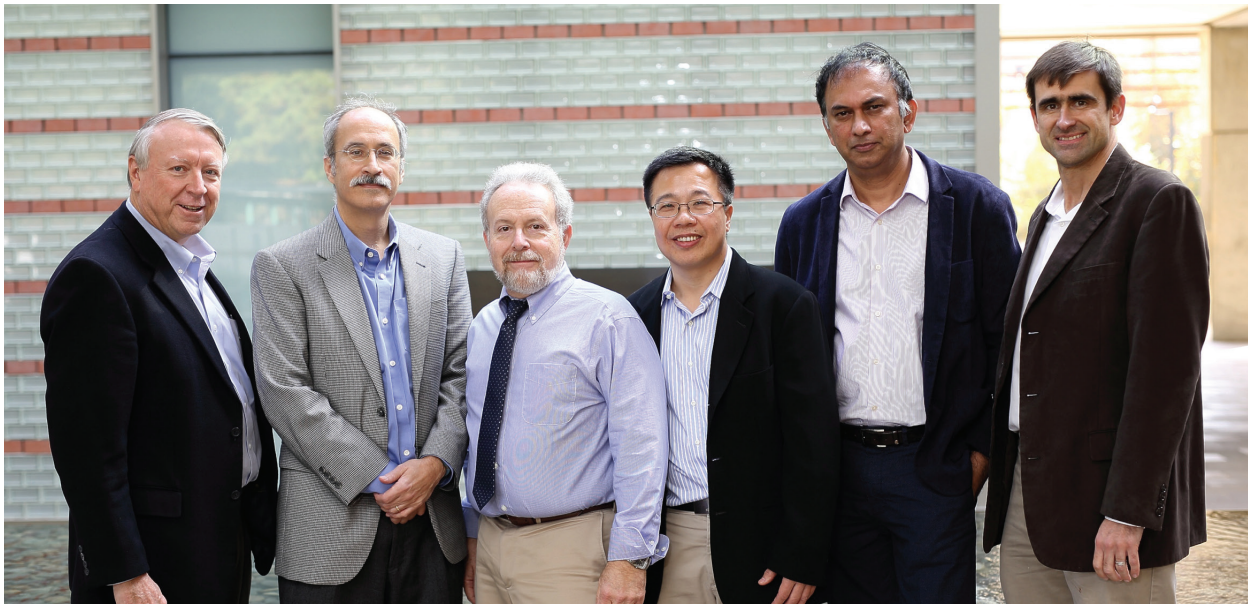
Gabriel Aeppli	PSI/ ETH Zürich
Giulia Galli	University of Chicago
Boris Spivak	University of Washington
Rong Yu	Renmin University



About RCQM

Mission Statement

Rice University's Center for Quantum Materials seeks to sustain and grow fundamental research of quantum materials on campus, and develop an international network in this area, with Rice at its hub. The center will incubate new research collaborations and directions by organizing scientific workshops, supporting distinguished visitors to Rice, sponsoring postdoctoral scholars and student researchers and developing international and domestic partnerships.

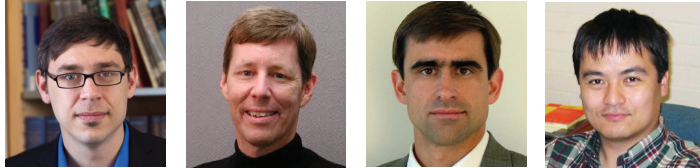


From left: Ned Thomas, dean of the George R. Brown School of Engineering; Yousif Shamoo, Vice Provost for Research; Peter Rossky, dean of the Wiess School of Natural Sciences; Qimiao Si, director of the Center for Quantum Materials; Pulickel Ajayan, the Benjamin M. and Mary Greenwood Anderson Professor in Materials Science and NanoEngineering and of chemistry; and Tom Killian, department chair and professor of physics and astronomy.



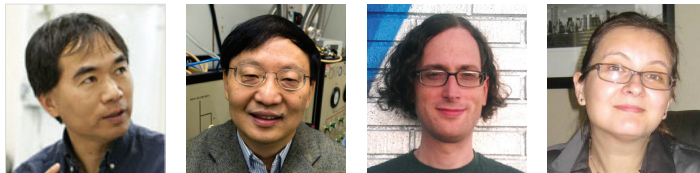
RCQM Membership

ATOMIC, MOLECULAR AND OPTICAL ENGINEERING

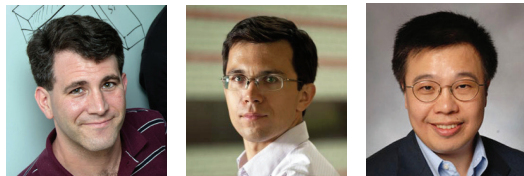


Kaden Hazard
Randy Hulet *
Tom Killian
Han Pu

CONDENSED MATTER

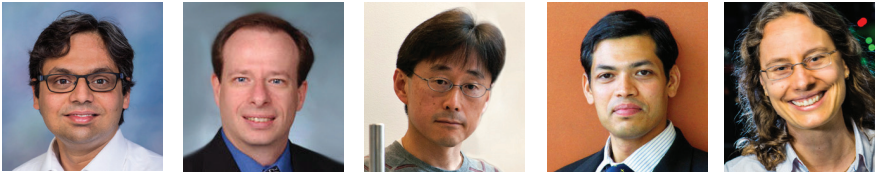


Pengcheng Dai *
Rui-Rui Du
Matthew Foster
Emilia Morosan



Doug Natelson
Andriy Nevidomskyy
Qimiao Si * Director

ELECTRICAL AND COMPUTER ENGINEERING



Palash Bharadwaj
Kevin Kelly
Jun Kono *
Gururaj Naik
Isabell Thomann

MATERIALS SCIENCE AND NANOENGINEERING



Pulickel Ajayan
Jun Lou
Emilie Ringe
Boris Yakobson *

CHEMISTRY



Peter Rossky
Gus Scuseria
James Tour

*Executive Committee Members



RCQM Advisory Board

Thanks and Appreciation

RCQM would like to express our appreciation to the members of the Advisory Board for their continued time and dedication to the center.

Frank Steglich

Max Planck Institute for Chemical Physics
of Solids, Dresden

Hongjie Dai

Stanford University

Laura Greene

University of Illinois at Champaign-Urbana

Meigan Aronson

Texas A&M University

Allan H. MacDonald

University of Texas at Austin

Jason Ho

Ohio State University

Elihu Abrahams

UCLA

(not pictured)





Gabriel Aeppli, Ph.D.

Professor of Physics
Paul Scherrer Institute
and ETH Zürich and EPF Lausanne
Switzerland

Control and Readout of Quantum States in Solids

Over the last decades, the focus of atomic physics has moved from spectroscopy to deterministic preparation and read-out of quantum states. We describe here how a similar approach which treats silicon as a vacuum“ leads to new quantum matter“.

Refs:

Schofield et al. Nature Communications DOI: 10.1038/ncomms2679 (2013)

Litvinenko et al. Nature Communications DOI: 10.1038/ncomms7549OI (2015)

Gabriel Aeppli is professor of physics at ETH Zürich and EPF Lausanne, and head of the Synchrotron and Nanotechnology division of the Paul Scherrer Institute. All of his degrees are from MIT and include a BSc in mathematics and electrical engineering, and MSc and PhD in electrical engineering. A large fraction of his career was in industry, where, starting as a work-study student at IBM and moving after his PhD to Bell Laboratories and then NEC, he worked on problems ranging from liquid crystals to magnetic data storage. He was subsequently co-founder and director of the London Centre for Nanotechnology and Quain Professor at University College London. Aeppli also cofounded the Bio-Nano Consulting Company, of which he remains a non-executive director. He is a frequent advisor to numerous private and public entities worldwide (including China, Australia, Europe and the US) engaged in the funding, evaluation and management of science and technology. Honours include the Mott Prize of the Institute of Physics (London), the Oliver Buckley prize of the American Physical Society, the Néel Medal/International Magnetism Prize of the International Union of Pure and Applied Physics, and election to the American Academy of Arts and Sciences and the Royal Society (London).



Meigan Aronson, Ph.D.

Professor
 Department of Physics and Astronomy
 Texas A&M University
 College Station, TX, USA

Quantum Criticality in the Quasi-two-Dimensional Ferromagnet $\text{YFe}_2\text{Al}_{10}$

It is now well accepted that the suppression of ordered states, such as magnetism, can give rise to a novel state with highly anomalous metallic characteristics. It remains a challenge to understand the role of the quantum critical fluctuations associated with the $T=0$ phase transition in inducing this new state, and if there is feedback between the fluctuations and the essential properties of the quasiparticles in the non-Fermi liquid electronic state. A lack of detailed experimental results on suitable QC systems has slowed progress towards this understanding. The quasi-two dimensional metal $\text{YFe}_2\text{Al}_{10}$ is a very promising system, comprised of layers of nearly square nets of Fe atoms, whose d-electrons are apparently completely delocalized. There is no evidence of magnetic order above 0.02 K. We review here the scaling properties of the magnetization and specific heat in $\text{YFe}_2\text{Al}_{10}$, characterizing the QC behavior that is expected near a $T=0$ phase transition. Inelastic neutron scattering measurements demonstrate a strong energy divergence of the scattering, which is wave vector independent over a wide range of temperature, energy, and fields. The dynamical susceptibility is found to be a function of E/T , a key signature of QC systems. The picture that emerges from our experiments is that $\text{YFe}_2\text{Al}_{10}$ has strong quantum critical dynamics that are nearly completely localized in space. We consider the experimental evidence that this unusual quantum criticality in $\text{YFe}_2\text{Al}_{10}$ may be a consequence of its magnetic anisotropy, prompting a description in terms of the quantum 2D-XY model.

Prof. Aronson works in experimental condensed matter physics, with emphasis on the discovery and characterization of new compounds where different types of electronic order can be induced to occur exactly at zero temperature. The unusual quantum critical phenomena associated with these $T=0$ phase transitions are explored in materials as diverse as f-electron based heavy fermion compounds, low dimensional d-electron compounds that are proximate to insulator-metal transitions, and unconventional surface states in topological insulators. Prof. Aronson received her A.B. from Bryn Mawr College in 1980, and the M.S and Ph.D degrees from the University of Illinois at Urbana-Champaign in 1982 and 1988. Following a postdoc at Los Alamos National Laboratory, she joined the Physics faculty at the University of Michigan in 1990. She moved her lab in 2007 to Stony Brook University, where she held a joint position between the Department of Physics and Astronomy, and Brookhaven National Laboratory. She joined Texas A+M University in 2015, where she is both the Dean of the College of Science as well as a professor in the Department of Physics and Astronomy.



Immanuel Bloch, Ph.D.

Experimental Physicist
Ludwig-Maximilians University
Max Planck Institute of Quantum Optics
Germany

Controlling and Exploring Quantum Matter Using Ultracold Atoms in Optical Lattices

More than 30 years ago, Richard Feynman outlined the visionary concept of a quantum simulator for carrying out complex physics calculations. Today, his dream has become a reality in laboratories around the world. In my talk I will focus on the remarkable opportunities offered by ultracold quantum gases trapped in optical lattices to address fundamental physics questions ranging from condensed matter physics over statistical physics to high energy physics with table-top experiment.

Immanuel Bloch is scientific director at the Max Planck Institute of Quantum Optics (Garching) and holds a chair for experimental physics at the Ludwig-Maximilians-University (Munich). His scientific work is among the most highly cited in the field of quantum physics and has helped to open a new interdisciplinary research field at the interface of atomic physics, quantum optics, quantum information science and solid state physics. For his research, he has received several national and international prizes, among them the Senior Prize for Fundamental Aspects of Quantum Electronics and Optics of the European Physical Society, the Körber European Science Prize and the Harvey Prize of the Technion.



Girsh Blumberg, Ph.D.

Experimental Physicist
 Department of Physics and Astronomy
 Rutgers University
 Piscataway, NJ, USA

Critical Nematic Fluctuations in Iron Pnictide Superconductors

The multiband nature of iron pnictides gives rise to a rich temperature-doping phase diagram of competing orders and a plethora of collective phenomena. At low doping concentrations, the tetragonal-to-orthorhombic structural transition is closely followed by a concomitant spin density wave transition both being in close proximity to the superconducting phase. A divergence of the electronic nematic susceptibility upon approaching the structural phase transition has been revealed by experimental probes which can couple to quadrupolar nematic fluctuations. More importantly, quantum critical behavior of a nematic character at doping concentration when superconducting T_c is close to the highest has been reported, suggesting that the critical nematicity plays a role in superconductivity. Because the critical fluctuations may simultaneously carry orbital, lattice and magnetic degrees of freedom, there is still lack of consensus on the main origin of the critical nematicity. Here we study the 111, 11 and 122 families of iron pnictide superconductors using low energy polarization resolved Raman spectroscopy [1-3]. The Raman susceptibility shows critical non-symmetric charge fluctuations across the entire phase diagram. The charge fluctuations are interpreted in terms of plasma waves of Pomeranchuk-like quadrupole excitations in which the electron and hole Fermi surfaces deform correlatively. We demonstrate that above the structural phase transition the quadrupolar fluctuations with long correlation times are precursor to the discrete four-fold symmetry breaking transition. This is manifested in the critical slowing down of XY-symmetry collective fluctuations observed in dynamical Raman susceptibility and strong enhancement of the static Raman susceptibility. Below superconducting transition, these collective excitations undergo a metamorphosis into a coherent in-gap collective mode of extraordinary strength and at the same time serve as a glue for non-conventional superconducting pairing. We acknowledge collaboration with Pengcheng Dai, H. Ding, M. Khodas, P. Richard, A.S. Sefat, S.-F. Wu, Weilu Zhang, Research at Rutgers was supported by US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0005463 and by the National Science Foundation under Award NSF DMR-1104884.

References:

- [1] V. K. Thorsmølle, M. Khodas, Z. P. Yin, C. Zhang, S. V. Carr, Pengcheng Dai, G. Blumberg. *Critical Charge Fluctuations in Iron Pnictide Superconductors*. *Phys. Rev. B* 94 054515 (2016).
- [2] S.-F. Wu, W.-L. Zhang, D. Hu, H.-H. Kung, A. Lee, H.-C. Mao, P.-C. Dai, H. Ding, P. Richard and G. Blumberg. *Collective excitations of dynamic Fermi surface deformations in BaFe₂(As_{0.5}P_{0.5})₂*. *arXiv:1607.06575* (2016).
- [3] S.-F. Wu, P. Richard, H. Ding, H.-H. Wen, Guotai Tan, Meng Wang, Chenglin Zhang, Pengcheng Dai, G. Blumberg. *Electronic Raman study of Ba_{1-x}K_xFe₂As₂ from under-doping to over-doping*. *arXiv:1608.06064* (2016).

Girsh Blumberg received the MS Cum Laude in Theoretical Physics and Physics Education from Tartu University in 1981. He received his Ph.D. in Physics and Mathematics from Estonian Academy of Sciences in 1987. Since 1981 he was Research/Senior Research Associate at the Institute of Chemical Physics and Biophysics, Estonian Academy of Sciences. Starting from 1992 visiting Assistant Professor at the University of Illinois at Urbana-Champaign, and at the NSF Science and Technology Center for Superconductivity before joining Bell Labs in 1998 as the Member of Technical Staff. Professor Blumberg joined the faculty at Rutgers in 2008. Girsh Blumberg is a world expert in Raman scattering with research interests in spectroscopic instrumentation, general optical spectroscopy in solids, liquids and gases, single molecule spectroscopy, electronic and phononic Raman spectroscopy, surface enhanced Raman spectroscopy, optics and spectroscopy at nano-scale. He is probably best known for his contribution to electronic Raman scattering studies in strongly correlated electron systems, superconductors and quantum spin systems. He has organized numerous spectroscopy meetings and served in advisory boards of numerous national and international conferences. He has co-authored over 100 publications and is inventor on numerous patents in the fields of electronic and optical devices, spectroscopy and nano-plasmonics. He is elected Fellow of the American Physical Society for seminal contributions to elucidating the physics of spin, charge and superconducting correlations in 1D and 2D complex oxide compounds using Raman scattering techniques.



Silke Buehler-Paschen, Ph.D.

Professor of Physics,
Institute of Solid State Physics
Vienna University of Technology, Vienna Austria

Department of Physics and Astronomy
Rice Center for Quantum Materials,
Rice University, Houston, TX, USA

Quantum Criticality in a Heavy Fermion System with Quadrupolar Order

Quantum criticality is a key organizing principle for strongly correlated electron systems. In heavy fermion compounds, it typically emerges when a magnetic – mostly antiferromagnetic – phase is continuously suppressed to zero and the system becomes paramagnetic. Such a situation is for instance encountered in the much studied tetragonal compound YbRh_2Si_2 : It displays a Kondo destruction quantum critical point (QCP) [1] as its antiferromagnetic phase is suppressed by an applied magnetic field [2]. In the cubic material $\text{Ce}_3\text{Pd}_20\text{Si}_6$, however, quantum critical behavior is observed [3,4] in more unusual settings: both within the magnetically ordered portion of the phase diagram [3,5] and at the border of a phase with quadrupolar order [4,5]. Experimental evidence for the different phases and the transitions between them will be presented. The findings will be discussed in the context of the global phase diagram for heavy fermion compounds [6]. We acknowledge financial support from the European Research Council (ERC Advanced Grant No 227378) and the Austrian Science Fund (project P29296-N27).

[1] Q. Si et al. *Nature* 413, 804 (2001). P. Coleman et al., *J. Phys. Condens. Matter* 13, R723 (2001). T. Senthil et al., *Phys. Rev. B* 69, 035111 (2004).

[2] S. Paschen et al., *Nature* 432, 881 (2004). S. Friedemann et al., *Proc. Natl. Acad. Sci.* 107, 14547 (2010).

[3] J. Custers et al., *Nat. Mater.* 11, 189 (2012).

[4] V. Martelli et al., unpublished.

[5] P. Y. Portnichenko et al., *Phys. Rev. B* 91, 094412 (2015). P. Y. Portnichenko et al., unpublished.

[6] Q. Si, *Physica B* 378-380, 23 (2006). Q. Si, *Phys. Status Solidi B* 247, 476 (2010).

Silke Bühler-Paschen is an experimental condensed matter physicist, working in the fields of strongly correlated electron systems and thermoelectrics. She graduated in physics from Graz University of Technology in Austria, with an external diploma work at the Paul Scherrer Institute in Switzerland. After her PhD studies at EPFL in Lausanne and a postdoctoral stay at ETH Zurich she moved to Germany, where she joined the Max Planck Institute for Chemical Physics of Solids in Dresden, first as scientific collaborator and then as associate professor. After a visiting professorship at the Nagoya University in Japan she was appointed full professor at the Vienna University of Technology in Austria. She received a C3 professorship from the Excellence Program of the Max Planck Society for the Advancement of Outstanding Female Scientist in 2003 and an ERC Advanced Grant from the European Research Council in 2008. She is APS fellow and leader of various national and international research projects. Her team is active in materials synthesis and characterization, using a large pool of different physical property measurements under multiple extreme conditions – spanning, for instance, 7 orders of magnitude in temperature. Topics of current interest include quantum criticality, heavy fermion systems, Kondo insulators, new topological phases, and thermoelectrics.



Francisco Camargo

Department of Physics and Astronomy
Rice Center for Quantum Materials
Houston, TX, USA

From Ultralong-Range Molecules to Rydberg Polarons in a Bose Gas

I will describe the excitation of Rydberg atoms in a Bose-Einstein condensate of strontium atoms. In a few body regime, we observe a dense, highly structured spectrum reflecting excitation of ultralong-range molecules consisting of one or more ground-state atoms bound to the Rydberg core in potential wells formed by the Rydberg-electron wave function. This represents a new molecular bonding mechanism and novel ultracold chemistry. In a many-body regime, with hundreds of ground-state atoms within the Rydberg orbital, the Rydberg atoms can be viewed as impurity in a quantum gas, connecting to important concepts in condensed matter physics. The spectrum for impurity excitation displays signatures of polaronic states, in which the Rydberg atom significantly perturbs the density of the background Bose gas.

Research supported by the AFOSR, NSF and the Robert A. Welch Foundation.

Collaborators

F.B. Dunning¹, T.C. Killian¹, J. Whalen¹, R. Ding¹, H.R. Sadeghpour², R. Schmidt^{2,3}, E. Demler³, S. Yoshida⁴, J. Burgdorfer⁴

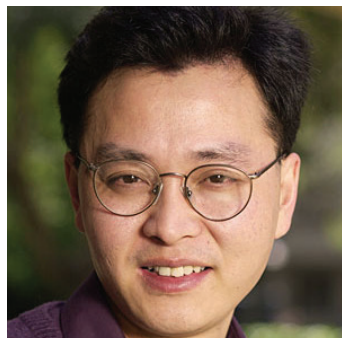
¹*Rice University, Department of Physics and Astronomy and Rice for Quantum Materials, Houston, Texas*

²*ITAMP, Harvard-Smithsonian Center for Astrophysics, 60 Garden St, Cambridge Massachusetts*

³*Department of Physics, Harvard University, Cambridge, Massachusetts*

⁴*Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria, EU*

Francisco Camargo is a graduate student working for Dr. Thomas Killian at Rice University. He obtained a B.S. in physics from UT Austin. His research interests are in the study of strongly-interacting many-body physics via ultra-cold Rydberg physics.



Hongjie Dai, Ph.D.

J.G. Jackson and C.J. Wood Professor in Chemistry
Stanford University
Stanford, CA, USA

Nanosciences for Renewable Energy

This talk will review our work on carbon based nanoscience and will focus on our work on advancing new types of electrocatalysts for renewable catalysis applications. I will talk about achieving record setting performance of electrocatalysts for water splitting including HER and OER. We have developed a novel Ni/NiO heterostructured hydrogen evolution reaction (HER) catalyst with near zero overpotential. The nanoscale nickel oxide/nickel NiO/Ni hetero-structures formed on carbon nanotube sidewalls are highly effective electrocatalysts for hydrogen evolution reaction with activity similar to Pt with near zero overpotential in HER onset in basic solutions. We have also developed a NiFe layered double hydroxide (NiFe LDH) oxygen evolution reaction (OER) catalyst with ~ 250mV overpotential, which was among the most active OER catalyst in basic solutions. The NiFe LDH exhibited higher OER catalytic activity and stability than commercial Ir based catalysts. Using the highly active Ni/NiO HER and NiFe LDH catalyst, we recently achieved enabling water splitting using a record low voltage of < 1.5 volt, making it possible to make an electrolyzer for hydrogen and oxygen gas generation running on a single AAA alkaline battery cell. Lastly, I will present our latest development of rechargeable Al ion battery

Hongjie Dai is the J.G. Jackson & C.J. Wood Professor of Chemistry at Stanford University. He is a leading figure in the study of carbon nanotubes. Dai received a B.S. in Physics from Tsinghua University, Beijing, in 1989, and M.S. in applied sciences from Columbia University in 1991, and a Ph.D. in Applied Physics from Harvard University in 1994 under the direction of Prof. Charles Lieber. After postdoctoral research at Harvard, he joined the Stanford faculty as an assistant professor in 1997. Among his awards are the American Chemical Society's ACS Award in pure chemistry, 2002, the Julius Springer Prize for Applied Physics, 2004, and the American Physical Society's James C. McGroddy Prize for New Materials, 2006. He was elected to the American Academy of Arts and Sciences in 2009, and to the American Association for the Advancement of Science in 2011.

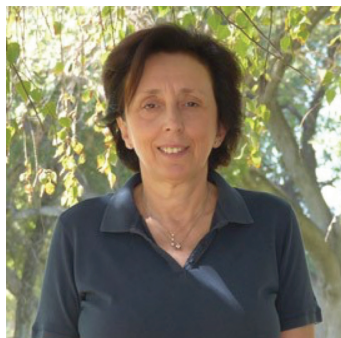


Cory Dean, Ph.D.

Assistant Professor
Department of Physics
Columbia University
New York, NY, USA

Designer 2D electronics

Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, is probably the best known, and most extensively characterized two-dimensional crystal. However, this represents just one of a larger class of van der Waals materials, in which atomic monolayers can be mechanically isolated from the bulk. By integrating these different materials with one another, new heterostructures can be fabricated with properties beyond those of the constituent layers. Moreover, the electronic properties of these systems are often highly sensitive to the lattice scale parameters such as layer number, inter-layer separation, and rotational order. In this talk I will examine how experimental control of these parameters is providing the capability to realize novel two-dimensional systems. The possibility to engineer new types of correlated phases, and with a degree of tunability beyond what has traditionally been possible, will be discussed.



Giulia Galli, Ph.D.

Liew Family Professor of Electronic Structure and Simulations
Institute for Molecular Engineering, University of Chicago
Senior Scientist, Argonne National Laboratory
Chicago, IL, USA

Materials discovery and scientific design by computation: what does it take?

Substantial progress has been made in the last three decades in understanding and predicting the fundamental properties of materials and molecular systems from first principles, employing electronic structure methods and atomistic simulations. Using specific examples, I will discuss some of the major challenges involved in enabling scientific discoveries by computation; in particular I will touch upon validation of methods and simulation results, and how to strengthen the connection between theory and experiments. I will also discuss some of the theoretical and algorithmic advances required to broaden the scope of properties accessible by current ab initio simulations.

Giulia Galli is the Liew Family Professor of Electronic Structure and Simulations in the Institute for Molecular Engineering at the University of Chicago. She also holds a Senior Scientist position at Argonne National Laboratory (ANL) and she is a Senior Fellow of the UChicago/ANL Computational Institute. Prior to joining UChicago and ANL, she was Professor of Chemistry and Physics at UC Davis (2005-2013) and the head of the Quantum Simulations group at the Lawrence Livermore National Laboratory (1998-2005). She holds a Ph.D. in Physics from the International School of Advanced Studies (SISSA) in Trieste, Italy. She is a Fellow of the American Physical Society (APS) and of the AAAS. She is the recipient of an award of excellence from the Department of Energy (2000) and of the Science and Technology Award from the Lawrence Livermore National Laboratory (2004). She is currently the director of MICCoM (Midwest Integrated Center for Computational Materials), established by DOE in 2015. Her research activity is focused on the development and use of theoretical and computational tools to understand and predict the properties and behavior of materials (solids, liquids and nanostructures) from first principles.



Tin-Lun Ho, Ph.D.

Distinguished Professor of Mathematical and Physical Science
 Department of Physics
 The Ohio State University
 Columbus, OH, USA

New Developments in Cold Atoms Research

I shall survey three recent developments in cold atom research and discuss the exciting opportunities they offer. The first is to use quantum gas to explore the century old problem of turbulence. I shall explain how the recent experimental results [1] implies that the classical turbulence is embedded in a much larger scale invariant structure of “cascade continuum”, and the possibility of understanding these scale invariant behaviors using Floquet approach. The second is the current effort to develop traps in the form of curved surfaces to study the quantum gas in curved space [2]. It is a plan currently being integrated in the US space program. The third is the recent success at NIST in measuring the second Chern number of the SU(2) Yang Monopole [3]. It illustrates the exciting prospect of studying physics above four dimensions using cold atoms.

[1] Nir Navon, Alexander L. Gaunt, Robert P. Smith, Zoran, to appear in *Nature*, arXiv: 1609.01271.

[2] Tin-Lun Ho and Biao Huang, *Phys. Rev. Lett.* 115, 155304 (2015), and to be published.

Expt. by I.B. Spielman et.al, preprint

[3] Topological transition from a non-Abelian Yang-Mills monopole, S. Sugawa, F. Salces-Carcoba, A.R. Perry Y. Yue and I.B. Spielman, preprint

Prof. Tin-Lun (Jason) Ho works in theoretical condensed matter physics, with particular focus on quantum fluids and cold atom physics. He has studied the topological properties of superfluid He-3, the physics of quasi-crystals, and has done pioneering works in different areas of quantum gases including spinor condensate, fast rotating Bose gas, universal thermodynamics of strongly interacting Fermi gas, Quantum Simulation, and spin-orbit coupled quantum gases. He received his B.Sc degree in the Chinese University of Hong Kong in 1972, a Ph.D at Cornell University in 1978. He was a Postdoctoral Associate at UIUC and at ITP from 1978-80 and from 1980-82. He joined The Ohio State University in 1982. He has been a Distinguished Professor of Mathematical and Physical Sciences of OSU since 2002; a Qian Ren Professor of the Institute for Advance Studies at Tsinghua University, Beijing, since 2012. He was elected Fellow of Alfred Sloan Foundation (1984), Fellow of John Simon Guggenheim Memorial Foundation (1999), Fellow of American Physical Society (2000), Fellow of American Association of Advancement of Sciences AAAS (2011), Simons Foundation Fellow (2011). He was the recipient of Lars Onsager Prize of the American Physical Society (2008), and was elected a Member of American Academy of Arts and Sciences (2015).



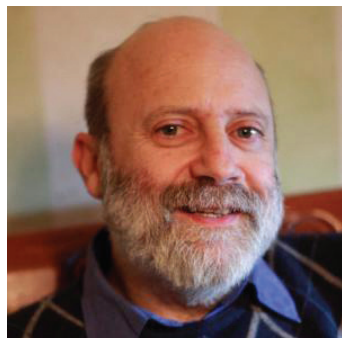
David Hsieh, Ph.D.

Assistant Professor of Physics
Department of Physics
Caltech
Pasadena, CA, USA

Revealing Hidden Order in the Pseudogap Region using Nonlinear Optics

The iridium oxide family of correlated electron systems is predicted to host a variety of exotic electronic phases owing to a unique interplay of strong electron-electron interactions and spin-orbit coupling. There is particular interest in the perovskite iridate Sr_2IrO_4 due to its striking structural and electronic similarities to the parent compound of high- T_c cuprates La_2CuO_4 . Recent observations of Fermi arcs with a pseudogap behavior in doped Sr_2IrO_4 and the emergence of a d-wave gap at low temperatures further strengthen their phenomenological parallels. In this talk I will describe our recently developed nonlinear optical spectroscopy and wide field microscopy techniques, which are highly sensitive to both the lattice and electronic symmetries of crystals. I will present results on the Sr_2IrO_4 system that reveal a subtle structural distortion and a hidden odd-parity electronic phase that have previously eluded other experimental probes. I will comment on its relevance to the pseudogap region and also draw comparisons with our recent nonlinear optical data in the pseudogap region of the cuprates.

Prof. David Hsieh is an experimental condensed matter physicist whose research focuses on macroscopic quantum electronic phases of matter in solid state systems. In particular, Prof. Hsieh is interested in developing novel nonlinear optics, time-resolved ultrafast optics and angle-resolved photoemission based spectroscopic probes to search for exotic topological and symmetry-broken quantum phases of matter. Prof. Hsieh earned his B.S in Physics and Mathematics from Stanford University in 2003 and his Ph.D. in Physics from Princeton University in 2009 where he worked on both neutron scattering studies of highly frustrated magnets as well as synchrotron-based spin- and angle-resolved photoemission spectroscopy of topological insulators. From 2009 to 2012 Prof. Hsieh was a Pappalardo Postdoctoral Fellow in Physics at MIT. There he developed several table-top laser-based techniques to study the ultrafast optical properties of topological insulators and wider classes of correlated spin-orbit coupled systems, with an eye towards their potential technological applications. He joined the Caltech faculty in 2012. Prof. Hsieh is the recipient of the 2012 William L. McMillan Award in condensed matter physics, the 2014 Sloan Research Fellowship and the 2015 Packard Fellowship in Science and Engineering.



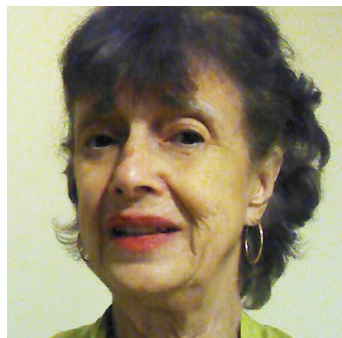
Gabriel Kotliar, Ph.D.

Board of Governors Professor Chair
Physics Department
Rutgers University
New Brunswick, NJ, USA

Theory of Iron Pnictides and Chalcogenides

We will discuss how these materials fit in the framework of strongly correlated superconductivity, and conclude on prospect of designing new superconductors

Dr. Gabriel Kotliar holds a Board of Governors Professor Chair in the Physics Department at Rutgers University. He is well known for his contributions to the theory of strongly correlated and disordered electron systems. He was an Alfred P. Sloan Research Fellow in 1986-1988, received a Presidential Young Investigator Award in 1987, a Lady Davies Fellowship in 1994, a Guggenheim fellowship in 2003, the Blaise Pascal Chair in 2005 and the Agilent Technologies Europhysics Prize in 2006. He has been a visiting professor at the Ecole Normale and the Ecole Polytechnique in Paris and the Hebrew University in Jerusalem. Dr. Kotliar has been organized and served in the the advisory board for numerous conferences and meetings. He is a Fellow of the American Physical Society since 2001 and has coauthored over two hundred publications in refereed Journals. His current research interests include the theory of the Mott transition, superconductivity in strongly correlated electron systems, the electronic structure of transition metal oxides, lanthanides and actinides, and the development of first principles approaches for predicting physical properties of materials.



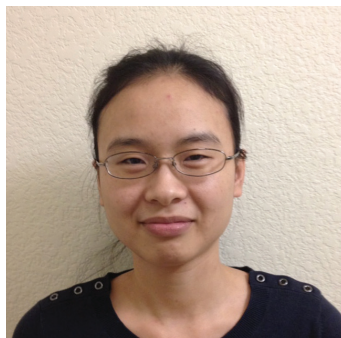
Kathryn Levin, Ph.D.

Professor of Physics
University of Chicago
Chicago, IL, USA

Atomic Fermi Gases as a Proxy Laboratory for Quantum Condensed Matter

In this talk I discuss how ultracold (mostly Fermionic) atomic superfluids can provide insights into a number of the focus areas of this conference. These include (i) unconventional superconductivity, (ii) quantum criticality, and (iii) low dimensional systems. In this context we discuss recent experiments in cold gas superfluids. Of major interest is the question of how and whether one can learn about phenomena which are not accessible from solid state condensed matter experiments. We discuss, perhaps the most striking example of these potentially unique insights. This comes from non-equilibrium physics elucidated by two important classes of dynamical experiments on cold gas superfluids.

Kathryn Levin, Ph.D., is a professor of physics at the University of Chicago. Her research interests have focused mainly on the theory of exotic magnetic and superfluid phases of condensed matter, including spin glasses, heavy fermion metals, superfluid helium-3 and high temperature superconductors. Levin also works on problems associated with ultracold atomic Fermi and Bose superfluids, with a focus on issues in which these systems can help shed light on problems and puzzles which are posed by the more “natural” forms of condensed matter. Levin viewed the BCS-BEC crossover observed in Fermi superfluids as a possible way of elucidating the pseudogap in high temperature superconductors. Similarly, of great interest are non-equilibrium dynamical studies of superfluids which are accessible in cold gases. Some recent work has addressed how 2-dimensional superfluidity is manifested in an atomic trapped system and the feasibility of observing topologically-ordered Fermi superfluids. In the solid state context, her team has been exploring Majorana zero modes in spintronics devices. Levin completed her undergraduate studies at the University of California, Berkeley, and received her Ph.D. at Harvard University (H. Ehrenreich).



Yunxiang Liao

Physics & Astronomy Department
Rice University
Houston, TX, USA

Many-body Delocalization: Keldysh Sigma Model Approach

Disordered, interacting quantum systems can exhibit many-body localization (MBL), a remarkable interference phenomenon that can preserve quantum mechanical coherence across a macroscopic sample at finite, even large energy densities. An isolated MBL system is non-ergodic and cannot thermalize, i.e., it cannot serve as its own heat bath and can act as a quantum memory. Although much has been recently clarified about the MBL phase, the nature (or even the existence) of the transition between MBL and the ergodic phases remains unclear, especially in dimensions higher than one. In this poster, we reformulate the Keldysh approach to interacting non-linear sigma models for Anderson localization in order to approach the transition from the metallic (ergodic) side in two spatial dimensions. We study class C, which is a system of superconductor quasiparticles that can undergo an interaction-driven, zero-temperature metal-insulator transition. Our goal is to explore the MBL-ergodic transition across a many-body mobility edge by deforming the quantum critical point to finite temperature in class C. We also investigate the symplectic spin-orbit metal class as a benchmark.

Yunxiang Liao is a graduate student from Physics and Astronomy department at Rice University, under the supervision of Dr. Matthew Foster. Prior to arriving at Rice, she obtained a B.S. in physics from Fudan University in Shanghai, China. Her current research interests lie in the study of interacting, disordered systems.

Research Partners

Alex Levchenko
Matthew S. Foster



Zhiqiang Mao, Ph.D.

Department of Physics and Engineering Physics
Tulane University
New Orleans, Louisiana, USA

Enhanced Electron Coherence in Atomically Thin Nb₃SiTe₆

J. Hu¹, X. Liu¹, C.L. Yue¹, J.Y. Liu¹, J. Wei^{1*}, and Z.Q. Mao^{1*}, P.B. Sorokin², P.W. Adams³, L. Spinu⁴, and D. Natelson⁵

It is now well established that many of the technologically important properties of two dimensional (2D) materials, such as the extremely high carrier mobility in graphene[1] and the large direct band gaps in MoS₂ monolayers [2], arise from quantum confinement. However, the influence of reduced dimensions on electron-phonon (*e-ph*) coupling and its attendant dephasing effects in such systems has remained unclear [3-7]. Although phonon confinement is expected to produce a suppression of *e-ph* interaction in 2D systems with rigid boundary conditions [6,7], experimental verification of this has remained elusive [8]. In this poster presentation, we will show that the *e-ph* interaction is, indeed, modified by a phonon dimensionality crossover in layered Nb₃SiTe₆ atomic crystals [9]. When the thickness of the Nb₃SiTe₆ crystals is reduced below a few unit-cells, we observe an unexpected enhancement of the weak-antilocalization (WAL) signature in magnetotransport [9]. This finding strongly supports the theoretically-predicted suppression of *e-ph* interaction caused by quantum confinement on phonons.

[1] K.S. Novoselov et al., *Science* 306, 666-669, (2004). [2] K. F. Mak et al., *Phys. Rev. Lett* 105, 136805, (2010).

[3] D. Belitz et al., *Phys. Rev. B* 36, 7701-7704, (1987). [4] K. Johnson et al., *Phys. Rev. B* 50, 2035-2038, (1994).

[5] S. Yu et al., *Phys. Rev. B* 51, 4695-4698, (1995). [6] B.A. Glavin et al., *Phys. Rev. B* 65, 205315, (2002).

[7] I.M. Tienda-Luna et al., *Appl. Phys. Lett.* 103, 163107, (2013). [8] J.J. Lin et al., *J. Phys.: Condens. Matter* 14, R501, (2002). [9] J. Hu et al., *Nature Physics* 11, 471 (2015)

Zhiqiang Mao is a professor at the Department of Physics and Engineering Physics of Tulane University. He received his PhD degree from University of Science and Technology of China and postdoctoral training at Kyoto University and the Pennsylvania State University. He joined Tulane University as a faculty member in 2002. His research is focused on strongly correlated oxides, unconventional superconductors and topological semimetals. He is an elected APS fellow.

Research Partners

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³Department of Physics and Astronomy, Louisiana State University, Baton Rouge, USA

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⁵Department of Physics and Astronomy, Rice University, Houston, USA



Aditya D. Mohite, Ph.D.

Scientist, Materials Physics and Applications
 Los Alamos National Laboratory
 Los Alamos, NM, USA

The Emergence of Hybrid Perovskites for Low-Cost, High-Efficiency Optoelectronics

Hybrid (inorganic-organic) perovskites have demonstrated an extraordinary potential for clean sustainable energy technologies and low-cost optoelectronic devices such as solar cells; light emitting diodes, detectors, sensors, ionic conductors etc. In spite of the unprecedented progress in the past six years, one of the key challenges that exist in the field today is the large degree of processing dependent variability in the structural and physical properties. This has limited the access to the intrinsic properties of hybrid perovskites and led to multiple interpretations of experimental data. In addition to this, the stability and reliability of devices has also been strongly affected and remains an open question, which might determine the fate of this remarkable material despite excellent properties. In this talk, I will describe our recently discovered approach for thin-film crystal growth as a general strategy for growing highly crystalline, bulk-like thin-films of both three-dimensional (3D) and layered two-dimensional (2D) hybrid perovskites that overcomes the above issues by allowing access to the intrinsic charge and energy transport processes within the perovskite thin-films and results in reproducible and stable high performance optoelectronic devices.

[1] Nie-Tsai et al , *Science* (2015).

[2] Nie-Blancon *Nature Comm.* (2016).

[3] Tsai-Nie *Nature* (2016)

[4] Blancon et al *Adv. Func. Materials* (2016)

Aditya D. Mohite is the PI of the Light-to-Energy team and directs an energy and optoelectronic devices lab working on understanding and controlling charge and energy transfer processes occurring at interfaces created with organic and inorganic materials for thin-film clean energy technologies. His research philosophy is applying creative and “out-of-the-box” approaches to solve fundamental scientific bottlenecks and demonstrate technologically relevant performance in devices that is on par or exceeds the current state-of-the-art devices. He received his Ph.D. from the University of Louisville in 2008. After 3 years of postdoctoral work at Rice University and Los Alamos National Laboratory and now is a Staff Scientist since Jan 2012. He has published more than 78 peer reviewed papers in journals such as *Science*, *Nature*, *Nature Materials*, *Nature Nanotechnology*, *Nano Letters*, *ACS Nano*, *Chemical Society Reviews*, *Applied Physics Letters* and *Advanced Materials* amongst others. He has also delivered more than 50 invited talks and generated more than \$ 12 million funding as a PI, Co-PI and Co-I.



Pramod Reddy, Ph.D.

Associate Professor of Mechanical Engineering and Materials Science
University of Michigan
Ann Arbor, Michigan, USA

Radiative Heat Transfer at the Nanoscale

Radiative heat transfer between objects separated by nanometer-sized gaps is of considerable interest due to its promise for non-contact modulation of heat transfer and for several energy conversion applications. Although radiative heat transfer at macroscopic distances is well understood, radiative heat transfer at the nanoscale remains largely unexplored. In this talk, I will describe ongoing efforts in our group to experimentally elucidate nanoscale heat radiation. Specifically, I will present our recent experimental work where we have addressed the following questions: 1) Can existing theories accurately describe radiative heat transfer in single nanometer sized gaps¹? 2) What is the role of film thickness on nanoscale radiation²? and 3) Can radiative thermal conductances that are orders of magnitude larger than those between blackbodies be achieved³? In order to address these questions we have developed a variety of instrumentation including novel nanopositioning platforms and microdevices, which will also be described. Finally, I will briefly outline how these advances can be leveraged for future investigations of nanoscale radiative heat transport, near-field thermophotovoltaic energy conversion and near-field based solid-state refrigeration.

[1] K. Kim, B. Song, V. Fernández-Hurtado, W. Lee, W. Jeong, L. Cui, D. Thompson, J. Feist, M. T. H. Reid, F. J. García-Vidal, J. C. Cuevas, E. Meyhofer and P. Reddy, "Radiative heat transfer in the extreme near-field", *Nature* 528, 387-391 (2015).

[2] B. Song, Y. Ganjeh, S. Sadat, D. Thompson, A. Fiorino, V. Fernández-Hurtado, J. Feist, F. J. García-Vidal, J. C. Cuevas, P. Reddy and E. Meyhofer, "Enhancement of near-field radiative heat transfer using polar dielectric thin films", *Nature Nanotechnology* 10, 253-258 (2015).

[3] B. Song, D. Thompson, A. Fiorino, Y. Ganjeh, P. Reddy and E. Meyhofer, "Radiative heat conductance between dielectric and metallic parallel plates at nanoscale gaps", *Nature Nanotechnology* 11, 509-514 (2016).

Prof. Pramod Reddy received a B. Tech and M. Tech in Mechanical Engineering from the Indian Institute of Technology, Bombay in 2002, and a Ph.D. in Applied Science and Technology from the University of California, Berkeley in 2007. He was a recipient of the NSF CAREER award in 2009, and the DARPA Young Faculty Award in 2012. He is currently an associate professor in the departments of Mechanical Engineering and Materials Science and Engineering at the University of Michigan, Ann Arbor.



Subir Sachdev, Ph.D.

Herchel Smith Professor of Physics
 Department of Physics
 Harvard University
 Cambridge MA, USA

Quantum matter without quasiparticles: SYK models, black holes, and the cuprate strange metal

I will describe and compare models for metallic states without quasiparticle excitations. The solvable Sachdev-Ye-Kitaev (SYK) model [1] provides a useful starting point, and also has remarkable and precise holographic connections to the quantum gravity of black holes in AdS2 [2]. Quantum critical states of two-dimensional metals are obtained by coupling the fermions to fluctuating bosonic order parameters or gauge fields. I will discuss recent experiments on the hole-doped cuprates, and the implications for a theory of their strange metal regime [3].

[1] S. Sachdev and J. Ye, *Phys. Rev. Lett.* 70, 3339 (1993).

[2] S. Sachdev, *Phys. Rev. Lett.* 105, 151602 (2010).

[3] S. Sachdev and D. Chowdhury, *arXiv:1605.03579*

Subir Sachdev's research describes the connection between physical properties of modern quantum materials and the nature of quantum entanglement in the many-particle wavefunction. Sachdev has worked extensively on the description of the diverse varieties of entangled states of quantum matter. These include states with topological order, with and without an energy gap to excitations, and critical states without quasiparticle excitations. Many of these contributions have been linked to experiments, especially to the rich phase diagrams of the high temperature superconductors. Extreme examples of complex quantum entanglement arise in metallic states of matter without quasiparticle excitations, often called strange metals. Remarkably, there is an intimate connection between the quantum physics of strange metals found in modern materials (which can be studied in tabletop experiments), and quantum entanglement near black holes: Sachdev has played a key role in proposing and developing this connection. Sachdev attended the Indian Institute of Technology, Delhi, the Massachusetts Institute of Technology and Harvard University, and received his Ph.D. in theoretical physics. He held professional positions at Bell Labs (1985–1987) and at Yale University (1987–2005), where he was a Professor of Physics, before returning to Harvard, where he is now the Herchel Smith Professor of Physics. He also holds visiting positions as the Cenovus Energy James Clerk Maxwell Chair in Theoretical Physics at the Perimeter Institute for Theoretical Physics, and the Dr. Homi J. Bhabha Chair Professorship at the Tata Institute of Fundamental Research. He is a member of the National Academy of Sciences, fellow of the American Physical Society and has been awarded several honors, among them the Dirac Medal (UNSW) in 2015, the Lorentz Chair (Instituut-Lorentz, Leiden University) in 2012, and the Salam Distinguished Lecturer (International Center for Theoretical Physics, Trieste).



Zhi-xun Shen, Ph.D.

Paul Pigott Professor of Physical Sciences
Stanford University
Stanford, CA, USA

Cooperative Interactions and Enhanced Superconductivity in FeSe

FeSe is a superconductor with a critical temperature of 8K. However, this relatively low superconducting transition temperature can be enhanced to about 40K by very modest pressure, or by electron doping. Interestingly, it can be further enhanced to above 60K by growing as ultrathin films on oxide surfaces. Using angle-resolved photoelectron spectroscopy, time-resolved photoemission spectroscopy, and time-resolved x-ray diffraction, we uncover evidence for cooperative interactions of electron-electron and electron-phonon interactions that give rise to these novel and enhanced properties. Insights gain may have general implications for pathways to high temperature superconductivity.

[1] J.J. Lee et al., *Nature* 515, 7526 (2014).

[2] Y. Zhang et al., *Phys. Rev. Lett.*; to appear, 2016

[3] S. Gerber, S.L. Yang et al., in review

Prof. Shen develops photon based experimental techniques, and applies them to frontier issues in condensed matter physics, with an emphasis on strongly correlated electron systems, and particularly unconventional superconductors. Prof. Shen is a member of the National Academy of Sciences, a recipient of the H. Kamerlingh Onnes International Prize for Superconductivity, the E.O. Lawrence Award of the Department of Energy, the Oliver Buckley Prize of the American Physical Society, and the Einstein Professorship Award of the Chinese Academy of Sciences. He was the first director of the Stanford Institute for Materials and Energy Sciences, and the Chief Scientist of SLAC National Accelerator Laboratory.



Yu Song

Pengcheng Dai Research Group
Rice University
Houston, TX, USA

Antiferromagnetic order and excitations in insulating $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$

Iron-based superconductivity develops near an antiferromagnetic order and out of a bad metal normal state, which has been interpreted as originating from a proximate Mott transition. Whether an actual Mott insulator can be realized in the phase diagram of the iron pnictides remains an open question. Doping Cu into a prototypical parent compound NaFeAs a superconducting dome appears for $1\% < x < 5\%$, and for $x > 10\%$ the system acquired an insulating ground state. We find the insulating behavior in $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$ is accompanied by Fe-Cu order and magnetic order with correlation lengths that increase with increasing Cu concentration, becoming long-range near $x \sim 50\%$ culminating in an antiferromagnetic insulator with $T_N \sim 200$ K. The insulating behavior persists above T_N , indicative of a Mott insulator. $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$ is therefore the only Fe-based system in which superconductivity can be continuously connected to the Mott insulating state, highlighting the important role of electron correlations in the high- T_c superconductivity.

In $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$ with $x \sim 50\%$, Fe and Cu order into stripes, forming a structural analogue of stripe magnetic order in NaFeAs . Magnetic excitations exhibit strongly one-dimensional character, dominated by the nearest-neighbor exchange coupling between Fe atoms along the stripes. Despite the differences in magnetic structure between NaFeAs and $\text{NaFe}_{1-x}\text{Cu}_x\text{As}$ with $x \sim 50\%$, the magnetic excitation spectra are remarkably similar at high energies.

Yu Song is a graduate student at Rice University in Pengcheng Dai's research group working on experimental condensed matter physics. He is interested in experimentally studying strongly correlated materials using neutron & x-ray scattering and other characterization techniques. He obtained his Bachelor's degree in 2010 from Zhejiang University.



Boris Spivak, Ph.D.

Professor of Physics
Department of Physics
University of Washington
Seattle, WA, USA

Macroscopic Character of Composite High Temperature Superconducting Wires and Enhancement of Superconductivity by Magnetic Field

“D-wave” symmetry of the superconducting order in the cuprate high temperature superconductors is a well established fact, and one which identifies them as “unconventional.” However, in macroscopic contexts – including many potential applications (i.e. superconducting “wires”) – the material is a composite of randomly oriented superconducting grains in a metallic matrix, in which Josephson coupling between grains mediates the onset of long-range phase coherence. Here, we analyze the physics at length scales large compared to the size of such grains, and in particular the macroscopic character of the long-range order that emerges. While XY-glass order and macroscopic d-wave superconductivity may be possible, we show that under many circumstances – especially when the d-wave superconducting grains are embedded in a metallic matrix – the most likely order has global s-wave symmetry. We also show that magnetic field may enhance superfluid density in the wires. Finally, we argue that any of mentioned above features exist in other unconventional disordered superconductors as well.



Frank Steglich, Ph.D.

Professor of Physics
Chemical Physics of Solids
Max Planck Institute
Dresden, Germany

Interplay Between Heavy-Fermion Quantum Criticality and Unconventional Superconductivity

Unconventional superconductivity (SC) often occurs in the vicinity of quantum critical points (QCPs) in antiferromagnetic (AF) heavy-fermion (HF) metals. For example, HF SC near a pressure-induced itinerant (“conventional”, i.e., 3D-SDW) QCP was revealed via inelastic neutron scattering for the first HF superconductor CeCu_2Si_2 . However, no SC has so far been detected near certain HF QCPs, such as the one induced by a magnetic field in YbRh_2Si_2 , a prototypical system exhibiting a *local* (“unconventional”) QCP, i.e., a 4*f*-orbital selective Mott transition at $T = 0$. This raises the question about the generality of the afore-mentioned quantum critical paradigm. Here, we explore the possibility of reaching the quantum critical regime of YbRh_2Si_2 by sufficiently weakening its AF order ($T_N = 70$ mK), namely by coupling it to nuclear spins at very low temperatures, instead of applying a pair-breaking magnetic field. To this end, we discuss results of magnetic and calorimetric measurements on YbRh_2Si_2 down to $T = 1$ mK. They reveal the onset of a hybrid nuclear-electronic type of AF order dominated by the Yb-derived nuclear spins at T_A slightly above 2 mK and the subsequent development of SC at $T_c = 2$ mK. The initial slope of the upper critical field curve, $B_{c2}(T)$, at T_c is found to be as large as $-B_{c2}' \simeq 25$ T/K. This indicates that the effective charge-carrier mass must be of the order of several 100 up to 1000 m_0 (m_0 being the rest mass of the electron), implying that the superconducting state is associated with the Yb-derived 4*f* electrons. This kind of HF SC in YbRh_2Si_2 may be called ‘*high* T_c ’, in the sense that it is limited by an exceedingly high ordering temperature of nuclear spins ($T_A > 2$ mK as compared to common values of nK). The transition at $T_c = 2$ mK from the antiferromagnetically ordered into the superconducting state is of first order, which suggests that the *intrinsic* T_c as expected in the absence of any AF order and at $B = 0$ would be substantially higher than 2 mK. We ascribe the formation of SC in YbRh_2Si_2 to the critical fluctuations associated with the *local* QCP of this antiferromagnet, which are revealed when the primary electronic order is diminished by the competing nuclear order. Our results demonstrate a new means to reach an AF QCP and provide further evidence that SC in the vicinity of such an instability is a general phenomenon. Work performed in collaboration with E. Schuberth, M. Tippmann, L. Steinke, S. Lausberg, A. Steppke, M. Brando, R. Yu and Q. Si

Frank Steglich received a Dr. rer. nat. from the University in Göttingen (Germany) in 1969. He was Professor of Physics at the Technical University of Darmstadt (Germany) for twenty years, before becoming Founding Director of the Max Planck Institute for Chemical Physics of Solids (MPI CPfS), Dresden (Germany) in 1996. At present, he is Director Emeritus at MPI CPfS and Founding Director of the Center for Correlated Matter, Zhejiang University, Hangzhou (China) as well as Distinguished Visiting Professor at the Institute of Physics, Chinese Academy of Sciences, Beijing (China). He received several awards, such as the DFG Leibniz Prize, the EPS Hewlett Packard Europhysics Prize, the Humboldt Award (Gay Lussac Humboldt Prize), the APS International Prize for New Materials (James C. McGroddy Prize), the IUPAP Magnetism Award, the DPG Stern Gerlach Medal, the Bernd T. Matthias Prize for Superconducting Materials and the Fellowship of the APS. He was Vice President of the DFG from 2001 to 2007.



Rong Yu, Ph.D.

Department of Physics
Remin University of China
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Antiferroquadrupolar and Ising-nematic Orders of a Frustrated Bilinear-Biquadratic Heisenberg Model and Implications for the Magnetism of FeSe

Motivated by the magnetic properties of the iron chalcogenides, we study the phase diagram of a generalized Heisenberg model with frustrated bilinear-biquadratic interactions on a square lattice. We identify zero-temperature phases with antiferroquadrupolar and Ising-nematic orders. The effects of quantum fluctuations and interlayer couplings are analyzed. We propose the Ising-nematic order as underlying the structural phase transition observed in the normal state of FeSe, and discuss the role of the Goldstone modes of the antiferroquadrupolar order for the dipolar magnetic fluctuations in this system. Our results provide a considerably broadened perspective on the overall magnetic phase diagram of the iron chalcogenides and pnictides, and are amenable to tests by new experiments.

[1] R. Yu and Q. Si, *Phys. Rev. Lett.* 115, 116401 (2015)

[2] H.-H. Lai, et al., *arXiv:1603.03027*

[3] W.-J. Hu et al., *arXiv:1606.01235*

Rong Yu obtained his Ph.D. degree from University of Southern California in 2007. He was a postdoctoral research associate at University of Tennessee, Knoxville (2007–2009) and at Rice University (2009–2013). Since 2013 he has been an associate professor at Department of Physics, Remin University of China. He has been working on theory of correlated electronic systems. Current main areas of his research includes phase transitions in heavy fermion systems, frustration and disorder effects in quantum magnets, superconductivity and correlation effects in iron-based superconductors.



Poster Presentations

1. 1D to 3D Crossover of a Spin-Imbalanced Fermi Gas

Yi Jin, Melissa C. Revelle, Jacob A. Fry, Anna L. Marchant, Randall G. Hulet., Department of Physics and Astronomy and Rice Quantum Institute, Rice University, Houston, Texas

We study the one to three-dimensional (1D to 3D) crossover of an ultracold spin-imbalanced Fermi gas [1]. In our experiment, we create a two-spin component gas of atomic fermions (lithium-6) in a 2D optical lattice. The lattice confines the atoms in an array of 1D tubes with a variable maximum lattice depth. Phase separation has been observed to occur in spin-imbalanced atomic Fermi gases in both 1D and 3D geometries [2,3]. Because the density distribution is inhomogeneous in a trap, phase separation results in a shell-like structure of the phases. This shell-structure is inverted in 1D compared to 3D. In 1D, the atomic cloud has a partially-polarized core and either fully-polarized or fully-paired superfluid wings. In 3D, the atomic cloud has a balanced superfluid core surrounded by a partially-polarized shell, enclosed by a fully-polarized outer shell. We probe the crossover regime between 1D and 3D by changing the interactions with a Feshbach resonance, and by varying the tunneling rates in the lattice by changing the lattice depth. We find that the measured phase boundaries depend universally on the tunneling scaled by the pair binding energy. Locating the crossover region will aid in our effort to directly detect the exotic superfluid state, FFLO [4]. *References [1] M. C. Revelle, et al., arXiv:1605.06986 (2016). [2] Y. A. Liao, et al., Nature 467, 567 (2010). [3] B. A. Olsen, et al., Phys. Rev. A 92, 063616 (2015). [4] M. M. Parish, et al., Phys. Rev. Lett. 99, 250403 (2007).*

2. Antiperovskite Ca₃BiP: A Topological Insulator to Dirac Semimetal Phase Transition Under the Application of Strain

Goh, Wen Fong, UC Davis

Searching for new and promising topological insulators has been an active topic for a decade. Compounds with antiperovskite structure have been suggested to be potential topological insulators, due to their small band gap or gapless electronic characteristics. Using first principles calculations, we survey the entire class of $3 \times 5 \times 5$ alkaline earth-pnictide antiperovskite compounds, viz. Ae₃PnA PnB, where Ae = Ca, Sr, Ba and PnA, PnB = N, P, As, Sb, Bi, and classified these compounds into either topologically trivial insulators or topologically non-trivial semimetals. The band topology of a topological insulator is characterized by band inversion. For the trivial insulators, strain can invert the band ordering to produce topologically non-trivial insulators, while for the topological semimetals, where the band ordering has been inverted by spin-orbit coupling but leaving a gapless bulk state, strain can open up a gap while maintaining the inverted band ordering. The cubic antiperovskite Ca₃BiP, a narrow gap semiconductor, is used as an example to illustrate the role played by the spin-orbit coupling and strain in the topological semimetallic nature of these antiperovskite compounds. Results show that it can be driven into a topological insulating phase under uniaxial compression, or a Dirac semimetallic state under uniaxial expansion. A band inversion picture, as well as the topological surface states and Fermi arc will be shown.

3. Direct Fabrication of Functional Ultrathin Single-Crystal Nanowires from Quasi-One-Dimensional Van Der Waals Crystals

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Micromechanical exfoliation of two-dimensional (2D) van der Waals materials has triggered an explosive interest in 2D material research. The extension of this idea to 1D van der Waals materials, possibly opening a new arena for 1D material research, has not yet been realized. In this paper, we demonstrate that 1D nanowire with sizes as small as six molecular ribbons, can be readily achieved in the Ta₂(Pd or Pt)₃Se₈ system by simple micromechanical exfoliation. Exfoliated Ta₂Pd₃Se₈ nanowires are n-type semiconductors, whereas isostructural Ta₂Pt₃Se₈ nanowires are p-type semiconductors. Both types of nanowires show excellent electrical switching performance as the channel material for a field-effect transistor. Low-temperature transport measurement reveals a defect level inherent to Ta₂Pd₃Se₈ nanowires, which enables the observed electrical switching behavior at high temperature (above 140 K). A functional logic gate consisting of both n-type Ta₂Pd₃Se₈ and p-type Ta₂Pt₃Se₈ field-effect transistors has also been successfully achieved. By taking advantage of the high crystal quality derived from the parent van der Waals bulk compound, our findings about the exfoliated Ta₂(Pd or Pt)₃Se₈ nanowires demonstrate a new pathway to access single-crystal 1D nanostructures for the study of their fundamental properties and the exploration of their applications in electronics, optoelectronics, and energy harvesting.



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4. Disorder-Enhanced Topological Protection and Universal Quantum Criticality in a Spin-3/2 Topological Superconductor

Davis, Seth, Rice University, Co-Authors: Seth Davis (1), Sayed Ali Akbar Ghorashi (2,1), Matthew S. Foster (1,3) (1) Department of Physics, Rice University Houston, TX; (2) Department of Physics and Texas center for superconductivity, University of Houston, Houston, TX; (3) Rice Center

Topological effects in quantum materials are a central focus in condensed matter physics, as evidenced by the 2016 Noble Prize in Physics. Of particular interest are bulk (3D) topological superconductors (TSCs), predicted to host 2D Majorana fermion surface fluid states with many remarkable properties. For example, the surface fluid of a TSC formed from spin-1/2 electrons enjoys “topological protection” from Anderson localization in the presence of quenched surface disorder. Instead, the surface states are predicted to be critically delocalized, possess universal transport spin and/or heat coefficients, and exhibit universal local density of states fluctuations; these nonperturbative results have been established analytically via 2D conformal field theory (CFT) [1,2,3]. Motivated by applications to cold atom physics and the half-Heusler materials, we investigate p-wave and f-wave pairing models for a 3D topological superconductor with spin-3/2 carriers [4]. For the model with p-wave pairing, we derive the exact analytic form of the surface states, the surface effective hamiltonian, and the most general form of coupling to quenched disorder. The system hosts both linear and cubic topological surface bands [4]. Via an RG analysis, we determine that the only allowable interaction leads to a marginally relevant BCS instability on the surface; by contrast, disorder is a strongly relevant perturbation. Numerically, we show that disorder drives the system to a stable fixed point of the RG flow governed by the same type of CFT that appears for spin-1/2 TSCs. In particular, the critical behavior of the global density of states and the multifractality of the surface wavefunctions are entirely universal (independent of disorder or band structure parameters, in agreement with CFT), and the system is stabilized against interactions. For the model with f-wave pairing, we again derive the effective surface Hamiltonian and the most general form of disorder coupling, analytically showing that the effective surface theory is equivalent to the Dirac surface theory governing the spin-1/2 carrier TSC theory, (mentioned above), with an additional Sine-Gordon term. We show numerically that, independent of the strength of the sine-Gordon term, the physics of the system is described by the same CFT that controls the spin-1/2 Dirac theory. See also the poster by Sayed Ghorashi et al. *References: [1] H. Y. Xie, Y.Z. Cho, and M. S. Foster, Phys. Rev. B 91, 024203 (2015). [2] M. S. Foster, H. Y. Xie, and Y. Z. Chou, Phys. Rev. B 89, 155140 (2014). [3] M. S. Foster and E. A. Yuzbashyan, Phys. Rev. Lett. 109, 246801 (2012). [4] W. Yang, Y. Li, and C. Wu, Phys. Rev. Lett. 117, 075301 (2016).*

5. Exactly Solvable Majorana-Like Ground States in a Number-Conserving Double Wire Model

Zhiyuan Wang, Youjiang Xu, Han Pu and Kaden Hazzard

Majorana fermions have sparked interest in condensed matter and cold atoms as emergent quasiparticles with fundamentally new properties, in particular non-Abelian statistics. However, most theoretical calculations start with a Bogoliubov mean field approximation from which they show that the resulting model possesses Majorana states. It then remains an open question whether and when this mean field approximation is valid. We make progress towards this question in two ways. First, we demonstrate a model in which mean field theory incorrectly predicts a gapped phase with Majorana ground states, in contrast to the gapless phase that we find from numerically exact DMRG calculations. Secondly, we construct new families of interacting exactly solvable models with Majorana ground states without relying on a mean field approximation. Significantly, one of these exactly solvable models is a number-conserving model but nevertheless can be shown to host robust Majorana-like degenerate ground states. These results give a deeper conceptual understanding of how Majorana fermions can be realized in nature.

6. Finite Temperature Quenches of Fermions in an Optical Lattice

Ian G. White, Randall G. Hulet, Kaden R. A. Hazzard

Although interaction quenches are known to drive interesting dynamics, much prior work has focused on quenches initiated from states that are well below the system's ordering temperature. Motivated by experiments with ultracold fermions in optical lattices, which are currently outside this regime, we study interaction quenches in the Fermi-Hubbard model starting from finite-temperature initial states. We show that interesting dynamics occurs even under these conditions. In particular, we study quenches to noninteracting systems, which despite their simplicity have been the focus of recent work concerning integrability and prethermalization. Even in the limit where the initial temperature T is much greater than the tunneling t , we find that there is transient growth of intertwined two-site spin and charge correlations. We also study a case in which the initial system contains a single hole defect, and show that the propagation of this defect affects spin correlations even in the absence of interactions.



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7. Fermi Level Tuning and Microscopic Band Gap Study of Magnetically Doped and Undoped Telluride Thin Films

Maximenko, Yulia, University of Illinois, Urbana-Champaign

The topological properties of V-VI chalcogenides have been known for some time. Bi₂Te₃ and Sb₂Te₃ are the materials from this group that have been studied extensively, both microscopically and macroscopically. One of the biggest hurdles in effectively using these materials for applications is the propensity of these materials to have vacancies and anti-site defects which push the Fermi energy onto the bulk bands, thereby increasing the bulk contribution to transport. In this context, it has recently been shown that alloys of Bi₂Te₃ and SbTe₃ (Bi_xSb_(1-x))₂Te₃, also called BST may be ideal topological materials. Defects can be minimized in BST which in turn leads to a decrease in bulk carrier contributions. BST films show clear topological surface states and have been used to demonstrate spin-polarized currents as well as the Quantum Anomalous Hall Effect. In previous works, the primary control parameter in film growth was the Sb:Bi evaporation ratio. However, there are large variations in the literature on the reported compositions where the Fermi level is tuned to the middle of the band gap. In this work, we present a scanning tunneling microscopy (STM) study of BST thin films and show the importance of crystallinity and surface roughness for the final bulk carrier concentration, thus explaining the drastically different Sb:Bi ratios in previously reported recipes. We also report on the growth of Cr-doped BST thin films with a clear integral ferromagnetic hysteresis. We measure the local density of states and the band gap of the magnetically doped samples with the atomic resolution STM. We find that the effect of the Cr atoms on the band gap depends on the Cr concentration. In small concentration, increase of the band gap is strongly correlated with the density of Cr atoms. However, as the Cr concentration is increased, the gap magnitude is anti-correlated with Cr density. This behavior is explained with the antiferromagnetic ordering of Cr atoms which are in close proximity with each other. Our STM data are supported by atomic force microscopy, X-ray diffraction and X-ray photoelectron spectroscopy.

8. Frustrated Magnetism and Bicolinear Order in FeTe

Lai, Hsin-Hua, Rice University

Iron chalcogenides display a rich variety of electronic orders in their phase diagram. A particularly enigmatic case is FeTe, a metal which possesses co-existing hole and electron Fermi surfaces as in the iron pnictides but has a distinct (3.14/2, 3.14/2) bicollinear antiferromagnetic order in the Fe square lattice. While local-moment physics has been recognized as essential for understanding the electronic order, it has been a long-standing challenge to understand how the bicollinear antiferromagnetic ground state emerges in a proper quantum spin model. We show here that a bilinear-biquadratic spin-1 model on a square lattice with nonzero ring-exchange interactions exhibits the bicollinear antiferromagnetic order over an extended parameter space in its phase diagram. Our work shows that frustrated magnetism in the quantum spin model provides a unified description of the electronic orders in the iron chalcogenides and iron pnictides.

9. Frustrated Magnetism and Quantum Transitions of Nematic Phases in FeSe

Hu, Wenjun, Rice University

Since its discovery, iron-based superconductivity has been known to develop near an antiferromagnetic order, but this paradigm apparently fails in the iron chalcogenide FeSe, whose derivatives hold the record of superconducting transition temperature in the iron-based superconductors. The striking puzzle that FeSe displays a nematic order (spontaneously broken lattice rotational symmetry) while non-magnetic has led to competing proposals for the origin of the nematic order of FeSe, either in terms of the 3d-electron's orbital degrees of freedom or spin physics in the form of frustrated magnetism. Here we show that the phase diagram of FeSe can be fully described by a quantum spin model with highly frustrated interactions. We identify quantum transitions from a ($\pi, 0$) antiferroquadrupolar order to a ($\pi, 0$) antiferromagnetic state, either directly or through a ($\pi/2, \pi$) antiferromagnetic order; these phases, while distinct, are all nematic. Our results suggest that superconductivity in a wide range of iron-based materials has a common origin in the antiferromagnetic correlations of strongly correlated electrons.

10. Geometric Representation of Spin Correlations

Anthony Mirasola, Jacob Hollingsworth, Ian G. White, Kenneth Wang, Rick Mukherjee, Kaden R. A. Hazzard

We develop a general method to visualize spin correlations and we demonstrate its broad utility in ultracold matter from fermions in lattices to trapped ions and ultracold molecules. Correlations are of fundamental interest in many-body physics: they characterize phases in condensed matter and AMO, and they are required for quantum sensing and computing. However, it is often difficult to understand even the simplest correlations – e.g. between two spin-1/2's – directly from the components $C^{ab} =$



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$[S_i^a S_j^b]$ for $\{a,b\} \in \{x, y, z\}$. The nine independent C^{ab} can be unwieldy, and considering the components individually obscures the natural geometric structure. For example, simple spin rotations lead to complex transformations among the nine C^{ab} . We provide a one-to-one map between the spin correlations and certain three-dimensional objects, analogous to the map between a single spin and Bloch vectors. This mapping makes the geometric structure of the correlations manifest. Moreover, much as one can reason geometrically about dynamics using a Bloch vector – e.g. a magnetic field causes the vector to precess and dephasing causes it to shrink – we show that one can reason analogously about the dynamics of correlations using our visualization.

11. Helicity Breaking and Electromagnetic Response of Interface States of Topological Insulator-Semiconductor Heterostructures

Asmar, Mahmoud M, Louisiana State University

The enticing properties of the robust states that appear at the boundary of topological insulators have made these materials one of the main targets of investigation for the last decade. Their potential uses cover fields as varied as thermoelectric, spintronic and quantum computing [1,2,3]. These new frontiers of applications require the combination of topological and non-topological materials in heterostructures. Despite the advancements in the field and the well-understood properties of the spin-momentum locked (helical) surface states of topological insulators [1,2,3,4], the properties of interface states and the factors determining their nature are not well investigated. We show, via symmetry arguments and microscopic calculations, that, even though the existence of the interface state between a topological insulator and a semiconductor is guaranteed by topology, the physical properties of the interface states are not universal. These properties depend on what additional symmetries of the bulk are broken by the interface potentials. In particular, we find that the spin accumulation under transport current is very sensitive to the interface properties. In addition, in contrast to the perfectly helical case, we find that an in-plane magnetic field leads to a gap opening in the interface spectrum. Our results give the general form of low-energy Hamiltonian of the semiconductor-topological insulator interface, providing a new framework for describing devices incorporating topological matter. *References: [1] J. E. Moore and L. Balents, Phys. Rev. B 75, 121306 (2007) [2] M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010) [3] XL. Qi and SC. Zhang, Rev. Mod. Phys. 83, 1057 (2011) [4] A. A. Burkov and D. G. Hawthorn, Phys. Rev. Lett. 105, 066802 (2010) [5] M. M. Asmar, D. E. Sheehy and I. Vekhter, in preparation (2016)*

12. Kondo Destruction and Pairing Enhancement in the Single and Two Impurity SU(2) Symmetric Bose-Fermi Anderson Model

Cai, Ang, Rice University, Co-Authors: Qimiao Si

Experiment on heavy fermion superconductor CeRhIn5 provides evidence of an underlying Kondo destruction quantum critical point (QCP) near the superconducting regime. Motivated by the experimental results, we studied the single impurity and two impurity SU(2) symmetric Bose-Fermi Anderson model with a vector bosonic bath, whose spectral function vanishes as a power-law. Using a recently developed continuous time quantum Monte Carlo algorithm [PRB 87 125102], in the single impurity problem we confirmed the epsilon expansion result [PRB 66 024426, PRB 66 024427] of the existence of a critical phase and a Kondo destruction QCP. We further studied the two impurity model, coupled via an antiferromagnetic RKKY interaction, and a bosonic bath to the difference of their spin, both in an SU(2) symmetric fashion. We have identified the transition from the Kondo screened phase to an impurity singlet phase or a local moment phase. In both cases, the singlet pairing susceptibility is enhanced on the verge of Kondo destruction. Together with related work on the two impurity Anderson model with Ising anisotropy [PRB 91 201109 (R), arXiv:1604.06449], our results suggest pairing enhancement being a robust feature of Kondo destruction QCP, and also help elucidating the role of spin symmetry on the pairing tendency.

13. Low Energy Properties of Bilayer Sr3Ru2O7 Compound

Mukherjee, Shantanu, Binghamton University

Bilayer material Sr3Ru2O7 (Sr327) consists of a rich phase diagram including metamagnetic transition, electronic nematic order, Mott insulating state, dopant induced structural transition, and long range magnetic order. The origin of these ordered phases is not well understood and currently a number of experimental observations on this compound remain unexplained. In this talk I will summarize our current understanding of the origin of the ordered phases in Sr327 compound. Our results on the calculation of spin susceptibility within a random phase approximation in this multi band material will be presented. Focusing on the observation of dopant induced long range magnetic order, I will show that by accounting for the structural changes in oxygen octahedral rotation with doping we can explain the formation of a long range magnetic order in agreement with observations by neutron scattering



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experiments. Finally, using a U(1) slave spin formalism, I will present some recent calculations that provide useful clues about the doping dependence of the Mott insulating and magnetic order in Sr327 compound.

14. Magnetic, Transport Properties, Δ , J_c , H_{c1} , H_{c2} , Anisotropy and Gap Evidences of Superconducting Electron-Doped $\text{Ca}_{10}(\text{Pt}_n\text{As}_8)[(\text{Fe}_{1-x}\text{Pt}_x)_2\text{As}_2]_5$ Single Crystals

Kalyan Sasmal¹ and Ching-Wu (Paul) Chu¹, ¹Texas Center for Superconductivity & Department of Physics, University of Houston, Houston, TX

Platinum iron arsenides $\text{Ca}_{10}(\text{Pt}_n\text{As}_8)[(\text{Fe}_{1-x}\text{Pt}_x)_2\text{As}_2]_5$ with $n = 3$ & 4 are the first Fe based superconductors with metallic PtAs intermediary layers in Ca-Fe-Pt-As system. Superconducting single crystals have been grown & characterized by X-ray diffraction, wavelength-dispersive spectroscopy electron probe microanalysis, magnetization, transport & thermodynamic measurements. Crystal structure have stacks of Ca (Pt_nAs_8) Ca (Fe_2As_2) consists of superconducting Fe_2As_2 layers alternating with Pt_nAs_8 layers, forming a triclinic P1, “10-3-8” phase with $n = 3$ (β - phase) and tetragonal P4/n, (“10-4-8” phase) with $n = 4$ (α -phase). Compared to other pnictides the difference lies in structural & electronic characters of metallic intermediary PtAs layers rather than insulating intermediary layers & difference in T_c arises because intermediary layer is semiconducting in 10-3-8 phase but metallic in 10-4-8 phase. Both metal-like (Pt_nAs_8) & (Fe_2As_2) blocks in $\text{Ca}_{10}(\text{Pt}_n\text{As}_8)(\text{Fe}_2\text{As}_2)_5$ phase make significant contributions to total density of states on Fermi level E_F . This leads to greater interactions between blocks & increased T_c . Pt-substitution is detrimental to higher T_c , which increases up to 38 K only by charge doping of pure FeAs layers. Two different negatively charged layers $[(\text{FeAs})_{10}]^{n-}$ and $(\text{Pt}_{3-y}\text{As}_8)^{m-}$ compete for electrons provided by Ca^{2+} -ions. In parent compound $\text{Ca}_{10}(\text{FeAs})_{10}(\text{Pt}_3\text{As}_8)$, no excess charge dopes FeAs-layer, & superconductivity has to be induced by Pt-substitution, although below 15 K. In contrast, additional Pt in Pt_4As_8 layer shifts charge balance between layers equivalent to charge doping by 0.2 electrons per FeAs. Only in this case T_c raises to 38 K, but decreases again if additionally Pt is substituted for Fe. Charge doping is supported by $T_c \approx 30$ K in electron-doped RE(La,Pr)-1038, $x = 0.2$ $(\text{Ca}_{1-x}\text{RE}_x)_{10}(\text{Pt}_3\text{As}_8)(\text{Fe}_2\text{As}_2)_5$ without significant Pt-substitution. With La/Pr doping, the structural/magnetic phase transitions are suppressed. Magnetic properties are explored. Magnetization measurements reveal fish-tail hysteresis loop & relatively high critical current density at low T . Exponential T dependence of J_c arises from nonlinear effective flux-creep activation energy, also suggests that anisotropy is much larger than that of 122 FeSC's. Normal-state magnetic susceptibility with characteristic T-linear dependence in a wide temperature range is indicative of strong spin/magnetic fluctuations as in most of the Fe-pnictides. Ginzburg-Landau (GL) parameters extracted from reversible magnetizations of single crystal data. Resistive transition for H/c axis shows modest broadening. Upper critical field determined by resistive transition along c and ab directions, shows a relatively large mass anisotropy. Anisotropic GL scaling parameter ν increases with decreasing temperature & is much larger than that of other FeSCs. This strong 2D character may lead to the absence of long-range AFM magnetic order. Lower critical field, H_{c1} deduced from vortex penetration into single crystals with a temperature dependence closer to that of two-gap (s-wave) superconductors. T -dependency of the H_{c1} is compared with BCS-gap models and anisotropy of H_{c1} are calculated. Anisotropic superconducting gap possibly due to multiband physics of the superconducting pairing.

15. Magneto-Optical Studies of Quantum Materials with a 30 T Pulsed Magnet

Fumiya Katsutani, G. Timothy Noe II, Gary L. Woods, and Junichiro Kono, Department of Electrical and Computer Engineering, Rice University, Houston, Texas 77005

An applied magnetic field can be used to tune the energy levels of electrons in matter via the spin and orbital degrees of freedom. However, optical experiments at high magnetic fields have many technical challenges. For example, optical access is often limited by optical fibers, which broaden femtosecond laser pulses due to dispersion of the fiber medium. Also, access to high magnetic fields is usually limited to national laboratories or equivalently large laboratories. Here, we have developed a 30 T table-top, pulsed magnet [Fig. 1(a)] and investigated the fundamental properties of materials in the near-infrared and terahertz frequency ranges. Figures 1(b)-1(d) show superfluorescence, a special case of Dicke superradiance, where excited two-level dipoles are initially prepared in an incoherent state with no phase relationship, and a macroscopic coherence between dipoles develops spontaneously [1]. This leads to a burst of radiation after a finite delay time. Compared with our previous measurements at the National High Magnetic Field Laboratory, we improved the time-resolution for the measurement of superfluorescence since the optical pulse was not dispersed by optical fiber. Cyclotron resonance of photoexcited carriers in intrinsic silicon was measured by combining a 30 T pulsed magnet with a single-shot terahertz time-domain spectrometer [2]. Figure 1(e) shows the magnetic field dependence of the cyclotron resonance line of photoexcited carriers. The shifting peak tracked by a dashed line is the electron cyclotron resonance absorption dip. From this slope, carrier effective mass m^* is calculated to be $0.19m_0$, where m_0 is the free electron mass in vacuum. We also performed circular-polarization-dependent



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magneto-absorption spectroscopy on indium selenide (InSe) in the near-infrared range. Figure 1(f) shows the magnetic field dependence of absorption spectra with both left and right circular polarizations. The $N = 0$ peak (where N is the Landau quantum number) at around 1.32 eV at 0 T is plotted in Fig. 1(g). When the magnetic energy is small compared with the exciton binding energy, the peak energy is expressed as $E(B) = E(B = 0) \pm \frac{1}{2}g_{\text{eff}}\mu_B B + \sigma B^2$, where σ is the diamagnetic shift constant and g_{eff} is the effective g-factor. From these results, we determine $\sigma = 4.08 \times 10^{-3} \text{ meV/T}^2$ and $g_{\text{eff}} = 2.12$.

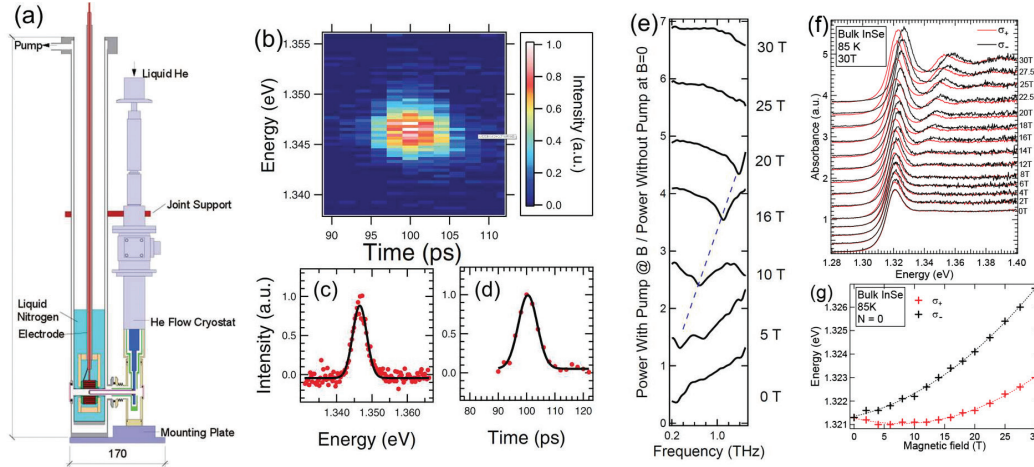


Figure 1 (a) Schematic diagram of 30 T pulsed magnet. (b) Superfluorescent burst of radiation from a highly excited InGaAs quantum well sample at 10 T measured using the mini-coil magnet. We show spectral (c) and temporal (d) slices of the data. (e) Magnetic field dependence of the relative THz transmission for optically pumped silicon. (f) Magneto-absorbance spectra on InSe. (g) $N = 0$ peak position as a function of magnetic field. *References: [1] Rev. Sci. Instrum. 84, 123906 (2013) [2] https://arxiv.org/abs/1608.08569*

16. Measuring the Speed of Sound in a 1D Fermi Gas

Jacob A. Fry, Anna L. Marchant, Melissa C. Reville, Yi Jin, and Randall G. Hulet, Department of Physics and Astronomy and Rice Center for Quantum Materials, Rice University, Houston, TX

We are planning to measure the speed of sound in a one-dimensional (1D) two-spin component gas of atomic fermions (lithium-6). We create an array of 1D tubes by confining atoms in a 2D optical lattice. By cooling the atoms to ultra-low temperatures (≤ 100 nK), we emulate electronic systems. We are interested in how charge and spin excitations propagate in a 1D system. In a 3D electron gas, the electron charge and spin propagate with the same velocity. However, in 1D, theory predicts that the electron charge travels faster than the spin when interactions are present, an effect known as spin-charge separation. We will measure the speed of a local density and spin defect propagate independently, when locally perturbed by a laser pulse. Depending on this laser's frequency, the atoms feel either a spin-sensitive or insensitive force. These excitations create notches or bumps in the atom density which can be followed after the laser pulse is turned off. The interaction dependence of the velocities will be determined by using a magnetically-tuned Feshbach resonance to tune the interactions.

17. Merging Symmetry Projection Methods with Coupled Cluster Theory: Lessons From the Lipkin Model

Wahlen-Strothman, Jacob, Rice University, Co-Authors: Matthew Hermes, Matthias Degroote, Thomas M. Henderson, Yiheng Qui, Jin-mo Zhao, Jorge Dukelsky, Gustavo E. Scuseria

Coupled cluster and symmetry projected mean field calculations are both useful and efficient calculation tools for the study of many-body quantum mechanical systems. Coupled cluster is a highly successful theory for the treatment of weakly correlated systems, but fails under strong correlation without sacrificing good quantum numbers. Symmetry projected methods are effective for the treatment of strong correlation through symmetry breaking and restoration of mean field and multireference wavefunctions. We examine the effect of symmetry projection on coupled cluster wavefunctions and apply them to the Lipkin model. We find that symmetry projected coupled cluster produces accurate results in the strong and weakly correlated limits as well as the recoupling limit.



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18. Non-Equilibrium Dynamics of Fermi Polarons

You, Jhih-Shih, Harvard University

We theoretically study the quantum impurities immersed in atomic Fermi gases. First, we propose an ultracold atom setup, analogous to a spintronics device, which allows one to study non-equilibrium spin transport and counting statistics. This setup can be realized in the currently available experiments by using quantum impurities to induce current tunneling between two imbalanced host fermion gases. The distribution function of non-equilibrium transport is discussed in various regimes. Moreover, by employing the Ramsey interferometry, one can reach the dynamic impurity response for full times, which could not be accessed in solid-state systems. This impurity response exhibits a non-trivial exponential decay, different from the standard power-law decay of Anderson's orthogonality catastrophe, which is expected in the case of single host fermions. By mapping this system to a multi-Fermi edge problem, we provide analytical expressions for the impurity response for long time dynamics. Furthermore, we can apply designed pulses to the impurity potential to create single particle excitations on top of one Fermi sea. Such excitations are called as levitons. In our protocol, one can obtain a source of clean single-particle transmission between two Fermi seas. The noise, as well as the counting statistics of spin transport, should be of single particle character. Our study paves a way for controlling and harnessing fermionic many-body states in atomtronics.

19. One Dimensional Quantum Excitations in the f-Electron Metal Yb₂Pt₂Pb

Gannon, William, Texas A&M, Co-Authors: William J. Gannon 1, 2, 3, Liusuo Wu, 2, 3, 4 Igor A. Zaliznyak, 3, Franz Demmel, 5, and Meigan C. Aronson, 1, 2, 3 1) Texas A&M University, USA, 2) Stony Brook University, USA, 3) Brookhaven National Laboratory, USA, 4) Oak Ridge National Laboratory, USA

Quantum magnetic excitations are generally thought to exist only in systems with small, isotropic magnetic moments which can be easily reversed. In metallic Yb₂Pt₂Pb, the Yb³⁺ ions form large, seemingly classical magnetic moments, with the spin-orbit coupling of the 4f-electrons leading to a $J = \pm 7/2$ ground state doublet [1]. Inelastic neutron scattering measurements reveal that from this unlikely host emerges a continuum of quantum excitations — spinons along one dimensional chains — in good agreement with the expectations for $S = \pm 1/2$ moments [2]. In magnetic field, the continuum is modified through the formation of a spinon fermi surface for $B > 0.5$ T and the formation of spinon bound states between the Yb chains, persisting up to the saturation field of 2.3 T. The Yb ground state doublet ensures that transverse excitations are virtually nonexistent, giving direct access to the longitudinal excitation channel without the presence of transverse damping. References: [1] M. S. Kim et al., Phys. Rev. B 77, 144425 (2008); K. Iwakawa et al., J. Phys. Soc. Jpn. 81, SB058 (2012); M. S. Kim and M. C. Aronson, Phys. Rev. Lett. 110, 017201 (2013); W. Müller et al., Phys. Rev. B 93, 104419 (2016). [2] L. S. Wu et al., Science 352, 1206 (2016). Work at Stony Brook (L.S.W., W.J.G., M.C.A.) was supported by NSF-DMR-1310008. L.S.W. was also supported by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory (ORNL). Work at Brookhaven National Laboratory (I.A.Z) was supported by the Office of Basic Energy Sciences (BES), Division of Materials Sciences and Engineering, U.S. Department of Energy (DOE), under contract DE-SC00112704.

20. Phase Diagram of Ultracold Molecules in Lattice with Many-Channel Collisions

Kevin Ewart, Michael L. Wall, and Kaden R. A. Hazzard

Ultracold nonreactive molecules have long-ranged interactions and intricate internal structure that make them rich many-body systems, especially in an optical lattice. Prior work assumed that a Hubbard model governs them, as it does ultracold atoms (perhaps augmented with a dipolar interaction). However, recent results revealed that this assumption is incorrect: the Hubbard interaction must be replaced by a unique many-channel interaction. We show that this dramatically alters the phase diagram of bosonic molecules. Not only is the shape altered, but qualitatively new phenomena appear. For example, in a broad region of parameter space the long-range condensate order is strongly suppressed while number fluctuations remain large, reminiscent of exotic phases such as spin liquids. Our results are obtained by two methods, a Gutzwiller mean field approximation and, in one dimension, numerically exact DMRG calculations



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21. Photothermoelectric Voltage in Plasmonically Active Au Nanowires and Nanogaps

Zolotavin, Pavlo, Rice University, Co-Author: Pavlo Zolotavin, Charlotte Evans, Douglas Natelson

Nanoscale structuring holds promise to improve thermoelectric properties of materials for energy conversion and photodetection. We report a study of spatial distribution of thermoelectric voltage in single metal Au nanowires and nanowires with nanogaps formed by electromigration. We use a laser scanning microscope to excite a plasmon resonance to locally heat the metal nanostructure. In nanowires shorter than the size of the laser beam we observe the thermoelectric voltage distribution that is consistent with Seebeck coefficient being spatially dependent on the width of the nanowire. In longer structures we observe extreme variability of thermoelectric voltage along the length of the nanowire that includes multiple sign reversals and sensitivity to the metal grain structure and surface conditions. In the nanowires with plasmonically active nanogaps we observe a ~1000x increase in the photothermoelectric voltage. We discuss a range of possible explanations for the extraordinary enhanced thermoelectric voltage focusing on the role of non-equilibrium or “hot” carriers generated upon the plasmon excitation.

22. Quantum Phase Transitions and Anomalous Hall Effect in Frustrated Kondo Lattices

Grefe, Sarah, Rice University, Co-Author: Wenxin Ding, Silke Paschen, and Qimiao Si

The metallic variant of the pyrochlore iridates Pr₂Ir₂O₇ has shown characteristics of a possible chiral spin liquid state [PRL 96 087204 (2006), PRL 98, 057203 (2007), Nature 463, 210 (2010)] and quantum criticality [Nat. Mater. 13, 356 (2014)]. An important question surrounding the significant anomalous Hall response observed in Pr₂Ir₂O₇ is the nature of the f-electron local moments, including their Kondo coupling with the conduction d-electrons. The heavy effective mass and related thermodynamic characteristics indicate the involvement of the Kondo effect in this system’s electronic properties. In this work, we study the effects of Kondo coupling on candidate time-reversal-symmetry-breaking spin liquid states on frustrated lattices. Representing the f-moments as slave fermions Kondo-coupled to conduction electrons, we study the competition between Kondo-singlet formation and chiral spin correlations and determine zero-temperature phase diagrams. We derive an effective chiral interaction between the local moments and the conduction electrons and calculate the anomalous Hall response across the quantum phase transition from the Kondo destroyed phase to the Kondo screened phase. We discuss our results’ implications for Pr₂Ir₂O₇ and related frustrated Kondo-lattice systems.

23. Radiative Heat Transfer in Atomic-Sized Gaps

Longji Cui¹, Wonho Jeong¹, Edgar Meyhofer¹ & Pramod Reddy^{1,2} ¹Department of Mechanical Engineering, University of Michigan, ²Department of Materials Science and Engineering, University of Michigan

The atomic scale represents the ultimate limit to miniaturization of electronic and photonic devices. In addition, the study of photon and phonon transport in atomic-sized gaps is of fundamental interest as such junctions are excellent test-beds for quantum transport theories. Although vastly more attention has been directed to the investigations of optical and electronic properties, thermal transport from the atomic scale to the realm of few-nanometers has been barely explored due to experimental challenges. Here, we describe our experiments with custom-fabricated scanning probes that feature embedded high-resolution thermal sensors to quantitatively measure radiative thermal transport in Angstrom-scale vacuum gaps (extreme near-field regime). Previous measurements of extreme near-field radiative heat transfer showed giant thermal conductances that are several orders of magnitude larger than those predicted by the calculations of fluctuational electrodynamics [1, 2]. Our systematic studies (see Fig. 1) of radiative heat transfer in nanometer and sub-nanometer gaps unambiguously established the validity of fluctuational electrodynamics in modelling radiative heat transfer down to gap sizes as small as ~2-3 nm [3]. Further, our studies of radiative heat transfer in sub-nanometer gaps show that when the surfaces are sufficiently clean the substantial deviations from theoretical predictions (fluctuational electrodynamics), observed in past work, are no longer observed. Our studies firmly establish the validity of fluctuational electrodynamics and provide strong evidence that fluctuational electrodynamics can successfully model radiative heat transfer in nanometre and sub-nanometer gaps.



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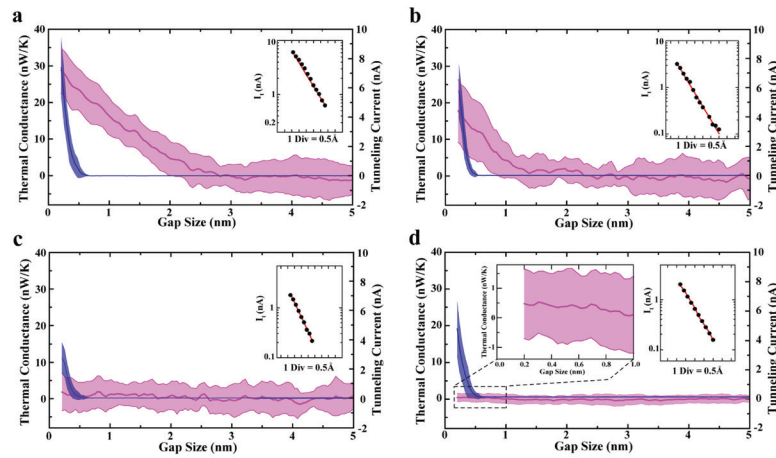


Figure 1: Measured thermal conductance (pink) and tunneling current (blue) between the gold-coated scanning probe and planar gold surface. The shaded region represents the standard deviation. The first three panels show representative experimental results from (a) organic solvent cleaned, (b) oxygen plasma cleaned, and (c) repeated oxygen plasma cleaned scenarios. The gold sample is heated up while the probe is maintained at a lower temperature to create a temperature difference $\Delta T = 40$ K. (d) shows the measurement results obtained in experiments where a large temperature differential (ΔT) of 130 K was applied. Further, the measured tunneling currents vs. displacement are shown as insets in each of the plots and were used in the analysis of the apparent tunneling barrier. The estimated values of which are 1.05, 1.61, 1.71, and 1.92 eV for figures (a)–(d), respectively. *References:* [1] A. Kittel et al., *Phys. Rev. Lett.* 95, 224301 (2005) [2] L. Worbes et al., *Phys. Rev. Lett.* 110, 134302 (2013) [3] K. Kim et al., *Nature.* 528, 387 (2015)

24. Remote Heating in Bowtie Nanoelectrodes by Propagating Plasmons

Evans, Charlotte, Rice University, Co-Authors: Pavlo Zolotavin, Douglas Natelson

Electronic transport and simultaneous optical measurements on molecule-containing junctions can provide critical information about the dissipation of energy through inelastic processes. Gold bowtie nanostructures have been used for electronic transport and as plasmonically active substrates for surface-enhanced Raman scattering (SERS), conventionally with exciting light incident directly on the molecular junction. Electromigrating these devices created interelectrode nanogaps with single-molecule sensitivity in which the Raman scattering rate is dominated by plasmonically enhanced electromagnetic fields due to the presence of the metal nanojunction near the molecules of interest. Direct optical excitation of the junction region, however, can cause heating of the metal, molecular instability via conformational and chemical changes, and breakdown over time. Adding metallic gratings to the electrode design enables the excitation of propagating plasmon modes that can couple into the junction region without direct excitation by far-field radiation. We will present data on remote heating of bowtie nanostructures by excitation of propagating plasmons. Efficiency of propagating plasmon excitation is assessed by measuring the temperature increase of the nanowire using the bolometric detection method. We discuss potential future applications for true low-temperature, simultaneous single-molecule SERS and electrical measurements. This research was funded by NSF GRFP DGE-1450681 and ARO award W911 NF-13-1-0476.

25. Shot Noise Measurement in hBN-Based Tunnel Junction

Zhou, Panpan, Rice University, Co-Author: Will Hardy, K. Watanabe, T. Taniguchi, Douglas Natelson

Shot noise, which originates from the discreteness of charge carriers, can provide more information about charge transport than the average current. The tunneling current noise in a normal single electron system is given by $S = 2eI$ when $eV \gg 2k_B T$. While in strongly correlated systems, where the electron Coulomb repulsion is not negligible, the shot noise might deviate from this classical result if electrons form quasiparticles. Here we demonstrate a technique that can be adapted to study the shot noise in strongly correlated systems. High quality Au/hBN/Au tunneling devices are fabricated using transferred atomically thin hexagonal boron nitride as the tunneling barrier. All tunneling junctions show specific resistance on the order of several $k\Omega/\mu m^2$, which agrees



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with previous reported hBN-based tunnel junction properties [1][2]. The ohmic-like I-V curves at small bias range indicate the sparsity of defects. Tunneling current shot noise is measured in these devices and the excess shot noise shows great consistency with theoretical expectations. These results show that atomically thin hBN is an excellent tunneling barrier, especially for the study of shot noise properties, which might be a useful tool to study the charge transport properties in complicated systems. [1] Electron Tunneling through Ultrathin Boron Nitride Crystalline Barriers, Liam Britnell et al, Nano Lett., 2012, 12 (3), pp 1707–1710. [2] Evidence for Defect-Mediated Tunneling in Hexagonal Boron Nitride-Based Junctions, U. Chandni et al, Nano Lett., 2015, 15 (11), pp 7329–7333.

26. Skyrmion Defects of Antiferromagnet and Its Competing Singlet States in a Kondo-Heisenberg Model

Liu, Chia-Chuan, Rice University, Co-Authors: Chia-Chuan Liu, Pallab Goswami, Qimiao Si

The competition between antiferromagnetism and a variety of proximate paramagnetic spin-singlet states is a common feature for many heavy fermion compounds, and has been discussed in the proposed global phase diagram [1]. It is important yet a challenging problem to develop a general scheme to access the paramagnetic, spin singlet states from the antiferromagnetically ordered side, and vice versa. In this work, we study the problem on a honeycomb lattice by starting from the Kondo-destroyed antiferromagnetic phase. Here, the local moment is represented by a non-linear sigma model field, whose topological defects are known to induce the singlet orders based on a perturbative gradient expansion [2]. By solving low energy effective Dirac Hamiltonian in the skyrmion background, we identify the singlet orders through an enhanced correlations in the corresponding channels. We find two leading singlet channels, one in the spin Peierls sector, and the other in the Kondo singlet sector. Our results provide new insight into the global phase diagram of the heavy fermion systems. References: [1] Q. Si, “Quantum criticality and global phase diagram of magnetic heavy fermions”, Phys. Status Solidi 247, 476 (2010); Physica B 378, 23 (2006). [2] P. Goswami and Q. Si, “Topological defects of Neel order and Kondo singlet formation for Kondo-Heisenberg model on a honeycomb lattice”, Phys. Rev. B 89, 045124 (2014).

27. Spatial Fluctuations Influence the Correlations and Spectra of Ultracold Rydberg Atoms

Ridge Liu, Thomas C. Killian, Kaden R. A. Hazzard

Ultracold Rydberg atoms – atoms that are excited to high principal quantum number $n \sim 50$ – combine the precise control of ultracold matter with strong van der Waals interactions that may be many orders magnitude larger than those between ground state atoms. Recent experiments have used Autler-Townes spectra to study the interplay of quantum coherence and interactions. However, discrepancies remain between the experimental measurements and the theory presented there, which averages over spatial configurations. Here we extend this theory to include spatial fluctuations of the atoms in the cloud. We find that the spatial fluctuations significantly change the spectra, in some cases reducing the deviations from the experimental results.

28. Strong Coupling Theory for 1D Interacting Spinor Quantum Gases

Li Yang, Han Pu, Rice University, Physics and Astronomy Department

We study one dimensional spinor quantum gases from the strong coupling perspective. A family of strong coupling ansatz wavefunctions (physically similar to spin-incoherent Luttinger liquid wavefunctions) can be used to describe the states in this regime. From those wavefunctions, we can interpret the system as a product of spin and charge parts, coupled by a p-wave interaction. Under zero temperature, when the interaction approaches infinity, the charge degree of freedom first frozen to the ground state, and the spin degree of freedom is governed by a spin chain Hamiltonian whose coupling constants depend on the charge state. We comprehensively studied this theory including the following topics: few bodies calculations, spin and charge dynamics, responds to spin-charge coupling perturbations, coupling constant renormalization for the p-wave interaction (similar to that of 3D s-wave interaction), one body density matrix and its relation to anyons, momentum distribution and Tan contacts. These studies pave the way to understanding (itinerant) magnetic phases emerged in 1D spinor quantum gases due to spontaneous symmetry breaking or exotic phases due to the topology of the ground state's symmetry.



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29. Strong Magnon-Phonon Coupling in NaFeAs Studied by Neutron Scattering

Li, Yu, Rice University, Co-Author: Yu Li [1], Zahra Yamani [2], Chenglin Zhang [1], Yu Song [1], Pengcheng Dai [1]

The origin of the nematic phases in iron based superconductors remains controversial [1]. As more experimental evidences available, the mainstream view could be classified into two sides: one supports orbital driven nematic phase and the other spin driven. Theoretically, both scenarios could explain the structural transition and the successive magnetic transition. In practice, a technical approach to distinguish these two is unachievable. However, a systematic study on the coupling between the dynamic structural and magnetic behavior would be informative for us to understand the emergent phenomenon in this exotic correlated electron systems. We carried on inelastic neutron scattering experiment on the triple axis spectrometer in CNBC in Chalk River. We measured both the phonon and magnon in NaFeAs single crystals and their temperature dependence. Since structural transition temperature (T_S) and the magnetic transition temperature (T_N) are well separated in NaFeAs, it provides us an unique chance to exclude the consequence of magnetic order and focus on the so called nematic phase ($T_S > T_N$). We observed that the phonon at small q ($q > 0.1$) are greatly softened above T_S and then recover quickly below T_S (Fig.1). When the temperature goes down below T_N , the phonon at certain q range shows hardening effect. Beside the strong momentum dependent phonon behavior, we observed a redistribution of the spectral weight of the low energy magnetic excitations across T_S and T_N . Our results suggest that there is strong coupling between the phonons and magnons in NaFeAs. References: [1] R.M. Fernandes, A.V. Chubukov and J. Schmalian, *Nat. Phys.* 10, 97-104 (2014), [2] C. Author et al., *Nano Lett.* 9, 1234 (2011), [3] D. Author, *Opt. Express* 18, 1234 (2012)

30. Surface State BCS Instability in a Spin-3/2 Time-Reversal Invariant Topological Superconductor

Ghorashi, Sayed Ali Akbar, University of Houston, Co-Authors: Sayed Ali Akbar Ghorashi [1], Seth Davis [2], Matthew S. Foster [2,3] Department of Physics and Texas center for superconductivity, University of Houston, Houston, Tx, USA; [2] Department of Physics, Rice University, Houston, Tx, USA [3] Rice Center for Quantum Materials

Bulk topological superconductors (TSCs) should host exotic 2D surface Majorana fermion fluids that have promise for topological quantum computing. The surface states of spin-1/2 TSCs are predicted to exhibit robust universal properties in the presence of both quenched disorder and interactions, including universal spin and heat conductivities [1,2,3]. In this poster, we study models of spin-3/2 TSCs in class DIII that have been proposed as generalizations of Helium 3B, with potential applications to ultracold atoms and the half-Heusler compounds [4]. A model with p-wave pairing has winding number four, and exhibits a cubically dispersing surface band in addition to the usual linear Majorana cone. Due to the cubic band the clean system shows a strong van Hove singularity. Naively the latter should render the clean surface theory strongly susceptible to arbitrarily weak interaction effects. Interestingly, we show that interactions are in fact only marginally relevant for an attractive coupling strength, and that the latter leads to a BCS-type instability that spontaneously breaks time-reversal symmetry at the surface. Moreover, we have shown that adding disorder stabilizes the surface Majorana fluid against interaction effects. See also the poster by Seth Davis et al.

31. Terahertz Spectroscopic Evidence for Er^{3+} - Fe^{3+} Coupling in ErFeO_3

Xinwei Li¹, Qi Zhang¹, G. Timothy Noe II¹, Maolin Xiang², Kai Xu², Shixun Cao², Zuanming Jin², Guohong Ma², Mischa Bonn³, Dmitry Turchinovich³, and Junichiro Kono¹, ¹Department of Electrical and Computer Engineering, Rice University, Houston, Texas 77005, USA
²Department of Physics, International Center of Quantum and Molecular Structures, and Materials Genome Institute, Shanghai University, Shanghai 200444, China, ³Max Plank Institute for Polymer Research, Ackermannweg 10, Mainz 55128, Germany

The magnetic properties of orthorhombic rare-earth orthoferrite compounds RFeO_3 , where "R" represents the rare-earth element, have attracted wide attention, ever since the observation of a temperature-driven spin reorientation transition in the 1960s [1]. These compounds are known to harbor two magnetic subsystems, the R^{3+} sublattice and the Fe^{3+} sublattice, and their coupling leads to a variety of interesting phenomena. In the modern topic of ultrafast magnetism (or 'femto'-magnetism), understanding the microscopic mechanism of such R^{3+} - Fe^{3+} coupling is important as it mediates the interaction between spin systems and ultrafast laser pulses [2]. Single crystal ErFeO_3 is an ideal material system for studying the R^{3+} - Fe^{3+} coupling mechanism using terahertz (THz) spectroscopic methods because of three reasons. First, ErFeO_3 , like all other RFeO_3 compounds, is an insulator and thus provides a magnetically robust environment with minimum magnon decay channels while maintaining high spin densities, leading to sharp and strong magnon lines in the THz frequency range. Second, due to small coupling between Er^{3+} 4f electrons and phonons, the optical transitions between 4f crystal-field-split levels are also minimally disturbed, exhibiting sharp spectral lines in THz spectra. Third, both magnon and crystal field transition (CFT) lines can be shifted by an external magnetic field, resulting in magnetically tuned interplay between them. Single crystals of ErFeO_3 were grown by the floating zone method. They were then cut in defined crystallographic orientations and polished into flat pieces with thicknesses of around 1 mm. We performed transmission time-domain THz magneto-



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spectroscopy measurements on the sample in a temperature-variable environment in the Faraday geometry. THz pulses were generated via optical rectification in a ZnTe crystal pumped by near-infrared pulses from a Ti:sapphire regenerative amplifier and detected by electro-optic sampling using another ZnTe crystal. A magnetic field up to 10 T was applied in the propagation direction of the incident THz wave (Faraday geometry).

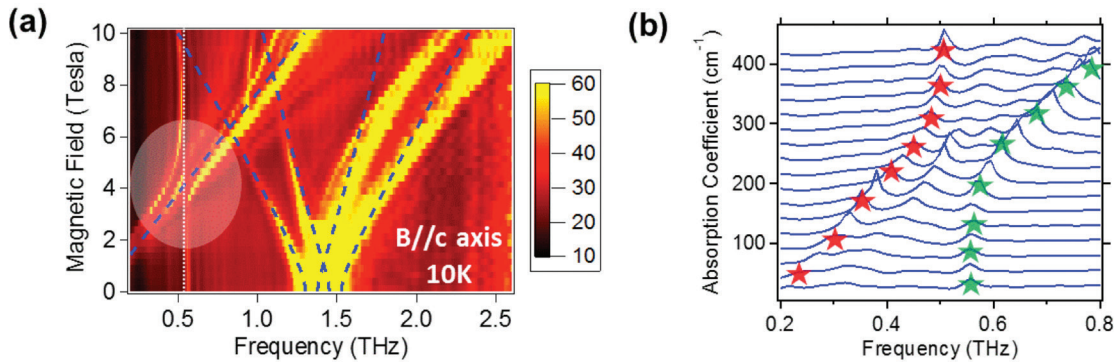


Figure 1. (a) Absorption coefficient (cm^{-1}) mapping as a function of frequency and external magnetic field for an ErFeO_3 single crystal. Dashed blue lines: theoretical fits to the CFT lines; white dotted line: guide-to-the-eye for the magnon line. (b) Enlarged spectra of the shaded region in (a). Stars mark peak positions of hybridized bands.

Figure 1 shows measured magneto-absorption spectra for a c -cut ErFeO_3 sample at 10 K. Fits to Er^{3+} CFTs from the ground atomic state $^4I_{15/2}$ to excited states are shown by blue dashed curves. Unlike the CFT lines, which are drastically tuned by the magnetic field through the Zeeman effect, the Fe^{3+} sublattice magnon frequency (white dotted line) does not change with the magnetic field in this particular configuration. In the frequency region between 0.2 THz and 0.8 THz, and at magnetic fields between 2 T to 6 T, where the magnon line is expected to cross one of the CFT lines, spectral anticrossing due to mode hybridization is observed. This anticrossing behavior represents the most direct evidence of Er^{3+} - Fe^{3+} coupling ever achieved for this system. *References: [1] R. L. White, J. Appl. Phys. 40, 1061 (1969) [2] A.V. Kimel et al., Nature 435, 655 (2005)*

32. Thermal Conductivity of Local Moment Models with Strong Spin-Orbit Coupling

Lapas, Panteleimon, UT Austin, Co-Authors: Panteleimon E. Lapas, Department of Physics, The University of Texas at Austin Georgios Stamokostas, Department of Physics, The University of Texas at Austin Gregory A. Fiete, Department of Physics, The University of Texas at Austin

We study the magnetic and lattice contributions to the thermal conductivity of electrically insulating strongly spin-orbit coupled magnetically ordered phases on a two-dimensional honeycomb lattice using the Kitaev-Heisenberg model. Depending on model parameters, such as the relative strength of the spin-orbit induced anisotropic coupling, a number of magnetically ordered phases are possible. In this work, we study two distinct regimes of thermal transport depending on whether the characteristic energy of the phonons or the magnons dominates. For spatially anisotropic magnetic phases, the thermal conductivity tensor can be highly anisotropic when the magnetic energy scale dominates since the magnetic degrees of freedom dominate the thermal transport process, for temperatures well below the magnetic transition temperature. In the opposite limit where the phonon energy scale dominates, the thermal conductivity tensor will be nearly isotropic, reflecting the (at low temperatures) isotropic phonon dispersion assumed for the honeycomb lattice. We further discuss the extent to which thermal transport properties are influenced by strong spin orbit induced anisotropic coupling in the local moment (strong coupling) regime of insulating magnetic phases. Last but not least, of all the other scattering mechanisms that can affect the thermal transport processes, such as boundary scattering, scattering from magnetic and/or non-magnetic defects, lattice disorder, magnon-magnon interactions, Umklapp processes, only the boundary scattering is taken into account in our analysis.



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33. Torque Magnetometry on Topological Superconductor Candidates

Lawson, Benjamin, University of Michigan

Topological superconductivity is an exciting new phase of matter that is eagerly being sought after due to hosting an elusive Majorana excitation and its potential applications to robust quantum computation. One of the leading avenues to realize the first topological superconductor is to dope known topological insulator Bi₂Se₃ with metals. I report here de Haas-van Alphen studies on topological superconductor candidates Cu-doped and Nb-doped Bi₂Se₃. In the Cu-doped case, an unchanged Fermi velocity with increased doping reveals Dirac electronic dispersion. In the newly discovered superconductor Nb-doped Bi₂Se₃, the doping changes the band structure of the parent compound introducing new Fermi Surfaces. In addition, our magnetic torque study demonstrates nematic order in the superconducting state revealing an interesting unconventional superconducting state in Nb-doped Bi₂Se₃.

34. Toward Selenene and Tellurene: Two-Dimensional Topological Insulators

Bianco, Elisabeth, Rice University, Co-Authors: Lede Xian, Angel Rubio, Emilie Ringe, P. M. Ajayan

The discovery of graphene and the unique electronic/optoelectronic phenomena that arise in two-dimensions, such as the room-temperature quantum Hall effect, ushered in a new era in materials research. Consequently, several two-dimensional (2D) materials beyond graphene have been synthesized from other layered crystals. Motivated by similar unique structure-property relationships, our goal is to grow a completely novel class of 2D materials by imposing new, unnatural crystal structures on elemental chalcogens (Se and Te) via different growth methods including molecular beam epitaxy, pulsed laser deposition, and physical vapor deposition. Density functional theory calculations suggest that selenene and tellurene can be grown in a stable, 2D square lattice configuration. Moreover, these materials could possess attractive electronic structures/properties including a single Dirac cone and, when considering spin-orbit coupling, potentially topological insulating (TI) behavior. Additionally, these materials are predicted to have stable van der Waals layered 3D analogs. Initial efforts toward growing selenene by physical vapor deposition have resulted in nm-thicknesses of crystals that appear in preliminary transmission electron microscopy studies to have the desired square lattice. X-ray photoelectron spectroscopy suggests this material is stable in air for several days. TIs have potential for application in quantum logic and spintronics, and the ballistic transport afforded by spin-locked states could allow for extremely high mobility devices. The results of these experiments will provide further insight to how well we can model and predictively determine the behavior of 2D TIs for computationally-guided materials by design.

35. Transport in a Model Heavy Fermion System

Van Dyke, John, Iowa State University, Co-Author: Dirk Morr

We explore transport in a model heavy fermion system at the nanoscale via large-N mean field theory. Spatially-resolved calculations of the current using non-equilibrium Green's functions reveal the important role of correlations in determining the complex current flow patterns. The local modification of the current flow around defects is studied in the presence of phonons. We find a self-consistent suppression of the hybridization in the presence of finite applied bias.

36. Transport Studies and Potential Fluctuations in Mesoscopic-Scale SmTiO₃/SrTiO₃/SmTiO₃ Quantum Wells

Hardy, Will, Rice University, Co-Author: Panpan Zhou, Brandon Isaac, Patrick Marshall, Evgeny Mikhchev, Susanne Stemmer, and Douglas Natelson

Heterointerfaces of rare earth titanates of the form RTiO₃ (R = rare earth) comprise an intriguing family of systems with a bounty of coexisting and competing physical orders. Some examples, such as the LaAlO₃/SrTiO₃ interface, are capable of supporting high carrier density quantum wells whose electronic properties are determined by a combination of lattice distortions, spin-orbit coupling, defects, and various regimes of magnetic and charge ordering. An improved understanding of these model systems, especially their quantum coherent properties, may lead to new insights into the nature of transport in strongly correlated materials that deviate from Fermi liquid theory. Here, we study electronic transport in mesoscale devices made with heterostructures of SmTiO₃ and SrTiO₃, in which unexpected, large, time-dependent surface potential fluctuations emerge at low temperatures. These fluctuations ramp up at temperatures below 10 K, are suppressed with increasing contact electrode size, and are independent of the drive current and contact spacing distance. Candidate interpretations of the underlying physical mechanism, in terms of a fluctuating Seebeck coefficient, are discussed.



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37. Unified Spin Model for Magnetic Excitations in Iron Chalcogenides

Bilbao Ergueta, Patricia, Rice University

Recent inelastic neutron scattering (INS) measurements on the iron chalcogenides FeSe and Fe(Te_(1-x)Se_x) have sparked intense debate over the role of magnetism in these materials. I will argue that magnetic frustrations of the underlying Fe spin-1 degrees of freedom are the key to understanding the nature of the ground state. We propose an effective bilinear-biquadratic spin model which is shown to consistently describe the evolution of low-energy spin excitations in FeSe, both under applied pressure and upon Se/Te substitution. The phase diagram, studied using a combination of variational mean-field, flavor-wave calculations, and density-matrix renormalization group (DMRG), exhibits a sequence of transitions between the non-magnetic ferroquadrupolar phase attributed to FeSe and several other magnetically ordered phases[1]. The calculated spin structure factors mimic closely those observed with INS in the Fe(Te_(1-x)Se_x) series[2]. In addition to the experimentally established phases, the possibility of incommensurate magnetic order is also predicted. *References: [1] P. Bilbao Ergueta, Z. Wang, W.-J. Hu, and A. H. Nevidomskyy, arXiv:1607.05295 [2] Z. Xu et al., Phys. Rev. B. 93, 104517 (2016)*

38. Ultracold Nonreactive Molecules in an Optical Lattice: Connecting Chemistry to Many-Body Physics

Rick Mukherjee, Kevin Ewart, Shah S. Alam, Nirav P. Mehta, Michael L. Wall, and Kaden R. A. Hazzard

We derive effective lattice models for ultracold bosonic or fermionic nonreactive molecules (NRMs) in an optical lattice. In stark contrast to the standard Hubbard model, which is commonly assumed to accurately describe NRMs, we find that the single on-site interaction parameter U is replaced by a multi-channel interaction. The complex, multi-channel collisional physics is unrelated to dipolar interactions, and so occurs even in the absence of an electric field or for homonuclear molecules. We find a crossover between coherent few-channel models and fully incoherent single-channel models as the lattice depth is increased. We devise ways to control the effective model parameters using external fields and lattice anisotropy. We show that these parameters can be determined in lattice modulation experiments, which measure molecular collision dynamics with a vastly sharper energy resolution than experiments in an ultracold gas.

39. YbRh₂Si₂ Thin Films Grown by Molecular Beam Epitaxy

Prochaska, Lukas, TU Wien

Quantum criticality is in the focus of studies on strongly correlated materials. Due to their small and competing energy scales, heavy fermion compounds have played a key role in this research. YbRh₂Si₂ is a prototypical quantum critical heavy fermion metal that exhibits a Kondo destruction quantum critical point as its antiferromagnetic phase is fully suppressed by the application of a small magnetic field [1]. By studying the cubic compound Ce₃Pd₂₀Si₆ it was realized that dimensionality is an efficient way to tune through the theoretically suggested [2] global phase diagram for antiferromagnetic heavy fermion compounds [3]. Thus, it would be of great interest to tune YbRh₂Si₂ towards the extreme 2-dimensional limit. The successful molecular beam epitaxy (MBE) growth of single crystalline thin films of YbRh₂Si₂ would provide the unique ability to achieve such tuning. Recent results on for CeIn₃/LaIn₃ [4], CeCoIn₅/YbCoIn₅ [5] and CeRhIn₅/YbRhIn₅ [6] superlattices are encouraging and validate our approach.

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Attendees List

Elihu Abrahams	UCLA
Gabriel Aepli	PSI/ ETH Zürich
Pulickel Ajayan	Rice University
Meigan Aronson	Texas A&M University
Mahmoud M. Asmar	LSU
Palash Bharadwaj	Rice University
Elisabeth Bianco	Rice University
Patricia Bilbao Ergueta	Rice University
Immanuel Bloch	Max Planck, Garching
Girsh Blumberg	Rutgers University
Matthew Butcher	Rice University
Ang Cai	Rice University
Francisco Camargo	Rice University
Longji Cui	University of Michigan
Pengcheng Dai	Rice University
Hongjie Dai	Stanford University
Seth Davis	Rice University
Cory Dean	Columbia University
Rui-Rui Du	Rice University
Charlotte Evans	Rice University
Kevin Ewart	Rice University
Matt Foster	Rice University
Giulia Galli	University of Chicago
William Gannon	Texas A&M University
Sayed Ali Akbar Ghorashi	University of Houston
Wen Fong Goh	University of California, Davis
Sarah Grefe	Rice University
Will Hardy	Rice University
Kaden Hazzard	Rice University
Jason Ho	Ohio State



Attendees List

David Hsieh	Caltech
Wenjun Hu	Rice University
Chien-Lung Huang	Rice University
Randy Hulet	Rice University
Fumiya Katsutani	Rice University
Kevin Kelly	Rice University
Tom Killian	Rice University
Jun Kono	Rice University
Gabriel Kotliar	Rutgers University
Hsin-Hua Lai	Rice University
Kathy Levin	University of Chicago
Yu Li	Rice University
Tingxin Li	Rice University
Xinwei Li	Rice University
Yunxiang Liao	Rice University
Ridge Liu	Rice University
Chia-Chuan Liu	Rice University
Vaideesh Loganathan	Rice University
Jun Lou	Rice University
Allan MacDonald	UT Austin
Zhiqiang Mao	Tulane University
Yulia Maximenko	University of Illinois at Urbana-Champaign
Tony Mirasola	Rice University
Aditya Mohite	Los Alamos
Emilia Morosan	Rice University
Shantanu Mukherjee	Binghamton University
Rick Mukherjee	Rice University
Gururaj Naik	Rice University
Doug Natelson	Rice University
Andriy Nevidomskyy	Rice University

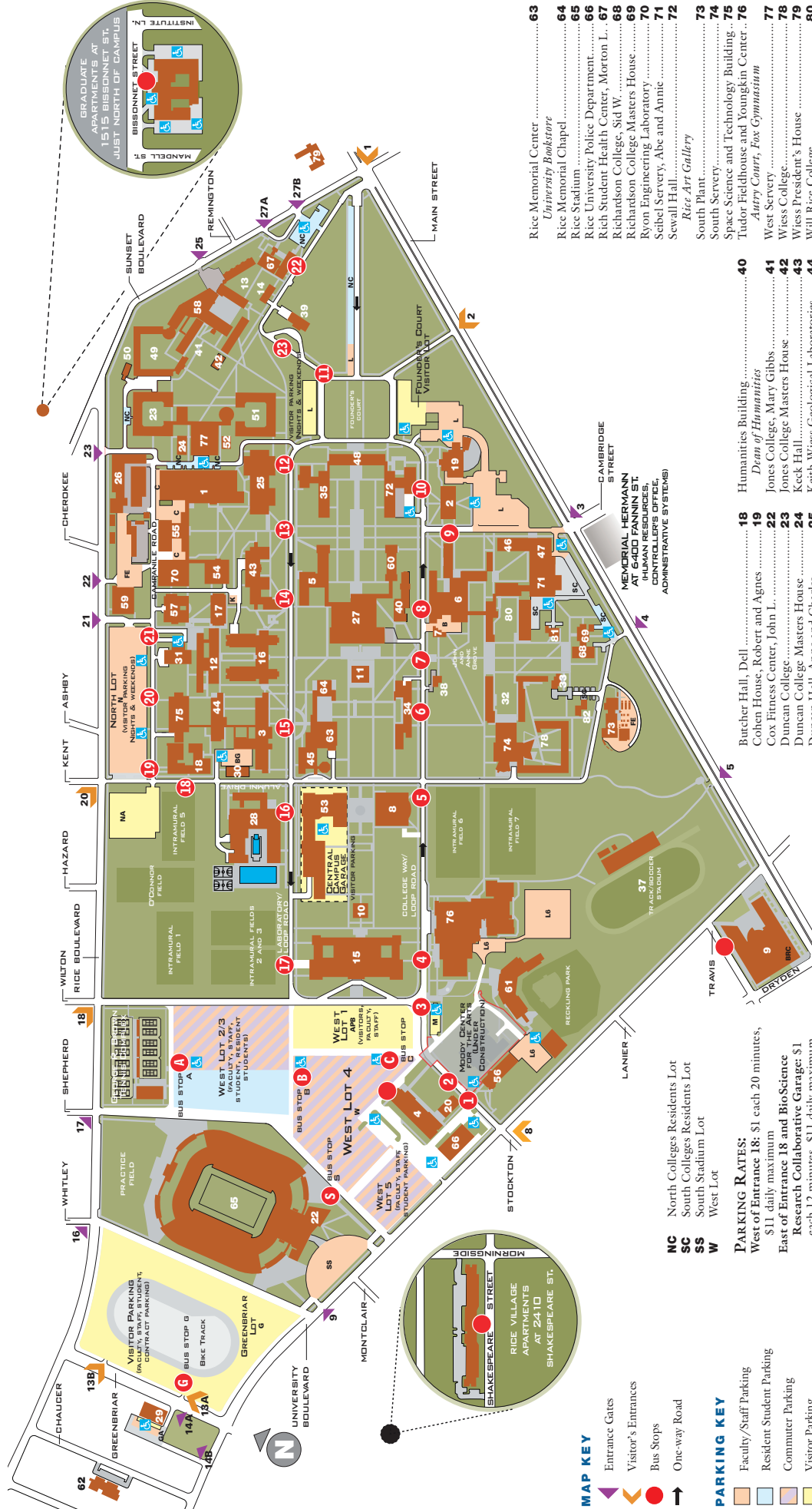


Attendees List

Tim Noe	Rice University
Lapas Panteleimon	UT Austin
Silke Paschen	TU Vienna/Rice University
Donald Powell	Gartland Foundry
Lukas Prochaska	TU Wien
Han Pu	Rice University
Binod Rai	Rice University
Pramod Reddy	University of Michigan
Emilie Ringe	Rice University
Peter Rossky	Rice University
Subir Sachdev	Harvard
Kalyan Sasmal	Texas Center for Superconductivity
Gustavo Scuseria	Rice University
Zhi-Xun Shen	Stanford University
Qimiao Si	Rice University
Yu Song	Rice University
Boris Spivak	University of Washington
Frank Steglich	Max Planck, Dresden
Isabell Thomann	Rice University
James Tour	Rice University
John Van Dyke	Iowa State University
Jacob Wahlen-Strothman	Rice University
Zhiyuan Wang	Rice University
Jiang Wei	Tulane University
Ginny Whitaker	Rice University
Ian White	Rice University
Boris Yakoson	Rice University
Li Yang	Rice University
Jihh-Shih You	Harvard Physics
Rong Yu	Renmin University of China/Rice University
Pavlo Zolotavin	Rice University

RICE UNIVERSITY CAMPUS MAP

8/28/2015



MAP KEY

- Entrance Gates
- Visitor's Entrances
- Bus Stops
- One-way Road

PARKING KEY

- Faculty/Staff Parking
- Resident Student Parking
- Commuter Parking
- Visitor Parking
- Accessible Parking

PARKING RATES:
 West of Entrance 18: \$1 each 20 minutes,
 \$11 daily maximum
 East of Entrance 18 and BioScience Research Collaborative Garage: \$1 each 12 minutes, \$11 daily maximum
 Greenbriar Lot: \$1 per entry, per day

PAYMENT METHODS:
 BioScience Research Collaborative Garage and Central Campus Garage: cash or credit card
 Greenbriar Lot, Founder's Court, North and West Lots Visitor Section: credit card

BUILDINGS

Abercrombie Engineering Laboratory	1	Baker Hall, James A. III	8	Humanities Building	40
Allen Business Center	2	Dean of Social Sciences, James A. Baker III	9	Dean of Humanities	41
President's Office	3	Institute for Public Policy	10	Jones College, Mary Gibbs	42
Anderson Biological Laboratories, M.D.	4	BioScience Research Collaborative	11	Jones College Masters House	43
Anderson-Clarke Center	5	Booth Centennial Pavilion, Suzanne Deal	12	Keck Hall	44
Dean of Suzanne M. Glasscock School of Continuing Studies	6	James Tierrell's "Twilight Epiphany" Skyspace	13	Keith-Wiess Geological Laboratories	45
Anderson Hall, M.D.	7	Brochstein Pavilion, Raymond and Susan	14	Ley Student Center	46
Moody Lot	8	Brockman Hall for Physics	15	Lovett College, Edgar Odell	47
Baker College	9	Brown College, Margaret Root	16	Lovett College Masters House	48
North Colleges Residents Lot	10	Brown College Masters House	17	Martel College	49
South Colleges Residents Lot	11	Herring Hall, Robert R.	18	Martel College Masters House	50
West Lot	12	Holway Hall	19	McMurry College, Burton and Deede	51
Faculty/Staff Parking	13	Herrstein Field	20	McMurry College Masters House	52
Resident Student Parking	14	Wendell D. Ley Track	21	McNair Hall, Janice and Robert	53
Commuter Parking	15	Housing and Dining	22	Dean of Jesse H. Jones Graduate School of Business	54
Visitor Parking	16	Hudspeth Auditorium	23	School of Business	55
Accessible Parking	17	Huff House, Peter and Nancy	24	Mechanical Engineering Building	56
	18	Alumni Affairs, Center for Student	25	Mechanical Laboratory	57
	19		26	Media Center	58
	20		27	Mudd Computer Science Building	59
	21		28	Natural Sciences, School of	60
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