“An open world of physics: A celebration of Sankar Das Sarma’s research career on his 60th birthday”

Saturday **March 16** and Sunday **March 17, 2013***

Venue **University of Maryland**

*This is the weekend prior to the 2013 APS March meeting in Baltimore, which might allow some participants the convenience of combining the two meetings into one trip

Confirmed Speakers

Eugene Demler, Harvard, Massachusetts **Matthew Fisher,** UCSB, California **Michael Freedman,** Microsoft, California **Steve Girvin,** Yale, Connecticut **Bert Halperin,** Harvard, Massachusetts **Philip Kim,** Columbia, New York **Klaus von Klitzing,** Stuttgart, Germany **Leo Kouwenhoven,** Delft, Netherlands **Tony Leggett,** UIUC, Illinois **Allan Macdonald,** UT-Austin, Texas **Charlie Marcus,** Copenhagen, Denmark **Andy Millis,** Columbia, New York **Bill Phillips,** NIST and UMD College Park, Maryland **Aron Pinczuk,** Columbia, New York **Subir Sachdev,** Harvard, Massachusetts **Amir Yacoby,** Harvard, Massachusetts **Peter Zoller,** Innsbruck, Austria

Organizing Committee

Shaffique Adam, Yale-NUS College, Singapore
Janet Das Sarma, University of Maryland
Victor Galitski, University of Maryland
Jainendra Jain, Pennsylvania State University
Chetan Nayak, UCSB, California
XinCheng Xie, Peking University, China

http://terpconnect.umd.edu/~galitski/SDS_Workshop/

An Open World of Physics

March 16 - 17
2013

A celebration of Sankar Das Sarma's research career on his 60th birthday

Program

University of Maryland
College Park, MD

Organizing Committee:

Shaffique Adam, Yale-NUS College, Singapore
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CMTC

Students and postdocs mentored by Sankar Das Sarma:

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SATURDAY, MARCH 16, 2013
MORNING AGENDA

8:00am - 9:00am **Breakfast & Registration (Grand Ballroom Lounge)**

9:00am - 9:15am **Welcome (Grand Ballroom)**

Jayanth Banavar, Dean, College of Computer, Mathematical and Natural Sciences, University of Maryland

Session 1 (Grand Ballroom)
Chair: Jainendra Jain, Pennsylvania

9:15am - 9:55am Klaus von Klitzing, Stuttgart, Germany
News from Quantum Hall Effect

9:55am - 10:35am Bill Phillips, NIST, Maryland
Atomic Physics Meets Condensed Matter

10:35am - 11:00am **Coffee Break (Grand Ballroom Lounge)**

11:00am - 11:40am Subir Sachdev, Harvard, Massachusetts
Entanglement, Holography and the Quantum Phases of Matter

11:40am - 12:20pm Andy Millis, Columbia, New York
"First-principles" Theory of Correlated Electrons: DFT+DMFT and the Mott Paradigm in Transition Metal Oxides

12:20pm - 1:45pm **Lunch (Colony Ballroom)**

Saturday, March 16, 2013
Afternoon Agenda

Session 2 (Grand Ballroom)
Chair: Shaffique Adam, Singapore

1:45pm - 2:25pm — Philip Kim, Columbia, New York
Ultimate Conductivity Limit in Graphitic Carbon

2:25pm - 3:05pm — Leo Kouwenhoven, Delft, Netherlands
Majorana in Nanowires

3:05pm - 3:30pm — **Coffee Break (Grand Ballroom Lounge)**

3:30pm - 4:10pm — Tony Leggett, UIUC, Illinois
The Berry Phase of a Quasiparticle in a Rotating Fermi Superfluid

4:10pm - 4:50pm — Allan MacDonald, UT Austin, Texas
Landau Level Mixing and Interactions in the Fractional Quantum Hall Effect

4:50pm - 5:30pm — Bert Halperin, Harvard, Massachusetts
Fractional Quantized Hall States in the Zeroth Landau Level of Graphene

6:00pm - 9:30pm — **Banquet Dinner (Colony Ballroom)**

Cocktail hour begins at 6:00pm; dinner begins at 6:30pm
Steve Girvin, Master of Ceremonies

Banquet Dinner Speakers (in order of appearance):

John Quinn (University of Tennessee)
Vic Korenman (University of Maryland)
Bob Joynt (University of Wisconsin)
Steve Girvin (Yale University)
Rodolfo Jalabert (University of Strasbourg, France)
Mike Stopa (Harvard University)
Michael Fisher (University of Maryland)
Chetan Nayak (UCSB/Microsoft)

Mike Lilly (Sandia National Labs)
Ady Stern (Weizmann Institute, Israel)
Vito Scarola (Virginia Tech)
David Reilly (University of Sydney, Australia)
Shaffique Adam (Yale-NUS College, Singapore)
Roman Lutchyn (Microsoft Research)
Drew Baden (University of Maryland)

SUNDAY, MARCH 17, 2013
AGENDA

8:00am - 9:00am **Breakfast & Registration (Grand Ballroom Lounge)**

Session 3 (Grand Ballroom)
Chair: Chetan Nayak, California

9:00am - 9:40am Matthew Fisher, UCSB, California
A 3D Boson Topological Insulator and the Statistical Witten Effect

9:40am - 10:20am Michael Freedman, Microsoft, California
Fusion of Topological Wires as a Computational Primitive

10:20am - 10:45am **Coffee Break (Grand Ballroom Lounge)**

10:45am - 11:25am Amir Yacoby, Harvard, Massachusetts
Quantum Information Processing and Metrology Using Few Electron Spins in Solids

11:25am - 12:05pm Charlie Marcus, Copenhagen, Denmark
The Resonant Exchange Qubit

12:05pm - 1:30pm **Lunch (Colony Ballroom)**

Session 4 (Grand Ballroom)
Chair: Victor Galitski, Maryland

1:30pm - 2:10pm Peter Zoller, Innsbruck, Austria
Quantum Simulation of Non-Abelian Lattice Gauge Theories with Cold Atoms

2:10pm - 2:50pm Eugene Demler, Harvard, Massachusetts
Exploring Topological States with Cold Atoms and Photons

2:50pm - 3:15pm **Coffee Break (Grand Ballroom Lounge)**

3:15pm - 3:55pm Aron Pinczuk, Columbia, New York
Magnetorotons in Fractional Quantum Hall Liquids

3:55pm - 4:35pm Steve Girvin, Yale, Connecticut
Quantum Engineering (Really) Big Schrödinger Cats

4:35pm - 4:50pm Closing remarks by Sankar Das Sarma

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NOTES

SHUTTLE TRANSPORTATION AND PARKING INFO

Shuttle between the Marriott Greenbelt Hotel and Stamp Student Union

Saturday, March 16th

Morning Schedule
Departs the Marriott at 7:45am and arrives at the Student Union at 8:00am
Departs the Marriott at 8:00am and arrives at the Student Union at 8:15am
Departs the Marriott at 8:15am and arrives at the Student Union at 8:30am

Evening Schedule
Departs the Student Union at 9:00pm
Departs the Student Union at 9:30pm

Sunday, March 17th

Morning Schedule
Departs the Marriott at 8:00am and arrives at the Student Union at 8:15am
Departs the Marriott at 8:15am and arrives at the Student Union at 8:30am
Departs the Marriott at 8:30am and arrives at the Student Union at 8:45am

Evening Schedule
Departs the Student Union at 5:00pm
Departs the Student Union at 5:15pm

Parking Information

Option 1: Pay Stations in Union Lane Garage

Union Lane Garage is equipped with pay stations to purchase parking in increments of 15 minutes, hours, or the whole day.

There are pay stations located at the pedestrian entrances/exits to the garage. You can pay for time with a credit card or cash at any of the pay stations or with a credit card only by calling 888-580-PARK [7275].

1. Park in garage.
2. Take note of your space number.
3. Make payment.
4. Optional: Add additional time later either at a pay station or by using your cell phone.

The pay stations will issue a paper receipt for your records, which you do not need to display in your vehicle.

Note: Pay stations do not issue change.

Hours of Enforcement: 7 am to 2 am, seven days a week
Rates: $3 per hour, with a $5 per weekend day maximum.

Option 2: Free Parking In Lot 1

Anytime on Saturday and Sunday, visitors may park for free in Lot 1, the large surface lot just beyond the Cole Fieldhouse. Lot 1 is a 5-10 minute walk from the Stamp Student Union.

SUMMARY OF CMTC MAJORANA WORKSHOP IN COLLEGE PARK OCT 29/30, 2016

DAY 1: Current Status of Majorana Nanowires

Consensus items:

Although varying definitions of `topological' and 'trivial' were discussed, there seemed to be general agreement that alternate explanations for ZBCP that do not involve Majoranas in some way (e.g. Kondo physics) are inconsistent with the totality of the observed ZBCP behavior. This leaves open the possibility of multiple Majorana or Majorana-like modes near the wire end. One suggested mechanism for such multiple-Majorana physics was an inhomogeneous potential within the wire. Another possibility mentioned was disorder, including possibly in the parent superconductor. It was pointed out that signatures looking for bulk topological phase transition such as heat conductance and bulk gap closure could be an independent check to identify bulk topological order.

Open questions:

What governs the height, width, and line shape of the ZBCP? Temperature and dissipation were raised as possibilities. For instance, why is the peak width still of order 20 micro-eV? Is it purely a thermal or dissipative effect? How much should one worry about the fact that many of the presented experimental ZBCPs are less than a factor of 20 of the quantized Majorana value?

It was pointed out that ZBCPs in realistic nanowires could arise from multiple- nearby MZMs (essentially equivalent to an Andreev state) of non-topological origin (i.e. no non-Abelian braiding statistics) which could smoothly go over to localized MZMs with topological properties. This crossover is not easily distinguishable in tunneling experiments. Perhaps this could be the origin for the weird ZBCP line shapes seen in some experiments.

What governs the observed particle-hole asymmetry? It was suggested that this asymmetry may result from dissipative effects, and therefore, the samples observed to have better p-h symmetry (presumably with less dissipation) may be better suited for TQC. It is not clear that braiding will succeed if dissipation is strong. Interaction was also mentioned as a possibility for p-h asymmetry.

There was considerable discussion on possible source(s) for dissipation. It was generally agreed that intrinsic dissipation is not a good thing here, particularly in the context of achieving TQC. It appears that the best simulation fits to the best current experimental ZBCP data necessarily require the presence of finite dissipation on a phenomenological level since pure thermal effects lead to finite ZBCP peak height and width, but cannot explain the p-h symmetry breaking. Also, the observed ZBCP height/width is smaller/larger than that implied just by the experimental temperature.

What leads to the observed (lack of) oscillating splitting with increasing amplitude in magnetic field? One suggested mechanism was a `squeezing' effect due to level repulsion from above-gap energy levels as the bulk gap closes due to increased magnetic field. Another was the possibility of the observed splitting coming from nearby overlapping Majoranas at the wire end. The possibility of coupling through the bulk SC as a reason for suppressed MZM oscillations was mentioned and debated also. Finally, it is not known what role Coulomb interactions might play in suppressing (or enhancing) these oscillations. The generic lack of MZM oscillations in NS tunneling measurements was discussed and possible reasons suggested were multiple MZMS, large SO-coupling, disorder, dissipation, and image charge effect. Also not discussed extensively (but mentioned in the Introduction to the conference) is the lack of end-to-end correlations in the experimental Majorana wires, which may be connected with the lack of MZM oscillations.

There was a lot of discussion on the recent Copenhagen finding of topologically protected MZM oscillations in the Coulomb blockaded regime of Inas/Al nanowires. The non-increasing amplitude of these oscillations with increasing magnetic field remains a mystery in spite of considerable theoretical efforts in understanding the observation. Furthermore, it is also a mystery that in the experiment, the parity sometimes does not switch as the two peak spacings are closed, but the theoretical prediction is that parity should always switch due to the Majorana hybridization. Various possibilities were suggested including coupling through the parent superconductor, complicated trajectories through density-chemical potential landscape with increasing magnetic field, and perhaps accidental end Andreev state induced oscillations. There was a feeling that the observed nature of these oscillations (i.e. amplitude not increasing with increasing magnetic field) probably cannot be explained simply by using a magnetic field induced proximity gap which is collapsing-- in fact, such a procedure by itself produces the opposite effect of further enhancing the oscillation amplitude with increasing magnetic field.

Why is the gap consistently softer in the region where ZBCPs are observed? Is this observed softness purely due to the width of the observed zero-bias peak (often comparable to the induced gap) or are there additional soft modes (e.g. from disorder- or inhomogeneity-induced fermionic states)? It was pointed out that there is no obvious gap region in many of the experimentally topological regimes (i.e. with ZBCP) - rather a minimum between two peaks. Other suggested possibilities included Griffiths physics or superconductor-induced disorder.

The effect of the orientation of the applied magnetic on the existence (or not) of the ZBCP still remains a somewhat open experimental issue, perhaps because of orbital effects of the applied field.

What is the full role of orbital effects in this system? One suggestion was an anisotropic g-factor. Simulations including full 8-band Kohn-Luttinger model may be necessary to understand quantitative details.

What is the best/most practical signature of a bulk gap closure? Suggestions ranged from thermal conductance measurements to ARPES. Can a trijunction be used to probe the bulk spectrum?

All experiments to date have been conducted in wires for which the proximitized region is around a micron in length or smaller. Finite-size effects (both on the topological phase transition and the Majoranas themselves) may still be quite significant in such systems, putting one in a somewhat murky regime where topological and trivial physics remains rather smoothly connected. It could be that some of the outstanding issues would be resolved by going to significantly longer wires. Doing so will certainly be necessary anyway for longer-term applications (e.g. for TQC applications discussed on Day 2 which would eventually need long wires keeping the end MZMs far from each other). On the other hand, longer wires are more susceptible to inhomogeneous potential and disorder effects (both intrinsic disorder in the wire and SC-induced disorder) possibly leading to problems, so the situation is not completely clear. Perhaps experiments should be carried out both in much longer and much shorter wires to discern various issues.

Day 2: Future TQC in Majorana nanowires

Consensus items:

Even if `Fusion' and 'Braiding' experiments do not succeed in producing results consistent with non-Abelian Ising anyons, they can provide valuable information characterizing the nanowire systems that is unavailable from conductance measurements into the wire ends. For instance, the 'Fusion'-type experiment may be able to constrain the value of the Majorana splitting further than transport experiments by varying the time taken to cut the system with a tunnel barrier. Cutting speeds slow on the scale of the splitting produce deterministic results, while those fast compared with the splitting produce probabilistic results. There was a definite consensus that such fusion/braiding/qubit experiments should now begin in earnest even if not all the questions for Day 1 are answered yet.

Experimentalists have requested `User Manual' summaries for device proposals as the devices and the experimental protocols are becoming increasingly complex.

There appears to be tentative experimental consensus toward moving forward with a box-qubit-like device. Advantages include having all nanowires colinear and avoiding complications associated with complex Josephson junction engineering. Challenges include engineering phase coherence in the `reference' arms or in any wires required to run perpendicular to the nanowires. One disadvantage of box qubits over transmon based proposals is that the range of distance over which qubits can be entangled through a single measurement is expected to be shorter.

If Majorana-based qubits reach the same level of stability as other superconducting qubits, but do not have much greater stability, it may still be advantageous to replace SC qubits with MZM based ones in a surface code implementation due to the ease with which stabilizer operators may be measured in an arrangement of MZM qubits. This seems to be still some time in the future.

Significant materials/modeling challenges remain in building working MZM-based TQC elements. There is a serious need for experiment/theory/modeling to work together here.

As a matter of nomenclature, ‘teleportation’ was deemed an inaccurate portrayal of the process of hopping one electron onto a TSC region at one MZM and another off the TSC region near a second MZM. Single electron coherent transport (SECT) was suggested as a replacement for ‘teleportation’ in this context.

<u>Open questions:</u>

If dissipation broadening is of order 200mK, as may be indicated by particle-hole asymmetry in tunneling measurements, will braiding work?

How long does it take to measure a qubit in each proposed measurement scheme (quantum dot/resonator setups, conductance measurements, etc.). How susceptible is each scheme to an error in the Hamiltonian or environmental decoherence?

How should the Josephson microwave measurements be interpreted? Why is no bulk gap closure observed and only an ordinary Andreev state observed (is it possibly connected with multiple MZM story discussed on Day 1)?

When an additional symmetry is introduced, such as time-reversal symmetry or reflection combined with time-reversal symmetry, the symmetry class is changed. The 1D superconducting chain can host multiple Majorana bound states on one end protected by the additional symmetry. Observing these multiple states without breaking the symmetry in an experiment is still an open question.   Will braiding work at all in this situation, or in other words, can fusion/braiding help answer these questions?