Aspen Center for PHYSICS

Final Report for 2012 DOE #DE-SC0007479

# New Paradigms for Low-Dimensional Electronic Materials

# FEDERAL FINANCIAL REPORT

(Follow form instructions)

| 1. Federal Agency and Organizational Element to Which Report is Submitted | 2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) | Page | of |
|---|---|---|---|
| DOE | DE-SC0007479 | 1 | 1 |

3. Recipient Organization (Name and complete address including Zip code)
Aspen Center for Physics, 700 West Gillespie, Aspen, CO 81611

| 4a. DUNS Number | 4b. EIN | 5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment) | 6. Report Type | 7. Basis of Accounting |
|---|---|---|---|---|
| 848487583 | 84-6059504 | | □ Quarterly<br>□ Semi-Annual<br>Annual<br>X Final | X□ Cash □ Accrual |

| 8. Project/Grant Period From: (Month, Day, Year) | To: (Month, Day, Year) | 9. Reporting Period End Date (Month, Day, Year) |
|---|---|---|
| 10/01/11 | 9/30/12 | ## |

| 10. **Transactions** | Cumulative |
|---|---|
| *(Use lines a-c for single or multiple grant reporting)* | |
| **Federal Cash (To report multiple grants, also use FFR Attachment):** | |
| a. Cash Receipts | $10,000.00 |
| b. Cash Disbursements | $10,000.00 |
| c. Cash on Hand (line a minus b) | $0.00 |
| *(Use lines d-o for single grant reporting)* | |
| **Federal Expenditures and Unobligated Balance:** | |
| d. Total Federal funds authorized | $10,000.00 |
| e. Federal share of expenditures | $10,000.00 |
| f. Federal share of unliquidated obligations | |
| g. Total Federal share (sum of lines e and f) | $10,000.00 |
| h. Unobligated balance of Federal funds (line d minus g) | $0.00 |
| **Recipient Share:** | |
| i. Total recipient share required | |
| j. Recipient share of expenditures | |
| k. Remaining recipient share to be provided (line i minus j) | |
| **Program Income:** | |
| l. Total Federal program income earned | |
| m. Program income expended in accordance with the deduction alternative | |
| n. Program income expended in accordance with the addition alternative | |
| o. Unexpended program income (line l minus line m or line n) | |

| 11. Indirect Expense | a. Type | b. Rate | c. Period From | Period To | d. Base | e. Amount Charged | f. Federal Share |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | g. Totals: | | | |

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*

**13. Certification: By signing this report, I certify that it is true, complete, and accurate to the best of my knowledge. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)**

| a. Typed or Printed Name and Title of Authorized Certifying Official | c. Telephone (Area code, number and extension) |
|---|---|
| Paula Johnson, Finance Manager | 970-925-2585 |
| | d. Email address: paula@aspenphys.org |
| b. Signature of Authorized Certifying Official: Paula Johnson | e. Date Report Submitted (Month, Day, Year): ## |
| | 14. Agency use only: |

Standard Form 425
OMB Approval Number: 0348-0061
Expiration Date: 10/31/2011

# Aspen Center for Physics
# Project Summary
# DOE

Budget Period: 10/1/2011 to 9/30/2012
Contract # DE-SC0007479

**New Paradigms for Low-Dimensional Electronic Materials**

The 2012 Aspen Winter Conference on Condensed Matter Physics was held at the Aspen Center for Physics from February 5 to 10, 2012. Seventy-four participants from seven countries, and several universities and national labs attended the workshop titled, "New Paradigms for Low-Dimensional Electronic Materials." There were 34 formal talks, and a number of informal discussions held during the week. Talks covered a variety of topics related to DOE BES priorities, including, for example, advanced photon techniques (Hasan, Abbamonte, Orenstein, Shen, Ghosh) and predictive theoretical modeling of materials properties (Rappe, Pickett, Balents, Zhang, Vanderbilt); the full conference schedule is provided with this report.

The week's events included a public lecture ("*Quantum Matters*" given by Chetan Nayak from Microsoft Research) and attended by 234 members of the public, and a physics café geared for high schoolers that is a discussion with physicists conducted by Kathryn Moler (Stanford University) and Andrew M. Rappe (University of Pennsylvania) and attended by 67 locals and visitors. While there were no published proceedings, some of the talks are posted online and can be Googled. The workshop was organized by Joel Moore (University of California Berkeley), Chetan Nayak (Microsoft Research), Karin Rabe (Rutgers University), and Matthias Troyer (ETH Zurich). Two organizers who did not attend the conference were Gabriel Aeppli (University College London & London Centre for Nanotechnology) and Andrea Cavalleri (Oxford University & Max Planck Hamburg).

Six graduate students, 17 postdocs and four Assistant Professors (who received their PhDs each in 2007, 2008, 2009 and 2010) participated, making junior participation 36% of the total. More details on participants, ranks, PhD years and institutions is included in this document.


# Aspen Center for Physics Winter Conference

# Novel Paradigms for Low-dimensional Electronic Materials

## 5 February – 10 February 2012

**Organizing Committee:**

Gabriel Aeppli, University College London & London Centre for Nanotechnology

Andrea Cavalleri, Oxford University & Max Planck Hamburg

Joel Moore, University of California, Berkeley/LBNL

Chetan Nayak, Microsoft Station Q/UC Santa Barbara

Karin Rabe, Rutgers University

Matthias Troyer, ETH Zurich

Programs at the Aspen Center for Physics are supported by the National Science Foundation, the Department of Energy, and corporate & private donations. Additional support for this conference was provided by the Office of Naval Research, the Department of Energy, the Institute for Complex Adaptive Matter, and Nature Nanotechnology.






nature publishing group

# Aspen Winter Conference:
# Novel Paradigms for Low-Dimensional Electronic Materials
# February 5-10, 2012
# PROGRAM

## MONDAY February 6, 2012

Session chair: *Andrea Cavalleri*
8:00-8:10 welcome
8:10 – 9:00 Jochen Mannhart: Novel 2D-Electron Systems at Oxide Interfaces
9:00 – 9:50 Kirill Shtengel: Search for non-Abelian anyons in the $\nu$=5/2 FQH state
9:50-10:10 break
10:10 – 11:00 Shoucheng Zhang: interacting topological insulators and superconductors
MIDDAY BREAK
*Session chair: Joel Moore*
4:15-5:05 Amir Yacoby: Unconventional Sequence of Fractional Quantum Hall States in Suspended Graphene
5:05-5:55 Sayantani Ghosh: Visualizing Frustration in Magnetic Materials
5:55-7:30 poster session

## TUESDAY February 7, 2012

Session chair: *Dmitri Khveshchenko*
8:00-8:40 Eva Andrei: Probing Dirac fermions in graphene: from Landau levels to twist induced Van-Hove singularities
8:40-9:00 Dmitry Abanin: High-temperature topological insulator states in strained graphene
9:00-9:20 Divine Kumah: Physical structure and metal-insulator transitions in strained nickelate heterostructures
9:20-9:40 break
*Session chair: Leonid Rokhinson*
9:40-10:20 Leon Balents: Topological nodal semimetals
10:20-11:00 Andrew Rappe: Dirac semimetal in three dimensions
MIDDAY BREAK
*Session chair: Alexander Balatsky*
4:15-4:55 Michael Manfra: Understanding the impact of disorder on the 5/2 fractional quantum Hall state
4:55-5:35 Peter Abbamonte: Is graphene a strongly correlated electron system?
5:35-5:55 break
*Session chair: Khandker Quader*
5:55-6:15 Alex Levchenko: Nonequilibrium kinetics of interacting one-dimensional quantum systems beyond the Luttinger liquid paradigm
6:15-6:35 Kevin Garrity: Evanescent phonon coupling across the $La_{0.5}Sr_{0.5}MnO_3/SrTiO_3$ interface
6:35-7:15 Joseph Orenstein: Perspectives on time-resolved spectroscopies of spin and charge dynamics
7:30 GROUP DINNER, Aspen Meadows

## WEDNESDAY February 8, 2012

*Session chair: James Rondinelli*
8:00-8:40 Jean-Marc Triscone: Magneto-transport and electronic structure of the interfacial $LaAlO_3/SrTiO_3$ electron gas
8:40-9:00 Marc Gabay: Spin-orbit protected transport at the 2D LAO-STO interface
9:00-9:20 Lu Li: Magnetism of $LaAlO_3/SrTiO_3$ Heterostructure Interface

9:20-9:40 break

*Session chair: Girsh Blumberg*
9:40-10:20 Z. X. Shen: Dynamic Gap Competition in Trisected Superconducting Dome
10:20-11:00 Zahid Hasan: Surface States in topological insulators and superconductors: Discovery and Recent Results

4:30 PHYSICS CAFÉ, Wheeler Opera House, Kathryn Moler and Andrew Rappe
5:30 MAGGIE AND NICK DE WOLF PUBLIC LECTURE, Wheeler Opera House
Chetan Nayak: "Quantum Matters"

## THURSDAY February 9, 2012

*Session chair: Jonathan Spanier*
8:00-8:40 Andrea Young: Interaction driven quantum Hall effects in mono- and bilayer graphene
8:40-9:00 Xiaoxing Xi: Key material parameters for $LaAlO_3/SrTiO_3$ interfacial conductivity
9:00-9:20 David Goldhaber-Gordon: Signatures of Majorana Fermions in Hybrid Superconductor-Topological Insulator Devices

9:20-9:40 break

*Session chair: Matthias Troyer*
9:40-10:20 Philipp Werner: Tuning many-body interactions by light
10:20-11:00 Karyn Le Hur: Strong Correlation Effects in Topological Insulators

MIDDAY BREAK

*Session chair: Sudip Chakravarty*
4:15-4: 55 Minoru Yamashita: Study of Quantum Spin Liquid in Two-dimensional Antiferromagnets
4:55-5:35 Senthil: Theory of quantum spin liquids

5:35-5:55 break

*Session chair: Ron Cohen*
5:55-6:35 Warren Pickett: Two Dimensional Electronic Behavior in Metal-Oxide Nanostructures
6:35-7:15 Harold Hwang: Superconductivity and Magnetotransport in δ-Doped $SrTiO_3$
7:30 BANQUET, Aspen Meadows

## FRIDAY February 10, 2012

*Session chair: Franz Giessibl*
8:00-8:40 Angela Kou: Interferometry in the Fractional Quantum Hall Effect
8:40-9:20 Robert Willett: Interferometric evidence for non-Abelian quasiparticles at filling factor 5/2
9:20-9:40 Roman Lutchyn: The search for elusive Majorana particles in semiconductor-superconductor structures

9:40 – 10:00 break

*Session chair: Arzhang Ardavan*
10:00-10:40 Kathryn Moler: Landscapes of Magnetism and Superconductivity in LAO/STO heterostructures
10:40-11:20 David Vanderbilt: Orbital magnetoelectric coupling and surface anomalous Hall effect

## POSTERS

| | |
|---|---|
| Ardavan, Arzhang | Quantum information processing with artificial molecular nanomagnets |
| Blumberg, Girsh | Raman spectroscopy of iron-based superconductors |
| Cohen, Ron | Metallization of FeO at High Temperatures and Pressures: DFT-DMFT Computations and Comparisons with Experiments |
| Garate, Ion | Noninvasive probe of charge fractionalization in quantum spin Hall insulators. |
| Giessibl, Franz | Probing Low-dimensional Systems with Combined Scanning-Tunneling- and Atomic-Force- Microscopy |
| Goswami, Partha | Quasi-particle localization by disorder in $\nu$=5/2 fractional quantum Hall potential state and its potential application |
| Laumann, Chris | Disorder-induced Majorana metal in interacting non-Abelian anyon systems |
| Lee, Menyoung | Electrolyte gate-tuned Kondo effect in $SrTiO_3$ |
| Levkivskyi, Ivan | Non-equilibrium bosonization and its applications to quantum Hall systems |
| Loh, Yen Lee | Quantum liquid crystals: spontaneously modulated Fermi superfluids |

| | |
|---|---|
| Mandal, Ipsita | Majorana zero modes in a quantum Ising chain with longer-ranged interactions |
| May, Steven | Experimental studies of octahedral rotations in perovskite oxide heterostructures |
| Moore, Greg | Equivariant topological insulators |
| Nowack, Katja | Local imaging of the superfluid density at the LAO/STO interface as a function of gate voltage |
| Rachel, Stephan | Interacting 2D topological insulators |
| Roleder, Krystian | Precursor dynamics to the structural instability in $SrTiO_3$ |
| Rondinelli, James | Disentangling latent phase transitions in perovskite oxide thin films: insights from first principles |
| Seradjeh, Babak | Topological exciton condensate of imbalanced electrons and holes in magnetic field |
| Sergeev, Andrei | Magnetization currents: Poynting vector, metamaterials, thermomagnetic effects, and Onsager relations |
| Sochnikov, Ilya | Scanning SQUID measurements of thin high-$T_c$ superconducting films |
| Takei, So | Neutral mode heat transport and fractional quantum Hall shot noise |
| Vayrynen, Jukka | Chiral Topological Phases and Fractional Domain Wall Excitations in One-Dimensional Chains and Wires |
| Watson, John | Exploration of the limits to mobility in two-dimensional hole systems in C-doped (001) GaAs/AlGaAs quantum wells |

# New Paradigms for Low-Dimensional Electronic Materials

| Family Name | First Name | Institution | rankOther | PhD Yr. |
|---|---|---|---|---|
| Lee | Menyoung | Stanford University | Graduate Student | 2016 |
| Vayrynen | Jukka I | Yale University | Graduate Student | 2016 |
| Watson | John D | Purdue University | Graduate Student | 2014 |
| Kou | Angela | Harvard University | Graduate Student | 2013 |
| Taheri Nejad | Maryam | Rutgers University | Graduate Student | 2013 |
| Soluyanov | Alexey | Rutgers University | Graduate Student | 2012 |
| Bauer | Bela | Station Q, Microsoft Research | Postdoc | 2011 |
| Garrity | Kevin F | Rutgers University | Postdoc | 2011 |
| Levkivskyi | Ivan | University of Geneva | Postdoc | 2011 |
| Mandal | Ipsita | University of California Los Angeles | Postdoc | 2011 |
| Sochnikov | Ilya | Stanford University | Postdoc | 2011 |
| Laumann | Chris R | Harvard University | Postdoc | 2010 |
| Rondinelli | James | Drexel University | Assistant Professor | 2010 |
| Garate | Ion | Yale University | Postdoc | 2009 |
| Hou | Chang-Yu | Caltech and UC Riverside | Postdoc | 2009 |
| Kumah | Divine P | Yale University | Postdoc | 2009 |
| Levchenko | Alex | Michigan State University | Assistant Professor | 2009 |
| Lindner | Netanel | California Institute of Technology | Postdoc | 2009 |
| Matsuura | Shunji | McGill University | Postdoc | 2009 |
| Mulligan | Michael | Massachusetts Institute of Technology | Postdoc | 2009 |
| Nowack | Katja | Stanford University | Postdoc | 2009 |
| Abanin | Dmitry | Harvard University | Postdoc | 2008 |
| Li | Lu | University of Michigan | Assistant Professor | 2008 |
| Rachel | Stephan | Yale University | Postdoc | 2008 |
| Takei | So | University of Maryland College Park | Postdoc | 2008 |
| Fidkowski | Lukasz | Microsoft Station Q | Postdoc | 2007 |
| Lutchyn | Roman | Microsoft Research | Other | 2007 |
| May | Steven | Drexel University | Assistant Professor | 2007 |
| Segal | Michael | Nature Nanotechnology | Other | 2007 |
| Seradjeh | Babak | Indiana University - Bloomington | Assistant Professor | 2006 |
| Loh | Yen Lee | University of North Dakota | Assistant Professor | 2005 |
| Werner | Philipp | ETH Zurich | Assistant Professor | 2005 |
| Yamashita | Minoru | Kyoto University | Assistant Professor | 2005 |
| Ghosh | Sayantani | University of California, Merced | Assistant Professor | 2003 |
| Moore | Joel | University of California Berkeley | Professor | 2001 |
| Abbamonte | Peter | University of Illinois Urbana Champaign | Associate Professor | 1999 |
| Goldhaber- | David | Stanford University | Associate Professor | 1999 |
| Manfra | Michael | Purdue University | Associate Professor | 1999 |
| Shtengel | Kirill | University of California Riverside | Associate Professor | 1999 |
| Ardavan | Arzhang | University of Oxford | Other | 1998 |

# New Paradigms for Low-Dimensional Electronic Materials

| Family Name | First Name | Institution | rankOther | PhD Yr. |
|---|---|---|---|---|
| Le Hur | Karyn | Ecole Polytechnique and CRNS | Other | 1998 |
| Senthil | Todadri | MIT | Professor | 1998 |
| Hwang | Harold | Stanford University | Professor | 1997 |
| Nayak | Chetan | Microsoft Research | Professor | 1996 |
| Rokhinson | Leonid | Purdue University | Professor | 1996 |
| Moler | Kathryn | Stanford University | Professor | 1995 |
| Balents | Leon | University of California Santa Barbara | Professor | 1994 |
| Troyer | Matthias | ETH Zurich | Professor | 1994 |
| Yacoby | Amir | Harvard University | Professor | 1994 |
| Giessibl | Franz J | University of Regensburg | Professor | 1992 |
| Rappe | Andrew M | University of Pennsylvania | Professor | 1992 |
| Khveshchenko | Dmitri | University of North Carolina Chapel Hill | Professor | 1989 |
| Shen | Zhi-Xun | Stanford University | Professor | 1988 |
| Willett | Robert L. | Bell Laboratories | Physicist (in lab-not academic) | 1988 |
| Balatsky | Alexander | Los Alamos National Laboratory | Physicist (in lab-not academic) | 1987 |
| Blumberg | Girsh | Rutgers University | Professor | 1987 |
| Mannhart | Jochen | Max Planck Institute for Solid State | Professor | 1987 |
| Rabe | Karin | Rutgers University | Professor | 1987 |
| Sergeev | Andrei | SUNY at Buffalo | Associate Professor | 1987 |
| Triscone | Jean-Marc | University of Geneva | Professor | 1987 |
| Xi | Xiaoxing | Temple University | Professor | 1987 |
| Zhang | Shoucheng | Stanford University | Professor | 1987 |
| Goswami | Partha | University of Delhi | Associate Professor | 1986 |
| Cohen | Ronald | Carnegie Institution of Washington | Professor | 1985 |
| Moore | Gregory | Rutgers University | Professor | 1985 |
| Quader | Khandker | Kent State University | Professor | 1984 |
| Andrei | Eva | Rutgers University | Professor | 1981 |
| Gabay | Marc | Universite Paris-Sud, Centre d'Orsay | Professor | 1981 |
| Roleder | Krystian | University of Silesia | Professor | 1981 |
| Orenstein | Joe | UC Berkeley and LBNL | Professor | 1980 |
| Chakravarty | Sudip | University of California Los Angeles | Professor | 1976 |
| Pickett | Warren E | University of California Davis | Professor | 1975 |
| Abrahams | Elihu | University of California Los Angeles | Professor Emeritus/Emerita | 1952 |
| Young | Andrea | Columbia University | | |

# ASPEN
# CENTER FOR PHYSICS

## 2012 WINTER CONFERENCE
ON
## CONDENSED MATTER PHYSICS

### February 5 – 10, 2012
### Sunday Evening Reception
### Meetings Monday morning through Friday noon

## NEW PARADIGMS FOR LOW-DIMENSIONAL ELECTRONIC MATERIALS

Several of the most exciting recent developments in condensed matter involve new ways to create, probe and model low-dimensional electronic materials. The metallic interface between certain insulating oxides and the metallic surface of a three-dimensional (3D) topological insulator are both examples of novel 2D electron systems that inherit properties from the 3D host materials. The "conventional'' two-dimensional electron gas has continued to produce surprises such as paired quantum Hall states, while graphene is an intrinsically two-dimensional system with several novel features. Finally, various types of control, from electric fields at interfaces to stimulation with tailored light fields, are making it possible to generate out-of-equilibrium states of great interest.

This winter conference will bring together experimentalists and theorists working on the physics of low-dimensional electronic materials. The focus will be on the synergy and cross-fertilization of work on the various systems of current interest, with as much emphasis on the identification of common themes, challenges and approaches as on cutting edge research in each class of systems. Invited talks will be complemented by additional talks selected from abstracts submitted by participants and by poster sessions; the participation of junior scientists is strongly encouraged. This conference represents a unique opportunity for participants to grasp the remarkable recent progress in the physics of low-dimensional electronic materials and to identify key questions and novel approaches in a broader context.

### Application deadline is November 15, 2011

**Please complete your application at:www.aspenphys.org**

**ORGANIZERS:**

Gabriel Aeppli (University College London & London Centre for Nanotechnology)
Andrea Cavalleri (Oxford University & Max Planck Hamburg)
Joel Moore (University of California, Berkeley/LBNL)
Chetan Nayak (Microsoft Station Q/UCSB)
Karin Rabe (Rutgers University)
Matthias Troyer (ETH Zurich)

The Aspen Center for Physics is committed to a significant participation of women and under-represented groups in all of its programs.

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NSF