La Jolla Workshop *on* BIG Ideas *in* Quantum Materials

2015

Dec 14-17

Welcome to Big Ideas Workshop 2015

Dear Colleagues,

We would like to offer you a sincere welcome to **Big Ideas in Quantum Materials Workshop!** We hope that you find the conference intellectually stimulating and La Jolla refreshing and relaxing.

Dimitri Basov, Joe Orenstein, Andrew Millis

Meeting Contacts:

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La Jolla Workshop on BIG Ideas in Quantum Materials
2015
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Big Ideas Program

Monday December 14:

6:30 – 9:00 pm Reception for invited speakers and session chairs

Marine Room, La Jolla Beach and Tennis Club

Tuesday, December 15 - Scripps Seaside Forum

8:00 – 8:15 am Opening Remarks DB, JO and AJM.

8:15 – 10:15 ***Topology and New States of Matter - I***

8:15 – 8:30 Introduction by J. Moore (UCB)

8:30 – 8:50 S.C. Zhang (Stanford) Title: **Topological insulators and topological superconductors**

8:50 – 9:05 Discussion

9:05 – 9:25 P. Armitage (JHU) Title: **Low energy electrodynamics of topological insulators**

9:25 – 9:40 Discussion

9:40 – 10:00 N. Samarth (Penn State) Title: **Hybrid Topological Materials: from Novel Quantum Phases to Spintronics**

10:00 – 10:15 Discussion

10:15 – 10:45 Coffee Break

10:45 – 12:45 ***Societal Impact***

10:45 –11:00 Introduction by M. Aronson (Texas A & M)

11:00 – 11:20 P. Littlewood (ANL) Title: **Can the "market" drive science?**

11:20 – 11:35 Discussion

11:35 – 11:55 F. Koppens (ICFO) Title: **Will 2d materials live up to their hype?**

11:55 – 12:10 Discussion

12:10 – 12:30 E. Yablonovitch (UCB) Title: **Why We Need To Replace the Transistor, and What Would be the Newly Required Material Properties?**

12:30 – 12:45 Discussion

12:45 – 3:30 Lunch followed by **Poster Session 1** and Discussions

3:30 – 6:40 ***Two Dimensional Materials***

3:30 – 3:50 Introduction E. Andrei (Rutgers)

3:50 – 4:10 Philip Kim (Harvard) Title: **Electronic and Optoelectronic Physics in the van der Waals Heterojunctions**

4:10 – 4:25 Discussion

4:25 – 4:45 T. Heinz (Stanford) Title: **Interactions in atomically thin semiconductors and heterostructures**

4:45 – 5:00 Discussion

5:00 – 5:30 Coffee Break

5:30 – 5:50 F. Guinea (CSIC, Madrid) Title: **Novel quantum effects in graphene and two dimensional sichalcogenides**

5:50 – 6:05 Discussion

6:05 – 6:25 J. Hone (Columbia) Title: **Using van der Waals heterostructures to study 2D materials in the ultraclean limit**

6:25 – 6:40 Discussion

<u>Wednesday, December 16 - Scripps Seaside Forum</u>

8:00 – 10:00 ***Superconductivity - I***

8:00 – 8:15 Introduction by I. K. Schuller (UCSD)

8:15 – 8:35 L. Taillefer (Sherbrooke) Title: **Change of carrier density at the pseudogap critical point of a cuprate superconductor**

8:35 – 8:50 Discussion

8:50 – 9:10 S. Davis (Cornell/BNL) Title: **Cooper-pair Condensate Visualization - Spatial Symmetry Breaking & Intertwined Orders**

9:10 – 9:25 Discussion

9:25 – 9:45 A. Kapitulnik (Stanford) Title: **The Superconductor-(Metal)-Insulator Transition in Two Dimensions: A Possible Paradigm for Understanding Quantum Phase Transitions**

9:45 – 10:00 Discussion

10:00 – 10:30 Coffee Break

10:30 – 12:30 ***Quantum Control and Information***

10:30 – 10:45 Introduction by J. Petta (Princeton)

10:45 – 11:05 D. Awschalom (Chicago) Title: **Designing and controlling quantum materials with defects**

11:05 – 11:20 Discussion

11:20 – 11:40 M. Lipson (Columbia) Title: **Graphene photonics**

11:40 – 11:55 Discussion

11:55 – 12:15 M. Lukin (Harvard) Title: **New interface between quantum optics and nanoscience**

12:15 – 12:30 Discussion

12:30 – 3:00 Lunch followed by **Poster Session 2** and Discussions

3:00 – 6:10 ***Visualization of Physical Phenomena***

3:00 – 3:20 Introduction K. A. Moler (Stanford)

3:20 – 3:40 A. Yacoby (Harvard) Title: **Imaging Skyrmions and the Spatially Varying Order Parameter in Proximitized HgCdTe Quantum Wells**

3:40 – 3:55 Discussion

3:55 – 4:15 A. Pasupathy (Columbia) Title: **Advancing the state of the art in scanning tunneling microscopy**

4:15 – 4:30 Discussion

4:30 – 5:00 Coffee Break

5:00 – 5:20 M. Fogler (UCSD)   Title: **"Hot" topics in van der Waals materials**

5:20 – 5:35 Discussion

5:35 – 5:55 M. Crommie (UCB)   Title: **Tuning the Energy Landscape of Graphene through Molecular and Defect Charge Manipulation**

5:55 – 6:10 Discussion

7:00 – 10:00 Dinner & After Dinner Talk R. Ramesh (UC Berkeley)
Title: **Emergent Phenomena: Is it only in Correlated Systems?**

Thursday, December 17 - Scripps Seaside Forum

8:00 – 10:00 ***Topological States and New States of Matter - II***

8:00 – 8:15 Introduction by N. Gedik (MIT)

8:15 – 8:35 V. Madhavan (UIUC)   Title: **STM insights into topological insulators**

8:35 – 8:50 Discussion

8:50 – 9:10 N.P. Ong (Princeton)   Title: **Evidence for the chiral anomaly in Dirac and Weyl semimetals**

9:10 – 9:25 Discussion

9:25 – 9:45 A. Vishwanath (UCB)   Title: **Smoking gun signatures of 3D Weyl fermions and hidden Dirac fermions in the half filled landau level**

9:45 – 10:00 Discussion

10:00 –10:30 Coffee Break

10:30 – 12:30 ***Superconductivity - II***

10:30 – 10:45 Introduction by A. Chubukov (Minnesota)

10:45 – 11:05 M.B. Maple (UCSD) Title: **Musings about strategies for searching for high temperature superconductors**

11:05 – 11:20 Discussion

11:20 – 11:40 B. Keimer (MPI-Stuttgart) Title: **Control of collective quantum phenomena in metal-oxide superlattices**

11:40 – 11:55 Discussion

11:55 – 12:15 Z. X. Shen (Stanford) Title: **Recent Progress on FeSe superconductors**

12:15 – 12:30 Discussion

12:30 – 3:30 Lunch followed by **Poster Session 3** and Discussions

3:30 – 6:40 ***Non-equilibrium Phenomena and Measurements Under Extreme Conditions***

3:30 – 3:50 Introduction R. Averitt (UCSD)

3:50 – 4:10 M. Murnane (Colorado) Title: **Capturing dynamics and function in quantum materials using tabletop coherent X-rays**

4:10 – 4:25 Discussion

4:25 – 4:45 A. Millis (Columbia)   Title: **Meeting Dirac's Challenge: Modern Materials Theory In and Out of Equilibrium**

4:45 – 5:00 Discussion

5:00 – 5:30 Coffee Break

5:30 – 5:50 A. Lanzara (UCB)   Title: **Switching quantum materials properties with light**

5:50 – 6:05 Discussion

6:05 – 6:25 G. Boebinger (NHMFL)   Title: **Measurements under extreme conditions**

6:25 – 6:40 Discussion

6:40 – 7.00 A. Cavalleri (MPI-Hamburg and Oxford) Title: **Mode-selective coherent control of the solid state**

7.00 – 7:15 Discussion

7:15 – 7:20 Concluding Remarks DNB, JO, AJM

Poster Session 1: Tuesday, December 15, 2015			
Poster #	**Authors**	**Affiliation**	**Title**
1	**Siyuan Dai**, Qiong Ma, Zhe Fei, Mengkun Liu, Michael Goldflam, Trond Andersen, Will Garnett, William Regan, Martin Wagner, Alex McLeod, Alexandr Rodin, Shou-En Zhu, Kenji Watanabe, Takashi Taniguchi, Gerardo Dominguez, Mark Thiemens, Antonio Castro Neto, G. C. A. M. Janssen, Alex Zettl, Fritz Keilmann, Pablo Jarillo-Herrero, Michael Fogler and Dimitri Basov	UC San Diego	Hyperbolic phonon polaritons in hexagonal boron nitride
2	**Valla Fatemi,** Benjamin Hunt, Hadar Steinberg, Stephen Eltinge, Fahad Mahmood, Nicholas Butch, Kenji Watanabe, Takashi Taniguchi, Nuh Gedik, Raymond Ashoori and Pablo Jarillo-Herrero	MIT	Electrostatic Coupling between Topological Insulator Surface States
3	**Landry Bretheau**, Philippe Campagne-Ibarcq, Emmanuel Flurin, Francois Mallet and Benjamin Huard	MIT	Quantum dynamics of an electromagnetic mode that cannot contain N photons
4	**Jimmy Hutasoit**, Brian Tarasinski, Denis Chevallier, Benjamin Baxevanis and Carlo W. J. Beenakker	Lorentz Intitute, Leiden University	A Bogoliubov-Majorana Gun: An On-demand Single Majorana Fermion Source (oral - regular)
5	**Benedikt Scharf,** Alex Matos-Abiague, Jong Han, Ewelina Hankiewicz, Jaroslav Fabian and Igor Zutic	University at Buffalo	Spin-Orbit Coupling in Hybrid Semiconductor Structures: From Majorana Fermions and Topological Insulators to Giant Transverse Hall Currents
6	**Kirk Post,** Brian Chapler, Mengkun Liu, Jih-Sheng Wu, H.T. Stinson, Michael Goldflam, Anthony Richardella, Joon Sue Lee, Anjan Reijnders, Kenneth Burch, Michael Fogler, Nitin Samarth and Dmitri Basov	UC San Diego	Sum rule constraints on the surface state conductance of topological insulators
7	Ying Wang, Zhiguo Chen, Raman Sankar, Nan-Lin Wang, Fang-Cheng Chou, Liang Fu and **Zhiqiang Li**	National High Magnetic Field Lab, Los Alamos	Infrared Study of Surface States and Bulk Bands of a Topological Crystalline Insulator
8	**Xiaomeng Liu**, Kenji Watanabe, Takashi Taniguchi and Philip Kim	Harvard University	Anomalous Coulomb drag in bilayer graphene double layers
9	**Luyi Yang**, Nikolai Sinitsyn, Weibing Chen, Jiangtan Yuan, Jing Zhang, Kathleen McCreary, Berry Jonker, Jun Lou and Scott Crooker	National High Magnetic Field Lab, Los Alamos	Long-lived spin relaxation and spin coherence of electrons in monolayer MoS2 (oral, regular)
10	**Yang Xu**, Ireneusz Miotkowski and Yong P. Chen	Purdue University	Observation of topological surface state quantum Hall effect in an intrinsic three-dimensional topological insulator
11	**Justin Song** and Mark Rudner	Caltech	Chiral plasmons without magnetic field

Poster Session 1: Tuesday, December 15, 2015			
Poster #	**Authors**	**Affiliation**	**Title**
12	**Guangxin Ni,** Haomin Wang, Jhih-Sheng Wu, Zhe Fei, Michael Goldflam, Friz Keilmann, Barbaros Özyilmaz, Antonio Castro Neto, Xiaoming Xie, Michael Fogler and Dimitri Basov	UC San Diego	Plasmons in graphene moiré superlattices
13	**Yinming Shao**, Kirk W. Post, Jhih-Sheng Wu, Anthony R. Richardella, Joon S. Lee, Michael M. Fogler, Nitin Samarth and Dimitri N. Basov	UC San Diego	Cyclotron resonance and Faraday rotation on topological insulator (Bi,Sb)2Te3
14	**Alex J. Frenzel**, C. H. Lui, Y. C. Shin, J. Kong and N. Gedik	UC San Diego	Semiconducting-to-metallic Photoconductivity Crossover in Graphene
15	**Fahad Mahmood**, Ching-Kit Chan, Dillon Gardner, Young Lee, Patrick Lee and Nuh Gedik	MIT	Floquet-Bloch & Volkov states on the surface of a topological insulator
16	**Shreyas Patankar**	UC Berkeley	Resonant magneto-optic Kerr effect in magnetic topological insulator thin films
17	**Christopher Homes**, M. N. Ali and R. J. Cava	Brookhaven National Laboratory	The optical properties of the perfectly compensated semimetal tungsten ditelluride
18	**Michael Fogler**	UC San Diego	“Hot” topics in van der Waals materials
19	**Jhih-Sheng Wu**, Dimitri Basov and Michael Fogler	UC San Diego	Topological Insulators Are Tunable Waveguides for Hyperbolic Polaritons
20	**Zhiyuan Sun**, Angel Gutierrez-Rubio, Dimitri Basov and Michael Fogler	UC San Diego	Hamiltonian optics of hyperbolic polaritons in nanogranules
21	**Bor-Yuan Jiang**, Guangxin Ni, Cheng Pan, Zhe Fei, Bin Cheng, Chun Ning Lau, Marc Bockrath, Dimitri Basov and Michael Fogler	UC San Diego	Optical signatures of a hypercritical 1D potential in a 2D Dirac metal
22	**Matthew Pelliccione**, Alec Jenkins, Preeti Ovartchaiyapong, Christopher Reetz, Eve Emmanuelidu, Ni Ni and Ania Bleszynski Jayich	UC Santa Barbara	Scanned probe imaging of nanoscale magnetism at cryogenic temperatures with a single-spin quantum sensor
23	**Jingdi Zhang**, Xuelian Tan, Mengkun Liu, Samuel W. Teitelbaum, Kirk W. Post, Feng Jin, Keith A. Nelson, Dimitri N. Basov, Wenbin Wu and Richard D. Averitt	UC San Diego	Cooperative photo-induced metastable phase control in strained manganite films
24	**Jing Wang** and Shou-Cheng Zhang	Stanford University	Quantum anomalous Hall effect in magnetic topological insulators and other materials
25	**Ling Miao**	Physical Review X	Physical Review X and Highlights in Quantum Materials Research.

Poster Session 2: Wednesday, December 16, 2015			
Poster #	**Authors**		**Title**
1	**Jiangping Hu**	Purdue University	Genes for unconventional high Tc superconductors
2	**Fengcheng Wu**, Fei Xue and Allan H. MacDonald	University of Texas, Austin	Theory of exciton condensation in transition metal dichalcogenide heterostructures
3	**Sarath Sankar** and Vikram Tripathi	TIFR, Mumbai, India	Role of spatial inhomogeneities and phase frustration in the magnetic response of disordered Josephson junction arrays
4	**Alex Matos-Abiague**, Petra Hogl, **Igor Zutic** and Jaroslav Fabian	University of New York, Buffalo	Magnetoanisotropic Andreev Reflection in Ferromagnet/Superconductor Junctions
5	**Alex Edelman** and Peter Littlewood	University of Chicago	Quantum Melting and Supersolidity in a Polariton Lattice (poster, student)
6	**Arnab Banerjee**, Stephen E. Nagler, Craig Bridges, Jiaqiang Yan, Johannes Knolle, Matthew B. Stone, Maxim Ziatdinov, Mark L. Lumsden, Bryan C. Chakoumakos, Huibo B. Cao, Roderich Moessner, David Alan Tennant, Adam A. Aczel and David G. Mandrus	Oak Ridge National Laboratory	Kitaev physics and fractionalized excitations in alpha-RuCl3 (poster, regular)
7	**Christopher A. Watson**, Hilary Noad, Ilya Sochnikov, Genda Gu, John M. Tranquada and Kathryn A. Moler	Stanford University	Scanning SQUID Microscopy of the Meissner State in La1.875Ba0.125CuO4
8	**H. T. Stinson**, J. S. Wu, B. Y. Jiang, A. S. Rodin, B. Chapler, A. S. Mcleod, A. Castro Neto, Y. S. Lee, M. M. Fogler and D. N. Basov	UC San Diego	Terahertz nano-spectroscopy and imaging of superfluid surface plasmons in conventional and anisotropic superconductors
9	**Aliaksei Charnukha**	UC San Diego	Critical non-adiabatic superconductivity from strong correlations in iron oxypnictides
10	**Hai-Ping Cheng** and Yun-Peng Wang	University of Florida	First-principles simulations of a graphene-based field-effect transistor
11	**Wang Yang**, Yi Li and Congjun Wu	UC San Diego	High partial-wave channel counterparts of the ^{3}He-B phase -- isotropic and topological pairings in 3D
12	**Verner Thorsmolle**, Maxim Khodas, Zhiping Yin, Chenglin Zhang, Scott Carr, Pengcheng Dai and Girsh Blumberg	UC San Diego	Critical Quadrupole Fluctuations and Collective Modes in Iron Pnictide Superconductors
13	**Christian Wolowiec**, Noravee Kanchanavatee, Kevin Huang and Brian Maple	UC San Diego	Combined effect of Fe substitution and applied pressure on the ordered phases in the heavy fermion compound URu2Si2

Poster Session 2: Wednesday, December 16, 2015			
Poster #	**Authors**		**Title**
14	**Sheng Ran**, Noravee Kanchanavatee, Kevin Huang, Dinesh Martien, Tyler Dapron, Stefano Spagna, Andrew Gallagher, Kuan-Wen Chen, David Graf, Ryan Baumbach, M. Brian Maple, David Snow and Mark Williamsen	UC San Diego	Thermal expansion and high magnetic field electrical transport measurements on Fe substituted URu2Si2
15	Yuankan Fang, Christian Wolowiec, Duygu Yazici, Inho Jeon, Benjamin White, Colin McElroy, Kevin Huang and M. Brian Maple	UC San Diego	Enhancement of Superconductivity in BiS2-Based Compounds
16	**Inho Jeon,** Kevin Huang, Duygu Yazici, Noravee Kanchanavatee, Benjamin D. White, Pei-Chun Ho, Sooyoung Jang, Naveen Pouse and M. Brian Maple	UC San Diego	Investigation of the superconducting and normal state properties of the filled-skutterudite system PrPt4Ge12 via chemical substitution
17	**Paula Giraldo-Gallo**, Philip Walmsley, Boris Sangiorgio, Lisa Buchauer, Benoit Fauque, Scott Riggs, Gregory Boebinger, Ross McDonald, Theodore Geballe, Nicola Spaldin, Kamran Behnia and Ian Fisher	National High Magnetic Field Lab, FSU	Fermiology of Hole-Doped PbTe: Insights to Understand Superconductivity in a Valence-Disproportionated System
18	**Inna Vishik**, Fahad Mahmood, Zhanybek Alpichshev, Richard L. Greene and Nuh Gedik	MIT	Ultrafast dynamics in electron-doped cuprates: gap structure and antiferromagnetic correlations
19	**Abhay Shastry** and Charles Stafford	University of Arizona	Local temperatures and voltages in quantum systems far from equilibrium
20	**Alejandro Lopez-Bezanilla** and Peter Littlewood	Argonne National Lab	New Materials Exhibiting Unusual Properties
21	**Adam Aczel**	Oak Ridge National Laboratory	Exotic magnetic ground states of the zigzag chain systems BaR2O4 (R = Nd, Tb)
22	**Andrej Singer** and Oleg Shpyrko	UC San Diego	Enhancement of charge ordering via dynamic electron-phonon interaction
23	**Stephen D. Edkins**, Mohammad H. Hamidian, Sang Hyun Joo, Andrey A. Kostin, Hiroshi Eisaki, Shinichi Uchida, Michael J. Lawler, Eun Ah Kim, Andrew P. Mackenzie, Kazuhiro Fujita, Jinho Lee and J. C. Séamus Davis	Cornell University	Searching for a Pair Density Wave State in Bi2Sr2CaCu2O8 using Scanned Josephson Tunneling
24	**Runzhi Wang**, Emanuel Lazar, Hyowon Park, Andrew Millis and Chris Marianetti	Columbia University	Selectively localized Wannier functions
25	**Edgardo Solano Carrillo** and Andrew Millis	Columbia University	Nonequilibrium Thermodynamics at the Quantum Scale
26	**Ling Miao**	Physical Review X	Physical Review X and Highlights in Quantum Materials Research.

Poster Session 3: Thursday, December 17, 2015			
Poster #	**Authors**		**Title**
1	**Vikram Tripathi**, Alexey Galda and Valerii Vinokur	Argonne National Lab	Parity-time symmetry-breaking mechanism of dynamic Mott transitions in dissipative systems
2	**Arkady Shekhter**	NAMFL- Florida State University	Quantum oscillations near metallic quantum critical point.
3	**Alexey Galda** and Valerii Vinokur	Argonne National Lab	PT symmetry-breaking in non-equilibrium magnetic systems
4	**Alexandre Zimmers**	ESPCI - CNRS-UPMC	Metal Oxide Resistive Switching: Evolution of the Density of States Across the Metal-Insulator Transition (poster, regular registration)
5	**Chris Heinrich**	University of Chicago	Charge and neutral modes in an exactly soluble model
6	**Priscila F. S. Rosa**, Thales M. Garitezi, Zachary Fisk, Pascoal G. Pagliuso and Joe D. Thompson	Los Alamos National Laboratory	Tuning the 3d magnetism of ThCo2Sn2 single crystals by pressure
7	**Maxim Ziatdinov**, Artem Maksov, Wu Zhou, Tom Berlijn, Arnab Banerjee, Jiaqiang Yan, Stephen Nagler, David Mandrus, Arthur Baddorf and **Sergei Kalinin**	Oak Ridge National Laboratory	Real-space study of local atomic and electronic behavior in strongly correlated systems guided by multivariate statistics and machine learning
8	**Hilary Noad,** Eric M. Spanton, Julie A. Bert, Beena Kalisky, Katja C. Nowack, Christopher Bell, Minu Kim, Yasuyuki Hikita, Masayuki Hosoda, Hiroki K. Sato, Yanwu Xie, Pascal Wittlich, Harold Y. Hwang, Jochen Mannhart and Kathryn A. Moler	Stanford University	Magnetism in LaAlO3/SrTiO3 Heterostructures Probed with Scanning SQUID
9	Shenglong Xu and **Congjun Wu**	UC San Diego	Strong Correlation and Topological States in Orbital-Active Honeycomb Lattices
10	**Jianda Wu**, Wang Yang, Congjun Wu and Qimiao Si	UC San Diego	Finite-temperature Dynamics and Quantum Criticality in a Model for Insulating Magnets
11	**Yoshiteru Maeno**, Chanal Sow, Shingo Yonezawa and Fumihiko Nakamura	Kyoto University	Melting the Electron Solid under Non-Equilibrium Conditions -- Mott Transition in Ca2RuO4 --
12	**Verner Thorsmolle**, Jingdi Zhang, Srimanta Middey, Elsa Abreu, Gufeng Zhang, Jak Chakhalian and Richard Averitt	UC San Diego	Conductivity Dynamics of the Metal-to-Insulator Transition in Nickelate Superlattices - Poster

Poster Session 3: Thursday, December 17, 2015			
Poster #	**Authors**		**Title**
13	**Rashmi Singla**, Giovanni Cotugno, Stefan Kaiser, Michael Foerst, Matteo Mitrano, Haiyun Liu, Andrea Cartella, Cristian Manzoni, Hiroshi Okamoto, Tatsuo Hasegawa, Stephen Clark, Dieter Jaksch and Andrea Cavalleri	UC San Diego	Correlation-gap oscillations in an organic Mott-insulator induced by phase locked excitation of local molecular vibrations
14	**Aaron Sternbach**, Mengkun Liu, James Hinton, Tetiana Slusar, Alexander McLeod, Martin Wagner, Elsa Abreu, Ruben Iraheta, Fritz Keilmann, Alfred Leitenstorfer, Michael Fogler, Hyuntak Kim, Richard Averitt and Dimitri Basov	UC San Diego	Ultrafast Nano-Infrared Study of the Insulator-to-Metal Transition in Vanadium Dioxide
15	**Alexander S. McLeod**, Erik van Heumen, Juan Gabriel Ramirez, Siming Wang, Thomas Saerbeck, Stefan Guenon, Loic Anderegg, Priscilla Kelly, Andrew Mueller, Mengkun Liu, Ivan K. Schuller and Dimitri N. Basov	UC San Diego	Nano-textured phase coexistence in the correlated insulator V2O3
16	**Clarina Dela Cruz**, Huibo Cao and Youwen Long	Oak Ridge National Laboratory	Multiferroicity in a highly symmetric Cubic perovskite system: LaMn3Cr4O12
17	**Igor Zuitc**, Predrag Lazic and Kirill Belashchenko	University at Buffalo	What Makes Gating Possible in Two Dimensional Heterostructures?
18	**Sean Bearden**, Igor Zutic, Evan Wasner and Jeongsu Lee	UC San Diego	Spin-Lasers: Threshold Reduction, Digital Operation, and Eye Diagrams (Poster, Student)
19	**Yi Chen**, Miguel Ugeda, Aaron Bradley, Yi Zhang, Seita Onishi, Wei Ruan, Claudia Ojeda-Aristizabal, Hyejin Ryu, Mark Edmonds, Hsin-Zon Tsai, Alexander Riss, Sung-Kwan Mo, Dunghai Lee, Alex Zettl, Zahid Hussain, Zhi-Xun Shen and Michael Crommie	UC Berkeley	Characterizing the electronic ground states of single-layer NbSe2 via STM/STS
20	**Hsin-Zon Tsai**, Jiong Lu, Sebastian Wickenburg, Arash A. Omrani, Alexander Riss, Johannes Lischner, Sinisa Coh, Alpin N. Tatan, Liang Z. Tan, Hyungju Oh, Christoph Karrasch, Young-Woo Son, Dillon Wong, Aaron J. Bradley, Miguel M. Ugeda, Han Sae Jung, Ramin Khajeh, Griffin F. Rodgers, Andrew S. Aikawa, Patrick R. Forrester, Erik Piatti, Kenji Watanabe, Takashi Taniguchi, Alex Zettl, Felix R. Fischer, Steven G. Louie, Marvin L. Cohen, Vitor M. Pereira and Michael F. Crommie	UC Berkeley	Spatially-Resolved Molecular Nanostructures at the Surface of a Gated Graphene Device
21	**Ling Miao**	Physical Review X	Physical Review X and Highlights in Quantum Materials Research.

Topological insulators and topological superconductors

S. C. Zhang

Stanford University

In this talk, I will first give a brief overview on topological insulators and superconductors. I will then discuss the recent theoretical prediction and the experimental observation of the quantum anomalous Hall effect in magnetic topological insulators. I shall present a newly predicted material called stanene, and discuss its potential applications. Finally, I shall discuss how the subject could impact our understanding of fundamental laws of physics.

Low energy electrodynamics of topological insulators

N. Peter Armitage

Johns Hopkins University

Topological insulators (TIs) are a recently discovered state of matter characterized by an “inverted” band structure driven by strong spin-orbit coupling. One of their most touted properties is the existence of robust "topologically protected" surface states. I will discuss what topological protection means for transport experiments and how it can be probed using the technique of time-domain THz spectroscopy applied to thin films of Bi_2Se_3. By measuring the low frequency optical response, we can follow their transport lifetimes as we drive these materials via chemical substitution through a quantum phase transition into a topologically trivial regime. I will then discuss our work following the evolution of the response as a function of magnetic field from the classical transport regime to the quantum regime. In the highest quality samples, we observe a continuous crossover from a low field regime where the response is given by semi-classical transport and observed in the form of cyclotron resonance to a higher field quantum regime. In the later case, we find evidence for Faraday and Kerr rotation angles quantized in units of the fine structure constant. This quantized rotation angle can be seen as evidence for a novel magneto-electric of the TI’s surface e.g. the much heralded axion electrodynamics of topological insulators. Among other aspects this gives a purely solid-state measure of fine structure constant. I will also give some perspective on what I believe are interesting directions for the future in the investigation of the electrodynamic response of topological materials.

Hybrid Topological Materials: from Novel Quantum Phases to Spintronics

Nitin Samarth

Pennsylvania State University

We provide a perspective on the emergence of new scientific and technological directions that emerge from the synthesis of complex quantum materials created by interfacing topological insulators with other materials of contemporary importance. Molecular beam epitaxy provides excellent control over the surface states in these materials using quantum confinement effects within a homogeneous thin film [1] as well as using interactions with magnetic dopants [2,3] and at heterogeneous interfaces with superconductors, [4] ferromagnets [5] and oxides [6]. This talk will highlight some of the exciting open questions that remain to be resolved, such as understanding the interplay between edge state transport and magnetism in the quantum anomalous Hall insulator regime [7] and outline future directions, such as the design of new materials that might display robust quantum phases at high temperatures [8].

This work is supported by DARPA, ONR, ARO and by C-SPIN. The work is carried out in collaboration with David Awschalom, Dimitri Basov, Zahid Hasan, Chao-xing Liu, Dan Ralph, Ali Yazdani, Eli Zeldov and Shou-cheng Zhang.

[1] M. Neupane *et al.*, Nature Communications **5**, 3841 (2014).

[2] S.-Y. Xu *et al*., Nature Physics **8**, 616 (2012).

[3] A. Kandala *et al.,* Nature Communications **6**, 7434 (2015).

[4] S.-Y. Xu *et al*., Nature Physics **10**, 943 (2012)

[5] A. Mellnik *et al.*, Nature **511**, 449 (2014).

[6] A. Yeats *et al*., Science Advances (in press, 2015).

[7] E. Lachman *et al*., arxiv:1506.05114

[8] Q.-Z. Wang *et al*., Phys. Rev. Lett. **113**, 147201 (2014).

Can the ‘market’ drive science?

Peter Littlewood

Argonne National Laboratory

We commonly believe that blue sky science generates unexpected technology, and no doubt this is often true, but the process often runs in reverse. In general, the pull of societal needs drives science and technology in complex ways. One impetus that led to modern condensed matter physics – and at least to the eminence over many decades of a leading industrial research laboratory – was the technology need for a solid state amplifier. Quite likely the discovery of the quantum Hall effects was accelerated by the technology pull for faster electronics. Can we find societal needs that at the highest levels drive revolutionary science, rather than incremental engineering? I will discuss some potential opportunities in electrical storage.

Will 2d materials live up to their hype?

Frank Koppens

ICFO – The Institute of Photonic Sciences

The long list of unique properties for graphene and 2d materials have been the major driver for intense scientific research. Interestingly, this combination of unique properties has also been the justification for the advances in the development of technological applications. And this led to skyrocketed expectations that flatland applications will become the next disruptive technology impacting several cornerstones of our society.

However, adopting new materials is considered an inconvenience for most companies, as they prefer to improve existing technologies rather than adopting completely new concepts that require new production processes, new integration strategies and even a new way of thinking. Thus, risk-averse strategies are preferred.

The question arises what aspects of 2d materials can be the starting point to overcome this barrier. The true killer applications may come from an unexpected corner and the crucial material properties may be completely different than the ones that drove the initial scientific interest.

In this talk, recent scientific and technological progress of 2d materials in the context of applications for high societal impact will be highlighted with a critical reflection on the question whether they will live up to their hype.

Why We Need To Replace the Transistor, and What Would be the Newly Required Material Properties?

Eli Yablonovitch

University of California, Berkeley

In contemplating the headlong rush toward miniaturization represented by Moore's Law, it is tempting to think only of the progression toward molecular sized components. There is a second aspect of Moore's Law that is sometimes overlooked. Owing to miniaturization, the energy efficiency of information processing has steadily improved.

But there is an inefficiency for internal communications in a chip. It is caused by the difference in voltage scale between the wires and the transistor switches. Transistors are thermally activated, leading to a required voltage $\gg kT/q$. Wires are long, and they have a low impedance, allowing them to operate efficiently even at a few millivolts. Thus the main Figure-of-Merit for future transistors is low operating voltage or sensitivity, NOT mobility.

The challenge then is to replace transistors with a new low-voltage switch that is better matched to the wires. I will present the new material quantum level properties, which are being explored by the NSF Science & Technology Center for Energy Efficient Electronics Science. http://www.e3s-center.org/

Electronic and Optoelectronic Physics in the van der Waals Heterojunctions

Philip Kim

Harvard University

Recent advance of van der Waals (vdW) materials and their heterostructures provide a new opportunity to realize atomically sharp interfaces in the ultimate quantum limit. By assembling atomic layers of vdW materials, such as hexa boronitride, transition metal chalcogenide and graphene, we can construct novel quantum structures. Unlike conventional semiconductor heterostructures, charge transport of the devices are found to critically depend on the interlayer charge transport, electron-hole recombination process mediated by tunneling across the interface. We demonstrate the enhanced electronic optoelectronic performances in the vdW heterostructures, tuned by applied gate voltages, suggesting that these few atom thick interfaces may provide a fundamental platform to realize novel physical phenomena, such as hydrodynamic charge flows, cross-Andreev reflection across the quantum Hall edges states, and interlayer exciton formation and manipulations.

Interactions in atomically thin semiconductors and heterostructures

Tony F. Heinz

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We discuss recent advances in our understanding of the optical properties of monolayers of the transition metal dichalcogenide (TMDC) materials, including MoS_2, $MoSe_2$, $MoTe_2$, WS_2, WSe_2. These materials share several unusual characteristics, including a transition from an indirect-gap material in the bulk to a direct-gap, emissive material at monolayer thickness. They also exhibit selectivity to excitation of the degenerate K or K' valley under circularly polarized radiation.

In our discussion we will highlight progress in understanding two types of interactions in these materials: the many-body interactions between charge carriers in one layer and interactions between carriers that arise when two monolayer sheets of materials stacked on one another to form a bilayer.

The many-body electronic interactions in monolayer TMDC crystals play a central role in defining their optical properties. Here we will stress recent spectroscopic studies in which we have identified the progression of excited exciton states in precise absorption measurements. This study directly reveals exciton binding energies of several hundred meV. A strongly non-hydrogenic disposition of levels is also observed. The strength of Coulomb interactions is also manifest in high-order excitonic states, including the three-body trion (or charged excitons) and the recently observed four-body biexcitons. Also of note is the possibility of modifying the many-body interactions through carrier doping or through the presence of high densities of excitation.

Another unusual type of interaction associated with these materials concerns the electronic states and transitions expected in stacks of TMDC monolayers. We will present results of studies of the optical response of vertical heterostructures composed of two monolayers the same material (but with an adjustable twist angle) and bilayers of two different crystals. In the latter case, we have identified spectroscopic signatures for rapid charge separation associated with the staggered band structure.

Novel quantum effects in graphene and two dimensional sichalcogenides

Francisco Guinea

Consejo Superior de Investigaciones Científicas (CSIC), Madrid

Graphene and other two dimensional materials provide an excellent platform where novel quantum effects can be observed. We sketch a few examples:

- The nature of the edge states between graphene in the Quantum Hall regime and a superconductor, and the possibility of creating Majorana states.

- The interplay between lattice deformations and electrons in graphene and two dimensional dichalcogenides (TMD´s), and the extreme anharmonicity of graphene membranes.

- Effects due to the spin-orbit coupling in graphene intercalated with Pb, and in the TMD's.

Using van der Waals heterostructures to study 2D materials in the ultraclean limit

James Hone

Columbia University

Two-dimensional materials offer a wide range of outstanding properties but are highly sensitive to disorder from the environment. We have developed techniques to stack 2D materials on top of each other to create 'van der Waals Heterostructures' with nearly perfect interfaces, and to achieve high-quality contacts to the one-dimensional edge of buried layers. These techniques provide an ideal platform to study 2D materials in the ultraclean limit. Recent results in this area will be discussed, including: 1. Near-ideal performance in graphene monolayers and bilayers; 2. Hofstader physics and potential new quantum Hall states in graphene / BN superlattices; 3. Low-T magnetotransport in semiconducting MoS; 4. Ongoing studies of air-sensitive 2D materials.

Change of carrier density at the pseudogap critical point of a cuprate superconductor

Louis Taillefer

University of Sherbrooke & Canadian Institute for Advanced Research

The pseudogap is a partial gap that opens in the normal state of cuprate superconductors whose origin is a long-standing puzzle. Its connection to the Mott insulator at low doping p remains ambiguous and its relation to the charge order that reconstructs the Fermi surface at intermediate p is still unclear. I will report measurements of the Hall coefficient in magnetic fields up to 88 T, which reveal that Fermi-surface reconstruction by charge order in YBCO ends sharply at a critical doping $p = 0.16$, distinctly lower than the pseudogap critical point at $p^* = 0.19$ [1]. This shows that pseudogap and charge order are separate phenomena. I will also report measurements of the Seebeck coefficient in magnetic fields up to 45 T, which reveal a similar separation in a second, very different cuprate, the single-layer material LSCO [2]. In YBCO, we find that the change of carrier density from $n = 1 + p$ at high p to $n = p$ at low p starts at p^* [1]. This sharp loss of 1.0 carrier per Cu atom is a new signature of the pseudogap. I will discuss some possible underlying mechanisms.

[1] S. Badoux *et al*., arXiv:1511.08162 (2015).

[2] S. Badoux *et al*., arXiv:1512.00292 (2015).

Cooper-pair Condensate Visualization: Spatial Symmetry Breaking & Intertwined Orders

J.C. Séamus Davis

Cornell University/ Brookhaven NL / St Andrews University

In theory, Cooper-pairs can exist with finite momentum Q and thereby generate a spatially modulating Cooper-pair density with wavelength 2π/Q. Such a 'pair density wave' (PDW) state has not been observed directly in any superconductor. However, the recent discovery of a charge density wave state in cuprate superconductors has motivated several contemporary microscopic theories in which the cuprate pseudogap phase contains a PDW state.

To study this issue we developed a nanometer resolution, millikelvin operating temperature, scanned Josephson (Cooper-pair) tunneling microscope (SJTM). We image Cooper-pair tunneling from a d-wave superconducting STM tip at millikelvin temperatures to the Cooper-pair condensate of underdoped $Bi_2Sr_2CaCu_2O_8$. We demonstrate its condensate visualization capabilities directly using the Cooper-pair density variations surrounding Zn impurity atoms and those caused by the well known crystal supermodulation in $Bi_2Sr_2CaCu_2O_8$.

We then image the Cooper-pair condensate with nanometer resolution throughout large fields of view for $Bi_2Sr_2CaCu_2O_8$ samples within the pseudogap regime. Unprocessed, these images show clear Cooper-pair density modulations oriented along the Cu-O bond directions. By using Fourier analysis we detect the direct signature of a Cooper-pair density modulation at wavevectors $Q_P \approx (0.25,0)2\pi/a_0;(0,0.25)2\pi/a_0$; the amplitude of these modulations is ~ 5% of the homogeneous amplitude and their form factor exhibits primarily s/s'-symmetry. Such PDW phenomenology for cuprates could be anticipated based on general order-parameter symmetry principles, and is predicted by several contemporary microscopic theories for the cuprate pseudogap phase.

This technique for nanoscale imaging of a Cooper-pair condensate also opens the prospect of condensate visualization in other cuprates, and in pnictides and unconventional superconductors.
M.H. Hamidian and **S.D. Edkins** *et al* **arXiv:1511.08124**

The Superconductor-(Metal)-Insulator Transition in Two Dimensions: A Possible Paradigm for Understanding Quantum Phase Transitions

Aharon Kapitulnik

Stanford University

The conventional picture of possible ground states in a two-dimensional electron gas (2DEG) system, at zero temperature and in the presence of disorder, allows only superconducting or insulating phases (and in magnetic field also quantum Hall liquid phases). Tuning the disorder and/or magnetic field between superconducting and insulating ground states -- the so called superconductor-insulator transition (SIT) -- has received acute attention because they led to exploration of new ground states and appear to be broadly relevant to other canonical QPTs and unsolved puzzles such as unconventional superconductivity in the high-Tc cuprates. In particular, detailed experimental studies of disordered superconducting thin-films near the magnetic-field tuned superconductor-insulator transition (SIT) have revealed several unexpected new ground states for films that otherwise superconduct at zero field. First, in weakly disordered films (with normal state resistivity small compared to the quantum of resistance, the superconducting state gives way to an anomalous metallic phase with a resistivity that extrapolates to a non-zero value as the temperature tends to zero. Second, for highly disordered superconducting films with normal state resistance close to the quantum of resistance a direct SIT occurs at a field Hc, giving way to a bosonic "Cooper pair" insulator. In new experiments, where the longitudinal resistance is supplemented with Hall resistance data, additional information can be obtained about the SIT. Some of the more striking results include: 1) the resistivity tensor at criticality approaches the universal value expected at a point of vortex-particle self-duality, 2) the critical exponents governing the quantum critical behavior appear to be the same as those observed at both the integer and fractional QHIT, and 3) the insulating phase proximate to the SIT appears to be a Hall insulator in which in the limit of zero temperature the longitudinal resistance tends to infinity while the Hall resistance is finite, approaching a value of ~H/nec. These new results shade light on the nature of the SIT and bare important consequences to other QPT in two-dimensional films.

Designing and controlling quantum materials with defects

David Awschalom

Institute for Molecular Engineering, University of Chicago

Our technological preference for perfection can only lead us so far: as traditional transistor-based electronics rapidly approach the atomic scale, small amounts of disorder begin to have outsized negative effects. Surprisingly, one of the most promising pathways out of this conundrum may emerge from recent efforts to embrace materials with controlled defects and construct 'quantum machines' to enable new information technologies based on the quantum nature of the electron and atomic nucleus. Defects in materials have attracted interest as they possess an electronic spin state whose quantum properties can be controlled at and above room temperature. We focus on recent developments and emerging opportunities in engineered quantum materials. An all-optical scheme is used to manipulate and measure geometric phases (Berry phase) in a single spin in diamond [1], investigate its robustness to noise, and explore the foundation for optical geometric manipulation in implementations of photonic networks of quantum states. Surprisingly, quantum states in silicon carbide have long electron spin coherence times [2], can achieve near-unity nuclear polarization at room temperature [3], and reveal robust ensemble entanglement at room temperature [4]. The addressability of individual or ensemble spins in materials amenable to advanced growth and microfabrication techniques is an exciting route to create novel structures for exploring the foundations of quantum mechanics as well as applications including quantum memories, repeaters, and nuclear gyroscopes.

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[2] D. J. Christle, A. L. Falk, P. Andrich, P. V. Klimov, *et al.*, Nature Materials **14**, 160 (2015).

[3] A. L. Falk, P. V. Klimov, *et al.*, Phys. Rev. Lett. **114**, 247603 (2015).

[4] P. V. Klimov, A. L. Falk, D. J. Christle, V. V. Dobrovitski, and D. D. Awschalom, Science Advances **1**, e1501015 (2015)

Graphene photonics

Michal Lipson

Columbia University

Photonics on chip could enable a platform for monolithic integration of optics and microelectronics for applications of optical interconnects in which high data streams are required in a small footprint. Traditional photonic devices have been limited in performance and the need for novel materials that could provide silicon with the electro-optic properties it lacks is now high. I will review the challenges and achievement of graphene-based photonics as a novel nanophotonic material. Graphene has generated exceptional interest as an optoelectronic material because its high carrier mobility, and broadband absorption. Electro-optic graphene modulators reported to date, however, have been limited in bandwidth to a few GHz because of the large capacitance required to achieve reasonable voltage swings. We have recently demonstrated a graphene electro-optic modulator based with drastically increased speed and efficiency. The modulator uniquely uses silicon nitride waveguides, an otherwise completely passive material platform, with promising applications for ultra-low-loss broadband structures and nonlinear optics.

New interface between quantum optics and nanoscience

Mikhail Lukin

Harvard University

We will discuss recent developments at a new scientific interface between quantum optics, nanoscience and quantum information science. Specific examples include the use of quantum optical techniques for manipulation of individual atom-like impurities at a nanoscale and for realization of hybrid systems combining strongly coupled quantum emitters and nanophotonic devices. We will discuss how these techniques are used for realization of quantum nonlinear optics and quantum networks, and for new applications such as magnetic resonance imaging with single atom resolution and nanoscale probing of complex materials.

Imaging Skyrmions and the Spatially Varying Order Parameter in Proximitized HgCdTe Quantum Wells

Amir Yacoby

Harvard University

The interplay between ‘traditional’ phases of mater such as magnetism and superconductivity, and materials with strong spin orbit interaction such as topological insulators and strong spin Hall media has recently led to a surge of new and relatively unexplored phenomena such as stable skyrmionic textures at room temperature, topological superconductivity with localized Majorana modes, superconductivity with controllable triplet pairing and many more. Very often the emergent physics in these systems appears at the physical boundary between the various phases and therefore requires new approaches for exploring and visualizing it. In this talk I will review some of the recent work we have been doing to develop new measurement approaches to such hybrid systems. These include scanning NV magnetometry and Fourier based current imaging techniques that are particularly suitable for unraveling some of the intrinsic competition between the spin and charge degrees of freedom in such systems.

Advancing the state of the art in scanning tunneling microscopy

Abhay Pasupathy

Columbia University

STM is now a well established experimental technique to study the low energy electronic structure of complex layered materials in real space. In this talk, I will discuss ways by which STM technology and methodology can be extended to get new information on materials systems. I will focus on three particular advances made recently in my group - (a) the ability to apply uniaxial strain on materials while measuring their response in the STM (b) a machine-learning based approach to extracting maximal information about scattering from impurities as visualized by the STM and (c) The use of multiprobe geometries to study quasiballistic transport in 2D materials.

"Hot" topics in van der Waals materials

Michael M. Fogler

Department of Physics
University of California, San Diego, La Jolla, CA

Artificial nanostructures can have physical properties not readily found in Nature, in particular, properties that may be far superior or very unusual compared to what the bulk materials exhibit. Van der Waals heterostructures are among the leading candidates to make this Big Idea a reality. I will discuss two examples illustrating how van der Waals materials built by stacking different atomic planes like Lego blocks can provide access to physical phenomena at temperatures that are unusually high for solid-state systems. The first example is our theoretical proposal [1] and the ongoing experimental quest [2] for room-temperature superconductivity of excitons in multilayer structures made of atomically thin metallic chalcogenides and hexagonal boron nitride (hBN). The second example is generation and probing of a "relativistic" electron-hole plasma in hBN-encapsulated graphene irradiated by femtosecond laser pulses [3].

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[3] G. Ni, L. Wang, M. Goldflam, M. Wagner, Z. Fei, A. S. McLeod, M. K. Liu, F. Keilmann, B. Özyilmaz, A. H. Castro Neto, J. Hone, M. M. Fogler, and D. N. Basov, Ultrafast control of plasmon polariton dispersion in high-mobility graphene (submitted to Nature Photonics).

Tuning the Energy Landscape of Graphene through Molecular and Defect Charge Manipulation

Mike Crommie

University of California, Berkeley

The local electronic properties of graphene devices are typically controlled via electrostatic fields arising from metallic gate electrodes. This common technique, however, is limited in its ability to achieve ultra-small feature size (e.g., single nanometer), as well as in its ability to achieve clean, surface-accessible electron confinement geometries. One alternative for engineering the local electronic properties of graphene is the use of single-molecule quantum dots. These can provide atomic-scale structural precision as well as flexible, gate-tunable electronic properties. With this in mind, we have used F_4TCNQ molecules as charge-tunable quantum dots to engineer the potential energy landscape of graphene at the nanoscale. By precisely positioning F_4TCNQ molecules into well-ordered linear arrays we have observed tunable Coulomb charging patterns at the single-molecule level via scanning tunneling microscopy (STM), as well as a new multi-impurity super-critical-like phenomenon. We have additionally used tunable defect charge in insulating substrates to manipulate the nanoscale energy landscape of graphene. This is facilitated by charge manipulation induced via the focused electric field of an STM tip. This new technique allows the patterning of gate-tunable quantum dots whose electronic properties can be imaged.

Emergent Phenomena : Is it only in Correlated Systems?

R. Ramesh

University of California, Berkeley

I was asked to give an after-dinner talk: my first reaction was : I am too young for this!! I was also reminded of a recent talk that Steve Chu gave at Berkeley where the after-dinner talk was “categorized” as coming from one who had gone way beyond credible science and into the domain reserved for other segments of our community (you can take a guess!). Dmitri asked me to “entertain” the group as well as talk about my experience in Washington. I took this cue and so my talk will focus on why I took on the Sunshot Director role, what was accomplished by an amazing team with your tax-dollars (if you are from the US of A and do pay taxes here!!) and lessons learnt. Sunshot is a good example of how federal R&D can be focused on solving BIG, “Mission Impossible” problems, while doing science all the way. Of course, the definition of science here is broader than just the science of photovoltaics. I hope to convince you that there are “emergent phenomena” at the macro-scale, paralleling the ones we work on at the electronic scale.

STM insights into topological insulators

V. Madhavan

University of Illinois at Urbana-Champaign

Topological crystalline insulators are recently discovered topological materials where topology and crystal symmetry intertwine to create relativistic massless Dirac electrons. Due to the importance of crystalline symmetry in generating and protecting the Dirac surface states, the topological states in these materials are expected to be highly sensitive to local structure. In this talk I will discuss how local disorder and strain influence the properties of topological crystalline insulators. In particular I will show that the Dirac point is surprisingly robust against short-range random disorder but sensitive to long-range coherent distortions that break mirror symmetry. I will also show how the effects of uniaxial strain in this system are counterintuitive and strongly influenced by the orbital nature of the bands.

Evidence for the chiral anomaly in Dirac and Weyl semimetals

N. P. Ong

Princeton University

In field theory, an anomaly is the breaking of a classically-allowed symmetry by purely quantum effects. The most famous example is the chiral anomaly, which is the breaking of chiral symmetry (handedness) in massless Dirac particles by the Adler-Bell-Jackiw mechanism (turning on the coupling to electromagnetic fields). In 1983, Nielson and Ninomiya predicted that massless Dirac electrons in a crystal should exhibit the chiral anomaly as an axial current associated with negative longitudinal magnetoresistance. I will describe results on the topological Dirac semimetal Na3Bi which show effects of the chiral anomaly. I will also describe the chiral anomaly in the presence of a thermal gradient.

Smoking gun signatures of 3D Weyl fermions and hidden Dirac fermions in the half filled landau level

Ashvin Vishvanath

University of California, Berkeley

I will review experimental signatures in magnetotransport and in quantum oscillations, related to the chiral anomaly and fermi arc surface states that characterize Weyl fermions. I will also briefly mention a remarkable recent development that associates a Dirac character with composite fermions of the half filled landau level.

Musings about strategies for searching for high temperature superconductors

M. Brian Maple

University of California, San Diego

Prior to ~1980, most superconducting materials were believed to be s-wave BCS superconductors in which electron pairing is mediated by phonons. However, during the past 3-1/2 decades, four major classes of correlated electron materials have been discovered that exhibit an unconventional type of superconductivity, often with d-wave symmetry and a nodal gap, in which the electron pairing appears to be mediated by magnetic excitations: heavy fermion *f*-electron materials, organic conductors, layered copper oxides (cuprates), and iron pnictides/chalcogenides. The maximum values of T_c that have been observed are ~2 K for heavy fermion compounds, ~20 K for organic conductors, ~130 K for layered cuprates ($HgBa_2Ca_2Cu_3O_8$), and ~56 K for iron pnictides/chalcogenides ($SmFeAsO_{1-x}F_x$). The layered cuprates and the Fe-based pnictides/chalcogenides, which have the highest values of T_c, generally have crystal structures that consist of conducting layers (CuO_2 layers for the cuprates and Fe*Pn* or Fe*Ch* layers for the Fe pnictides/chalcogenides) separated by so-called "blocking layers" that act as charge reservoirs and control the charge carrier concentration within the conducting layers. This new type of unconventional superconductivity is frequently found to emerge from a magnetically ordered phase (usually antiferromagnetic, but sometimes ferromagnetic) that is suppressed upon chemical substitution x or application of pressure P. The curve of T_c vs x or P has a "dome shape" that occurs in the vicinity of the critical values x_c or P_c where the magnetic order is suppressed towards 0 K. These attributes can be used to generate a new set of empirical rules for developing strategies for searching for new superconducting materials, analogous to "Matthias' rules" that have been used to guide searches for conventional superconductors. The application of very high pressures has been found to induce superconductivity in many elements in the periodic table (23, to date), some with relatively high values of T_c around 20 K at pressures in the 100 GPa range (Li, Ca, Sc, Y, S). The current record value of T_c achieved under pressure is ~165 K at ~30 GPa for the cuprate $HgBa_2Ca_2Cu_3O_8$. Drozdov, Eremets and Troyan recently reported a value of T_c ~ 190 K for H_2S at a pressure of ~150 GPa, although this result has not been confirmed by other researchers. Another promising approach would be to exploit interfaces between different compounds in multilayer structures. Even if such interfaces are not atomically smooth, rearrangements of atoms in the interface regions could generate new structures, which are favorable to superconductivity. Although the search for high T_c superconductors has been largely based on enlightened empiricism, theoretical approaches that are currently under development are expected to play an increasingly important role in this endeavor in the future.

Control of collective quantum phenomena in metal-oxide superlattices

Bernhard Keimer

Max Planck Institute-Stuttgart

A grand challenge in the field of correlated-electron physics is the transition from conceptual understanding of collective ordering phenomena to their control and design. We will outline an experimental program designed to meet this challenge through the synthesis and characterization of metal-oxide superlattices, with particular emphasis on copper and nickel oxides. Oxide molecular-beam epitaxy allows the synthesis of metal-oxide superlattices in with monolayer precision. We will show how polarized photon-based methods such as resonant elastic and inelastic x-ray scattering and Raman scattering can be used to obtain a comprehensive description of the electron system in these systems, and outline perspectives for control of their phase behavior by modifying the occupation of transition metal d-orbitals, the dimensionality of the electron system, and the electron-phonon interaction.

Recent Progress on FeSe superconductors

Zhi-Xun Shen

Department of Physics and Applied Physics
Stanford University

We will present recent progress on the FeSe superconducting monolayer on STO surface. We will discuss the physics that boosts the superconducting transition temperature, and the superconducting gap anisotropy that put constraints on the pairing symmetry of this superconducting system. We will also discuss the phase diagram by tuning the material with electron doping.

Capturing dynamics and function in quantum materials using tabletop coherent X-rays

M. Murnane

University of Colorado Boulder

Meeting Dirac's Challenge: Modern Materials Theory In and Out of Equilibrium

Andrew Millis

Columbia University

Almost a century ago, PAM Dirac established the theoretical framework for understanding the physics of electrons in solids, writing ``the fundamental laws necessary for the mathematical treatment…[of condensed matter physics]…are known…. the difficulty lies only in the fact that these laws lead to equations too complex to be solved. It therefore becomes necessary that approximate practical methods of applying quantum mechanics should be developed". The last decade has seen spectacular progress towards meeting Dirac's challenge. In this talk I will summarize what has been achieved (with emphasis on the conceptual developments), indicate some of the scientific doors that have been opened, and delineate some of the important open issues.

Switching quantum materials properties with light

Alessandra Lanzara

University of California, Berkeley

The recent advancements in laser technology have dramatically expanded the applications of lasers to table top experiments in condensed matter physics. Femtosecond time-resolved spectroscopy techniques are emerging tools in the study of quantum materials, offering new paths to disentangle coexisting phases with similar energy scale, selectively tune a specific phase across a quantum critical point and create hidden states that do not exist in equilibrium, to name a few. In this talk I will present some of our work where ultrafast light is used to investigate the superconducting and pseudogap state in cuprates and to drive manipulate spin texture in
topological insulators and will discuss future directions in the field.

Measurements under extreme conditions

Gregory Boebinger

National High Magnetic Field Laboratory

Research probing the biggest of the Big Ideas in Quantum Materials often motivates the performance of experiments under extreme conditions:

1. low temperatures that minimize thermal fluctuations, to explore complex phase diagrams of competing correlated electronic ground states;

2. high pressures that tune orbital overlap or exchange couplings, to access quantum phase transitions and probe quantum criticality that might accompany those transitions; and

3. high magnetic fields that boggle the mind due to their importance in the study of Big Ideas in Quantum Materials. After all, a magnetic field is a thermodynamic vector quantity that can be applied to the sample *in situ,* in a reversible and flexible way, infinitely tunable in both magnitude and orientation.

A survey of item 3 will dominate this presentation. Jokes will most likely be told.

Mode-selective coherent control of the solid state

Andrea Cavalleri

Max Planck Institute-Hamburg and Oxford University

In this talk I will discuss how the nonlinear excitation of lattice vibrations with coherent electromagnetic transients can be used to create new crystal structures and to dynamically modulate the properties of some quantum solids. Specifically, I will discuss how in some cases one can control the tilt angle of certain bonds, changing the electronic bandwidth and inducing insulator-metal phase switching. I will also discuss new experiments in which different modes are mixed nonlinearly, creating unconventional states in which the lattice is made to rotate and time-reversal invariance can be broken. Finally, I will reflect on the possibility of dynamically modulating the electronic properties and on the role that this appears to exert on many body coherence in various materials.

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