Nobel Symposium 156

New forms of matter: topological insulators and superconductors

Scientific Program

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Friday morning, June 13 – Topological Insulators I

09:00 - 09:15	Opening address
09:15 - 10:00	M.Z. Hasan (Princeton University, USA) *Topological Insulators: A New Form of Quantum Matter*
10:00 - 10:30	L. Molenkamp (Würzburg University, Germany) *HgTe, a Topological Insulator in 2 and 3 Dimensions*
10:30 - 11:00	Coffee break
11:00 - 11:30	Q.-K. Xue (Tsinghua University, China) *Experimental realization of quantum anomalous Hall effect*
11:30 - 12:00	S.C. Zhang (Stanford University, USA) *Topological insulators and topological superconductors*
12:00 - 12:30	L. Fu (Massachusetts Institute of Technology, USA) *Topological crystalline insulators*

Friday afternoon, June 13 – Topological Insulators II

14:00 - 14:45	E.J. Mele (University of Pennsylvania, Philadelphia, USA) *The winding road to topological insulators*
14:45 - 15:15	T. Neupert (Princeton University, USA) *Fractional Chern Insulators*
15:15 - 15:45	Coffee break
15:45 - 16:15	C. Chamon (Boston University, USA) *Fractional Topological Insulators*
16:15 - 16:45	A. Altland (Univeristy of Cologne, Germany) *Quantum criticality of the one dimensional topological Anderson insulator*
16:45 - 17:00	Short break
17:00 - 17:30	A. Stern (Weizmann Institute of Science, Israel) *Non-abelian physics between one and two dimensions*

Saturday morning, June 14 – One-dimensional systems and Majorana fermions I

09:00 - 09:45	J. Alicea (California Institute of Technology, USA) *Majorana Materializes*
09:45 - 10:15	C.W.J. Beenakker (Leiden University, The Netherlands) *Super-Ohmic conduction of edge modes in topological insulators and superconductors*
10:15 - 10:45	Coffee break
10:45 - 11:15	F. von Oppen (Free University Berlin, Germany) *Topological superconducting phase in helical Shiba chains*
11:15 - 11:45	M. Heiblum (Weizmann Institute of Science, Israel) *Proliferation of neutral modes in fractional quantum Hall states*
11:45 - 12:15	H.Q. Xu (Lund University, Sweden) *Majorana fermions in topological superconductor nanowires*

Saturday afternoon, June 14 – General Theory

14:00 - 14:45	A.W.W. Ludwig (University of California, Santa Barbara, USA) *Topological Phases: Classification of non-interacting topological insulators and superconductors, and beyond*
14:45 - 15:15	F.D.M. Haldane (Princeton University, USA) *"Quantum Geometry" and Topological Insulators*
15:15 - 15:45	Coffee break
15:45 - 16:15	T.L. Hughes (University of Illinois, Urbana-Champaign, USA) *Interplay between Symmetry and Geometry in Topological Phases*
16:15 - 16:45	S. Ryu (University of Illinois, Urbana-Champaign, USA) *Generalized Laughlin's argument for symmetry protected topological phases*
16:45 - 17:00	Short break
17:00 - 17:30	M.R. Zirnbauer (Univeristy of Cologne, Germany) *Bott periodicity for Z_2 symmetric ground states of gapped free-fermion systems with disorder*
17:30 - 18:00	X.-L. Qi (Stanford University, USA) *Layer construction of three-dimensional topological states*

Sunday morning, June 15 – One-dimensional systems and Majorana fermions II

09:00 - 09:45	C.M. Marcus (University of Copenhagen, Denmark) *Hard-gap superconductor-semiconductor devices and topological superconductivity*
09:45 - 10:15	C.L. Kane (University of Pennsylvania, Philadelphia, USA) *Topological Superconductivity and the Fractional Josephson Effect*
10:15 - 10:45	Coffee break
10:45 - 11:15	A. Yazdani (Princeton University, USA) *Visualizing Topological Quantum States: From Dirac edge states to Majorana zero modes*
11:15 - 11:45	A. Vishwanath (University of California, Berkeley, USA) *Beyond Band Insulators: Weyl semimetals and Strongly Interacting Topological Phases*
11:45 - 12:15	S. Das Sarma (University of Maryland, USA) *Has (the) Majorana really returned?*

Sunday afternoon, June 15 – Panel session

14:00 - 14:30	B.A. Bernevig (Princeton University, USA) *Topological Insulators Without Spin-Orbit Coupling*
14:30 - 15:00	N. Read (Yale University, USA) *Chiral topological phases and entanglement*
15:00 - 15:15	Short break
15:15 - 15:45	F. Wilczek (Massachusetts Institute of Technology, USA) *Entangled Histories*
15:45 - 16:15	G.E. Volovik (Aalto University, Finland) *From Standard Model of particle physics to room-temperature superconductivity*
16:15 - 16:45	Coffee break
16:45 - 17:45	*Panel discussion*
17:45 - 18:00	Closing remarks

Abstracts

J. Alicea (California Institute of Technology, USA)
Title: Majorana Materializes
Abstract: The 1937 theoretical discovery of Majorana fermions has since impacted diverse problems ranging from neutrino physics and dark matter searches to the quantum Hall effect and superconductivity. In condensed matter, the search for these elusive objects is fueled by the exotic form of exchange statistics that they underpin, which in turn leads to applications for fault-tolerant quantum information processing. In this talk I will provide an overview of some ingenious proposals for "engineered" Majorana platforms and discuss the experiments that they have inspired. I will also describe proposals of a similar spirit that can be used to stabilize even more exotic excitations including parafermions and Fibonacci anyons.

A. Altland (Univeristy of Cologne, Germany)
Title: Quantum criticality of the one dimensional topological Anderson insulator
Abstract: In the presence of even weak amounts of disorder, low dimensional topological band insulators turn into topological Anderson insulators (tAI). Translational invariance being absent, the tAI must be described by concepts different from the clean limit band structures classification schemes. In this talk we argue that much of the universal physics of the tAI is contained in the system size dependent flow of two parameters, the first of which is an average transport coefficient (at any finite size, the tAI is a conductor), and the second the mean value of a now statistically distributed topological index. These two parameters exhibit flow similar to that of the Pruisken-Khmelnitskii flow diagram of the quantum Hall insulator. Specifically, the flow describes describes quantum criticality at topological phase transitions, the approach towards an insulating configuration away from criticality, and, along with it, the emergence of a self averaging integer index. For some symmetry classes, that flow can be established in closed analytic form. However, we argue that the overall picture is of more general validity and provides a unified framework to describe both the bulk and the surface physics of the topological Anderson insulator.

C.W.J. Beenakker (Leiden University, The Netherlands)
Title: Super-Ohmic conduction of edge modes in topological insulators and superconductors
Abstract: Dissipationless edge currents are a striking feature of topological protection in two-dimensional (2D) systems. First discovered in connection with the Landau levels of the quantum Hall effect in a strong magnetic field, they are now known to exist also in the presence of time-reversal symmetry (for topological insulators) or particle-hole symmetry (for topological superconductors). The edge current can carry charge or heat, it can be uni-directional (chiral) or bi-directional (helical), but in each manifestation there is no backscattering – so that the corresponding electrical or thermal conductance is quantized, independent of system size.
When the symmetry that provides the topological protection is broken by disorder, backscattering is no longer forbidden and dissipation sets in. Still, localization may be avoided if the symmetry is preserved on average. We present this scenario for an anistropic 2D superconductor with spin-triplet p-wave pairing and (chiral or helical) Majorana edge modes. The statistical translational symmetry of random disorder drives the edge to the critical point of the Kitaev Hamiltonian, characterized by a super-Ohmic scaling with system size of the thermal conductance.

B.A. Bernevig (Princeton University, USA)
Title: Topological Insulators Without Spin-Orbit Coupling
Abstract: The topological insulators discovered up to now either require time reversal symmetry or spin-orbit coupling (or have chiral edge modes). We find the first-known 3D topological insulators without spin-orbit coupling, and with surface modes that are protected only by point groups, i.e., not needing time-reversal symmetry. To describe these systems, which have rotation axes and mirror planes, we introduce the notions of (a) a halved mirror chirality: an integer invariant which characterizes half-mirror planes in the 3D Brillouin zone, and (b) a bent Chern number: the traditional TKNN invariant generalized to bent 2D manifolds. We find that a Weyl semimetallic phase intermediates two gapped phases with distinct mirror halved chiralities.

C. Chamon (Boston University, USA)
Title: Fractional Topological Insulators
Abstract: The prediction and experimental discovery of topological band insulators and topological superconductors are recent and remarkable examples of how topology can characterize phases of matter. In these examples, electronic interactions (beyond mean-field) do not play a fundamental role. In this talk I shall discuss cases where interactions lead to phases of matter of topological character. Specifically, I shall discuss fractional topological states in lattice models which occur when interacting electrons propagate on fractionally filled flattened Bloch bands in the presence of spin-orbit coupling. These interacting models can display time-reversal symmetric phases, with fractionalized excitations in the bulk, with or without gapless edge modes. If time-reversal symmetry is spontaneously broken, a fractional quantum Hall effect can emerge, possibly at high temperatures. Finally, I discuss the possible applications of these types of states and the possible routes and hurdles to their experimental realization.

S. Das Sarma (University of Maryland, USA)
Title: Has (the) Majorana really returned?
Abstract: In my talk I will explain the meaning of the question posed in the title and provide an answer for the question through a critical theoretical analyses of the recent experiments searching for the non-Abelian Majorana mode in condensed matter systems. I will also describe the significance of the question/answer discussed in this talk in the context of topological quantum computation which is fault-tolerant as a matter of principle and does not require any quantum error correction.

L. Fu (Massachusetts Institute of Technology, USA)
Title: Topological crystalline insulators

F.D.M. Haldane (Princeton University, USA)
Title: "Quantum Geometry" and Topological Insulators
Abstract: "Quantum geometry" (the absence of "classical locality" after projection into a flat band) plays a key role in giving rise to topologically-ordered incompressible fractional quantum Hall states when the "flat bands" are Landau levels, with non-commuting Landau-orbit guiding-centers. It likewise plays a key role in a fractional Chern insulator (FCI), where, after projection, there is a fundamental intrinsic (uncorrectable) non-orthogonality between the more-than-one orbitals per unit cell in a projected topologically-non-trivial flat band with only one independent state per unit cell. It is this intrinsic non-orthogonality (which induces a non-trivial "quantum distance" between orbitals) that is responsible for producing incompressible liquid states (as opposed to crystalline solid states) of electrons in an FCI. A related intrinsic non-orthogonality of the surface states of symmetry-protected topological band-insulators may lead to surface topological order with unbroken time-reversal symmetry in the presence of strong interactions at the surface.

M.Z. Hasan (Princeton University, USA)
Title: Topological Insulators : A New Form of Quantum Matter
Abstract: In this talk I briefly review the basic concepts defining topological insulators and elaborate on the key experimental results that revealed and established their (symmetry protected or Z2) topological nature. I then present key experimental results that demonstrate magnetism, Kondo insulation, mirror chirality and superconductivity in topological insulator settings and how these new phases of matter arise through topological quantum phase transitions from conventional (textbook) band insulators via Dirac semimetals. I conclude by briefly outlining the future experimental directions, potential applications and visions of the field.

M. Heiblum (Weizmann Institute of Science, Israel)
Title: Proliferation of neutral modes in fractional quantum Hall states
Abstract: The fractional quantum Hall effect (FQHE) is a canonical example of a topological phase in a correlated 2D electron gas under strong magnetic field. With electric currents propagating as chiral downstream edge modes, chiral upstream neutral edge modes were recently observed only in hole-conjugate states (namely, $n+1/2 < \nu < n+1$, with n=0,1,2,...), and in the even-denominator state ν=5/2. It is believed that spontaneous 'density reconstruction' near the edges of the 2D gas leads to multiple counter propagating edge channels; however, unavoidable disorder induces inter-channel tunneling, accompanied by Coulomb interaction, to renormalize the multiple edge channels to a downstream charge mode and upstream neutral edge mode(s). Here, I report of highly sensitive shot noise measurements that revealed unexpected presence of neutral modes in a variety of non-hole-conjugate fractional states, but not in any of the integer states. In addition to the upstream neutral edge modes, we were surprised to also find neutral energy modes that propagate through the incompressible bulk. While along the edge, density reconstruction may account for the edge modes, we are not aware of a model that can account for the bulk modes. The proliferation of neutral modes, in every tested fractional state, changes drastically the accepted picture of FQHE states: an insulating bulk and 1D chiral edge channels. The apparent ubiquitous presence of these energy modes may (partly) account for decoherence of fractional quasiparticles - preventing observation of coherent interference in the fractional regime.

T.L. Hughes (University of Illinois, Urbana-Champaign, USA)
Title: Interplay between Symmetry and Geometry in Topological Phases
Abstract: In this talk I will discuss new developments that illustrate the interplay between topology, geometry, and symmetry in topological phases of matter. I will discuss the classification of some topological insulator/superconductor phases via their spatial symmetries and the consequences for topological defects such as disclinations and dislocations. Additionally, I will show how spatial symmetries can protect quantized topological responses in topological insulator phases. If time permits, I will discuss how interactions can generate a spatial protected topological phase in a symmetry class which only has trivial phases in the non-interacting limit.

C.L. Kane (University of Pennsylvania, Philadelphia, USA)
Title: Topological Superconductivity and the Fractional Josephson Effect
Abstract: Topological Superconductivity is a topic of current interest because of its potential for providing a new method for storing and manipulating quantum information. One of the most basic consequences of topological superconductivity is the fractional Josephson effect, which arises due to the coherent tunneling of single electrons between two superconductors, leading to an AC Josephson effect with half the usual Josephson frequency. In this talk we will review the theoretical foundations for the fractional Josephson effect and discuss prospects for observing it. We will then describe recent work in which we have clarified the role of time reversal symmetry. Time reversal symmetric Josephson junctions are classified by two distinct Z_2 topological invariants. One of these characterizes a junction mediated by the edge states of a quantum spin Hall insulator. In that case, we showed that electron interactions stabilize a "Z_4 fractional Josephson effect" with one quarter the usual Josephson frequency. For strong interactions this Josephson effect is associated with the tunneling of charge $e/2$ quasiparticles. For weak tunneling, this theory describes a fourfold ground state degeneracy that is similar to that of coupled "fractional" Majorana modes, but is protected by time reversal symmetry.

A.W.W. Ludwig (University of California, Santa Barbara, USA)
Title: Topological Phases: Classification of non-interacting topological insulators and superconductors, and beyond

C.M. Marcus (University of Copenhagen, Denmark)
Title: Hard-gap superconductor-semiconductor devices and topological superconductivity
Abstract: This talk presents recent transport studies of epitaxial superconductor-semiconductor hybrid InAs nanowires, demonstrating a hard induced gap and low quasiparticle density. Status of majorana end state measurements in these novel materials will be presented. Research supported by the DNRF Basic Research Foundation and Microsoft Corporation.

E.J. Mele (University of Pennsylvania, Philadelphia, USA)
Title: The winding road to topological insulators
Abstract: This talk will review progress in the classification of insulating states of matter, focusing on the unique properties of topological insulators and their discovery from a careful consideration of the low energy electronic physics of single-layer graphene. Physical realizations in two dimensional spin-orbit coupled semiconductors and in three dimensional materials will be discussed.

L. Molenkamp (Würzburg University, Germany)
Title: HgTe, a Topological Insulator in 2 and 3 Dimensions
Abstract: HgTe is a zincblende-type semiconductor with an inverted band structure. While the bulk material is a semimetal, lowering the crystalline symmetry opens up a gap, turning the compound into a topological insulator. The most straightforward way to do so is by growing a quantum well with (Hg,Cd)Te barriers. Such structures exhibit the quantum spin Hall effect, where a pair of spin polarized helical edge channels develops when the bulk of the material is insulating. Our transport data[1-3] provide very direct evidence for the existence of this third quantum Hall effect, which now is seen as the prime manifestation of a 2-dimensional topological insulator. To turn the material into a 3-dimensional topological insulator, we utilize growth induced strain in relatively thick (ca. 100 nm) HgTe epitaxial layers. The high electronic quality of such layers allows a direct observation of the quantum Hall effect of the 2-dimensional topological surface states[4]. Gating experiments show that these states appear to be decoupled from the bulk, and that their Dirac points can be tuned by the gate voltage. These observations open the route experimental investigations of proximity effects in the surface states. E.g., it proves possible to induce a robust supercurrent by contacting these structures with Nb electrodes [5], which could pave a road towards observing exotic superconductivity.
[1] M. König et al., Science 318, 766 (2007).
[2] A. Roth et al., Science 325, 294 (2009).
[3] C. Brüne et al., Nature Physics 8, 486 (2012).
[4] C. Brüne et al., Phys. Rev. Lett. 106, 126803 (2011).
[5] L. Maier et al, Phys. Rev. Lett. 109, 186806 (2012); J.B. Oostinga et al., PRX 3, 021007 (2013).

T. Neupert (Princeton University, USA)
Title: Fractional Chern Insulators
Abstract: Fractional Chern insulators are topologically ordered states of matter that arise in a class of lattice models of strongly interacting fermions or bosons. They share many of their universal properties with fractional quantum Hall states of interacting electrons in a strong magnetic field, but occur at zero external magnetic field. Based on numerical exact diagonalization results, I will characterize them via their quasiparticle excitations, their neutral magnetoroton excitation and their entanglement spectra. I will then highlight in which sense fractional Chern insulators depart form fractional quantum Hall physics and finally discuss prospects for their experimental realization.

F. von Oppen (Free University Berlin, Germany)
Title: Topological superconducting phase in helical Shiba chains
Abstract: Magnetic impurities in a superconducting host induce localized subgap (or Shiba) states. Chains of such Shiba states are a promising venue for topological superconductivity, especially when the magnetic moments develop helical order due to spin interactions mediated by the superconducting substrate. In this talk, I will discuss the resulting topological superconducting phases and their Majorana end states.

X.-L. Qi (Stanford University, USA)
Title: Layer construction of three-dimensional topological states
Abstract: Topological states and topologically ordered states have been studied extensively in two spatial dimensions (2D). On comparison, topological states in 3D are much less understood. In this talk, I will describe a generic construction of 3D topological states starting from stacked layers of two-dimensional topological states. Different topological states can be constructed, including states that are topologically ordered in the bulk, and those which are topologically ordered only at the surface. As a new feature that is intrinsically different from the 2D case, we show that there can be loop particles with nontrivial mutual braiding. We discuss the field theory description and generic properties of the loop braiding statistics.

N. Read (Yale University, USA)
Title: Chiral topological phases and entanglement

S. Ryu (University of Illinois, Urbana-Champaign, USA)
Title: Title: Generalized Laughlin's argument for symmetry protected topological phases
Abstract: We generalize Laughlin's flux insertion argument in a way that it is applicable to topological phase protected by symmetries such as unitary on-site symmetry and parity symmetry. We formulate it as a gappability/ingappablity condition of non-chiral gapless edge theories that appear at an edge of a bulk symmetry-protected topological phase.

A. Stern (Weizmann Institute of Science, Israel)
Title: Non-abelian physics between one and two dimensions

A. Vishwanath (University of California, Berkeley, USA)
Title: Beyond Band Insulators: Weyl semimetals and Strongly Interacting Topological Phases
Abstract: I will discuss new developments that go beyond the 'band insulator' paradigm of topological states, which is based on free fermions with a bulk energy gap. First, I will discuss topological aspects of three dimensional Weyl and Dirac semimetals, where the bulk gap vanishes but nevertheless exotic surface states in the form of Fermi arcs are predicted. Physical probes of these surface states, particularly their unusual quantum oscillation fingerprint, will be emphasized. In the second part I will discuss novel phenomena in strongly interacting topological phases, where one cannot invoke a single particle band structure. A new surface termination of 3D topological insulators and superconductors - surface topological order - that is both gapped and symmetry preserving will be introduced and utilized to show that interactions significantly modify the free electron based classification of these phases.

G.E. Volovik (Aalto University, Finland)
Title: From Standard Model of particle physics to room-temperature superconductivity
Abstract: Topological media are gapped or gapless fermionic systems, whose properties are protected by topology, and thus are robust to deformations of the parameters of the system and generic. We discuss here the class of gapless topological media, which contains normal metals, chiral superfluid 3He-A, graphene, cuprate superconductors, Weyl semimetals and quantum vacuum of Standard Model in its symmetric phase. These media have zeroes in the fermionic energy spectrum, which form Fermi surfaces, Weyl points, Dirac lines, etc. Zeroes are topologically protected, being characterized by topological invariants, expressed in terms of Green's function.
Vacua with Weyl points serve as a source of effective relativistic quantum field theories (QFT) emerging at low energy: chiral fermions, effective gauge fields and tetrad gravity with spin connection and torsion emerge together in the vicinity of a Weyl point. The accompanying effects (chiral anomaly and gravitational anomaly; chiral magnetic effect and chiral vortical effect; electroweak baryo-production, etc.) are expressed via symmetry protected topological invariants. Systems with degenerate Weyl or Dirac points may have Dirac fermions with nonlinear spectrum: instead of conical point they have quadratic, cubic, quartic, etc. touching of branches. Such systems experience emergent QFT with anisotropic scaling and serve as a source for the emergent quantum gravity of Horava-Lifshitz type.
The gapless topological media exhibit the bulk-surface and bulk-vortex correspondence: they have exotic gapless fermions living on the surface of the system or within the core of topological defects, where they form Fermi arc or flat band. Flat band appears in particular on the surface of semimetals with nodal lines in bulk: all electrons within the flat band have exactly zero energy. This property crucially influences the critical temperature of the superconducting transition in such media. While in all the known superconductors the transition temperature is exponentially suppressed as a function of the pairing interaction, in the flat band the transition temperature is proportional to the pairing interaction, and thus can be essentially higher. So topology gives us the general recipe for the search or artificial fabrication of the room-temperature superconductors.

F. Wilczek (Massachusetts Institute of Technology, USA)
Title: Entangled Histories
Abstract: The consistent histories approach to quantum theory invites consideration of a bigger Hilbert space – history space – and a wider class of observables than is usually considered in quantum theory. It leads naturally to the consideration of history observables, and of entangled histories. These are very natural to consider in anyon physics, and also in the description of radiation fields. I will define these concepts, some of which are new, and give examples and applications.

H.Q. Xu (Lund University, Sweden)
Title: Majorana fermions in topological superconductor nanowires
Abstract: We report on the observation of the signatures of Majorana fermions in topological superconductor nanowire quantum devices made from high crystal-quality InSb nanowires and superconductor Nb contacts. The InSb nanowires are known to have excellent physical properties [1-3] and have therefore been considered as one of the most promising material systems for realizing topological superconductor systems in which Majorana fermions can be created. In a fabricated device, an InSb nanowire quantum dot is formed between the two Nb contacts by Schottky barriers. Due to the proximity effect, the InSb nanowire segments covered by superconductor Nb contacts turn to superconductors with a superconducting energy gap ?* [4]. Under an applied magnetic field larger than a critical value for which the Zeeman energy in the InSb nanowire is Ez ?*, the entire InSb nanowire is found to be in a nontrivial topological superconductor phase, supporting a pair of Majorana fermions, and Cooper pairs can transport between the superconductor Nb contacts via the Majorana fermion states. This transport process will be suppressed when the applied magnetic field becomes larger than a second critical value at which the transition to a trivial topological superconductor phase occurs in the system. This physical scenario has been observed in our experiment [4]. We have also found that the measured zero-bias conductance for our hybrid devices shows a conductance plateau in a range of applied magnetic fields in quasiparticle Coulomb blockade regions [4]. Our work provides a simple, solid way of detecting Majorana fermions in solid state systems and should greatly stimulate Majorana fermion research and applications.
The author acknowledges collaborations with Mingtang Deng, Chunlin Yu, Guangyao Huang, Marcus Larsson, and Philippe Caroff for this work.
[1] H. A. Nilsson, P. Caroff, C. Thelander, M. Larsson, J. B. Wagner, L.-E. Wernersson, L. Samuelson, and H. Q. Xu. Nano Lett. 9, 3151 (2009).
[2] H. A. Nilsson, O. Karlström, M. Larsson, P. Caroff, J. N. Pedersen, L. Samuelson, A. Wacker, L.-E. Wernersson, and H. Q. Xu. Phys. Rev. Lett. 104, 186804 (2010).
[3] H. A. Nilsson, P. Samuelsson, P. Caroff, and H. Q. Xu, Nano Lett.12, 228-233 (2012).
[4] M. T. Deng, C. L. Yu, G. Y. Huang, M. Larsson, P. Caroff, and H. Q. Xu, Nano Lett. 12, 6414?6419 (2012); arXiv:1204.4130 (2012).

Q.-K. Xue (Tsinghua University, China)
Title: Experimental realization of quantum anomalous Hall effect
Abstract: Anomalous Hall effect (AHE) was discovered by Edwin Hall in 1880. Since the late 1980's, theories have been proposed for realizing the quantized version of AHE, the quantum anomalous Hall (QAH) effect. By breaking time-reversal-symmetry with magnetic doping of Cr into three dimensional topological insulator (Bi,Sb)2Te3 thin films grown by molecular beam epitaxy, we have experimentally observed the QAH effect at 30 mK. At zero magnetic field, the gate-tuned anomalous Hall resistance exhibits a quantized value of h/e2 accompanied by a significant drop of the longitudinal resistance. The longitudinal resistance vanishes under magnetic field whereas the Hall resistance remains at the quantized value. The realization of the QAH effect paves a way for exploring exotic quantum phenomena in condensed matter and for developing lower-power-consumption electronics.

A. Yazdani (Princeton University, USA)
Title: Visualizing Topological Quantum States: From Dirac edge states to Majorana
Abstract: Topological quantum states are characterized by the presence and novel properties of their boundary modes. Using scanning tunneling microscopy and spectroscopy we have not only visualized the presence of edge states for three-dimensional and two-dimensional topological insulators, but have probe some their exotic properties such as absence of backscattering or unusual transmission through strong barriers. [1-4] I will describe these experiments, as well as more recent efforts focused to realize a topological superconducting phase in nanometer-sized atomic chains fabricated on the surface of a superconductor. [5] These experiments show strong signatures of Majorana fermions zero modes at the end of these chains and suggest possible novel ways in which these exotic topological excitations can be manipulated.
[1] P. Roushan et al. Nature 460 1106 (2009).
[2] J. Seo et al. Nature, 466 434 (2010).
[3] H. Beidenkpof et al. Nature Physics, (2011).
[4] I. Drozdov et al. arXiv:1404.2598 (2014).
[5] S. Nadj-Perge et al. PRB 88, 020407(R) (2013).

S.C. Zhang (Stanford University, USA)
Title: Topological insulators and topological superconductors
Abstract: In this talk, I will first give a brief overview on topological insulators and superconductors, and review the theoretical predictions which led to the experimental observations of the 2D and 3D topological insulators. 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 number of proposed new materials for topological insulators and superconductors, and discuss their potential applications. Finally, I shall discuss how the subject could impact our understanding of fundamental laws of physics.

M.R. Zirnbauer (Univeristy of Cologne, Germany)
Title: Bott periodicity for Z_2 symmetric ground states of gapped free-fermion systems with disorder
Abstract: Building on the symmetry classification of disordered fermions, we give a proof of the proposal by Kitaev, Ludwig, and others, for a "Bott clock" topological classification of disordered ground states of gapped free-fermion systems with symmetries. Our approach differs from previous ones in that (i) we work in the standard framework of Hermitian quantum mechanics over the complex numbers, (ii) we directly formulate a mathematical model for ground states rather than spectrally flattened Hamiltonians, and (iii) we use homotopy-theoretic tools instead of K-theory. Key to our proof is a natural transformation relating the ground state of a d-dimensional system in symmetry class s to the ground state of a (d+1)-dimensional system in symmetry class s+1. This relation gives a new vantage point on topological insulators and superconductors. (Joint work with R. Kennedy)

Participants

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