Quantum Transport in Topological Materials

XXIV International Summer School 'Nicolas Cabrera'

September 4-8, 2017
Miraflores de la Sierra

SCHEDULE AND BOOK OF ABSTRACTS

UNIVERSIDAD AUTONOMA DE MADRID

IFiMaC

Instituto Universitario de Ciencia de Materiales Nicolás Cabrera

With the collaboration of:

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GREETINGS!

Dear participant,

We are delighted to present to you the XXIV International Summer School Nicolás Cabrera on "Quantum Transport in Topological Materials", funded by Fundación BBVA.

Topological materials constitute an exciting and very active research area in condensed matter physics. It studies new states of matter whose bulk properties are similar to those of 'ordinary' materials but that, at the same time, display edge or boundary states with very exotic properties. Since the discovery of topological insulators, roughly a decade ago, the field has rapidly expanded with the identification of other topological materials, such as topological superconductors and Weyl semimetals.

This Summer School will gather leading international experts to provide an introduction to the basic concepts underlying topology in condensed matter systems, followed by a discussion of recent developments, with a focus on quantum transport and hybrid devices. The goal is to cover not only theoretical aspects, but to also address the experimental progress, including the detection and manipulation of states associated with these materials.

We sincerely hope that you enjoy it!

The Organizers:

Eduardo Lee — eduardo.lee@uam.es
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SCHEDULE

	MONDAY 4th	TUESDAY 5th	WEDNESDAY 6th	THURSDAY 7th	FRIDAY 8th
9:00	Opening				
9:30-10:30	Recher	Oreg	Cortijo	Egger	Aguado
10:30-11:30	Ensslin	Zhang	Felser	Nichele	De Franceschi
11:30-12:00	COFFEE	COFFEE	COFFEE	COFFEE	COFFEE
12:00-13:00	Guéron	Klinovaja	Goffman	San-Jose	López
13:00-15:30	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
15:30-16:30	Schäfer	Ryu	**EXCURSION AND CONFERENCE DINNER**	Csonka Suderow	
16:30-17:00	COFFEE	COFFEE		COFFEE	
17:00-17:30	Stehno	Arrachea		Free time	
17:30-18:00	von Oppen	Stanescu			
18:00-18:30		**Poster Session A**		**Poster Session B**	
	Free time				
20:00	DINNER	DINNER		DINNER	

LEGEND
TUTORIAL Theory (55 + 5 min)
TUTORIAL Experiments (55 + 5 min)
SEMINAR (28 + 2 min)

	Monday 4th
9:00	**Openning**
9:30-10:30	**Patrik Recher** *Topological Insulators: Classification and transport signatures*
10:30-11:30	**Klaus Ensslin** *Introduction to InAs/GaSb and topological insulators*
11:30-12:00	COFFEE
12:00-13:00	**Sophie Guéron** *Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry*
13:00-15:30	LUNCH
15:30-16:30	**Jörg Schäfer** *Novel Quantum Spin Hall Paradigm in 2D Honeycomb Layers: Bismuthene*
16:30-17:00	COFFEE
17:00-17:30	**Martin Stehno** *The fractional Josephson effect in topological insulators: concepts and experiments*
17:30-18:30	**Felix von Oppen** *Color code quantum computing with Majorana bound states*
18:30	**Free time**
20:00	DINNER

	Tuesday 5th
9:30-10:30	**Yuval Oreg** *Superconducting topological phases, theory and application*
10:30-11:30	**Hao Zhang** *Quantized Majorana conductance plateau*
11:30-12:00	COFFEE
12:00-13:00	**Jelena Klinovaja** *Majorana fermions and parafermions in low-dimensional systems*
13:00-15:30	LUNCH
15:30-16:30	**Shinsei Ryu** *Many-body topological invariants for topological insulators and superconductors*
16:30-17:00	COFFEE
17:00-17:30	**Liliana Arrachea** *Fractional spin and Josephson effect in time-reversal-invariant topological superconductors*
17:00-17:30	**Tudor Stanescu** *Low-energy conductance of semiconductor-superconductor hybrid structures*
18:00	**Poster Session A**
20:00	DINNER

	Wednesday 6th
9:30-10:30	**Alberto Cortijo** *Physical properties of Weyl and Dirac semimetals: a theoretical perspective*
10:30-11:30	**Claudia Felser** *Weyl semimetals: Topology from a materials perspective*
11:30-12:00	COFFEE
12:00-13:00	**Marcelo Goffman** *Circuit Quantum Electrodynamics to address Andreev States*
13:00-15:30	LUNCH
16:00	EXCURSION AND CONFERENCE DINNER

	Thursday 7th
9:30-10:30	**Reinhold Egger** *Majorana box qubits and topological quantum computing*
10:30-11:30	**Fabrizio Nichele** *Majorana modes in superconducting InAs/Al two-dimensional heterostructures*
11:30-12:00	COFFEE
12:00-13:00	**Pablo San-Jose** *Overview of MathQ, a Mathematica simulator for quantum systems*
13:00-15:30	LUNCH
15:30-16:00	**Szabolcs Csonka** *Non-local probing of superconducting quantum dots via Yu-Shiba-Rusinov-state in Cooper pair splitter*
16:00-16:30	**Hermann Suderow** *Millikelvin scanning tunneling spectroscopy: electronic features of semimetals and putative topological superconductors at very low energies*
16:30-17:00	COFFEE
17:00-18:00	**Free time**
18:00	**Poster Session B**
20:00	DINNER

	Friday 8th
9:30-10:30	**Ramón Aguado** *Majorana nanowires coupled to quantum dots*
10:30-11:30	**Silvano De Franceschi** *Charge-localization vs ballistic transport in 1D semiconductor nanostructures for topological superconductivity*
11:30-12:00	COFFEE
12:00-13:00	**Rosa López** *Thermoelectrical transport in Majorana-Kondo systems*
13:00	LUNCH

INVITED CONTRIBUTIONS

Ramón Aguado (ICMM-CSIC, Madrid, Spain)

Majorana nanowires coupled to quantum dots

An interacting quantum dot coupled to a superconducting contact is an artificial analogue of a quantum impurity in a superconductor. The physics of such hybrid device is governed by the fermionic parity and spin of the two possible ground states, doublet or singlet (and their corresponding Shiba sub-gap excitations). After an introduction on the physics of Shiba excitations in superconductors, I will explain what happens when this paradigmatic model is generalised to the case where the superconductor becomes topological. Such a quantum dot-topological superconductor junction can be experimentally realised by e. g. creating quantum dots at the end of epitaxial hybrid semiconductor-superconductor nanowires.

As I will argue, the hybridisation between Shiba states in the dot and Majoranas in the nanowire show specific and measurable spectral features that arise from the interplay of these states. Interestingly, these features are enough to fully characterise the spin structure of the Majorana wavefunction, the degree of Majorana non-locality and the Majorana splitting. Thus, quantum dots used to perform spectroscopy of a Majorana nanowire are a powerful probe into the quantum structure of Majorana bound states and constitute an interesting alternative to other techniques for Majorana detection that will be discussed in other lectures during the school.

Alberto Cortijo (ICMM-CSIC, Madrid, Spain)

Physical properties of Weyl and Dirac semimetals: a theoretical perspective

Weyl semimetals are three dimensional metallic systems endowed with nontrivial topological structures. Contrary to other topological media, in the Weyl semimetals these topological structures enter in some dissipative transport properties, allowing for a direct observation in current transport (and optical) experiments. In fact, many of topologically related transport phenomena were originally suggested in the context of high energy physics, but they find their realization in condensed matter. In this tutorial we will review these topological transport properties from a theoretical perspective.

Silvano De Franceschi (CEA, Grenoble, France)

Charge-localization vs ballistic transport in 1D semiconductor nanostructures for topological superconductivity

One-dimensional (1D) semiconductor nanostructures with strong spin-orbit coupling are investigated as a promising material system for the realization of topological superconductivity. This exotic state of matter, which is characterized by the emergence of zero-energy Majorana edge modes, is expected to occur provided certain key requirements are simultaneously met. To begin with, the semiconductor nanostructure needs to be 1D, and at most only moderately disordered. Secondly, the application of magnetic field should open an energy window – so-called helical gap - where the 1D system is effectively spin-less. Understanding the 1D properties of semiconductor nanowires under relatively high magnetic fields is therefore crucial for experimental research on Majorana fermions. In this lecture I will present a set of experiments addressing this important issue.

INVITED CONTRIBUTIONS

Reinhold Egger (Heinrich Heine University, Duesseldorf, Germany)

Majorana box qubits and topological quantum computing

Mesoscopic superconducting islands with Majorana bound states have been proposed for the implementation of a topologically protected qubit, where the charging energy of the island plays a key role. In this talk, I will discuss this Majorana box qubit proposal in detail and outline its potential for topological quantum computation.

Klaus Ensslin (ETH, Zürich, Switzerland)

Introduction to InAs/GaSb and topological insulators

Band inversion in InAs/GaSb quantum wells occurs, because the conduction band of InAs lies below the valence band of GaSb. Coupling of neighboring electron and hole wave functions leads to a hybridization gap which can be tuned to a trivial gap by appropriate gate voltages. This material systems has been predicted to be a 2D topological insulator. In this tutorial we will discuss what possible experimental signatures of topological behaviour are, how edge transport can be detected and how an inverted band structure can be resolved in the experiment. Furthermore we show that spin-orbit interactions can dominate Landau level spectra. Also these unable systems can be fabricated into a lateral p-n junction, similar to graphene, but with quite different electronic properties.

INVITED CONTRIBUTIONS

Claudia Felser (Max Planck Institute for Chemical Physics, Dresden, Germany)

Weyl semimetals

Topology a mathematical concept became recently a hot topic in condensed matter physics and materials science. The topology of the electronic structure determines the electronic, thermal and magnetic properties of solids. Classically, we know insulators, semimetals and metals, determined by their band gaps and electronic structure. However, all known materials can be reclassified through the lens of topology. Topological insulators, Weyl and Dirac Semimetals and topological metals are a new quantum state of matter, which have attracted interest of condensed matter science and materials science. Surprising new properties such as protected surface states in topological insulators, extremely low conductivities, giant charge career mobilties and magneto resistance effects were predicted and experimentally realized in many compounds. Tunable families of compounds such as Heusler compounds, binary phosphides and chalcogenides allows for a design of these new properties and their systematic study. One important criteria for the identification of the material is in the language of chemistry the inert pair effect of the s-electrons in heavy elements and the symmetry of the crystal structure [1]. Beside of Weyl and Dirac new fermions can be identified via linear and quadratic 3-, 6- and 8- band crossings stabilized by space group symmetries [2].

Binary phoshides are the ideal material class for a systematic study of Dirac and Weyl physics. Weyl points, a new class of topological phases was also predicted in NbP, NbAs. TaP, MoP and WP2. [3-7]. Some of the Weyl semimetals were tested for catalysis [8], and have shown excellent performance. All this materials show exceptional properties such as high conductivity (higher than copper), high mobilties and a high magneto-resistance effect. Recently we found that hydrodynamic might count for these properties [9].

[1] B Bradlyn et al., Nature in print preprint arXiv:1703.02050
[2] B. Bradlyn, et al., Science 353, aaf5037A (2016).
[3] C. Shekhar, et al., Nature Physics 11, 645 (2015)
[4] Z. K. Liu, et al., Nature Mat. 15, 27 (2016)
[5] L. Yang, et al., Nature Physics 11, 728 (2015)
[6] C. Shekhar, et al. preprint arXiv:1703.03736
[7] N. Kumar, et al. preprint arXiv:1703.04527
[8] C. R. Rajamathi, et al. Advanced Materials 29 1606202 (2017)
[9] J Gooth et al., Nature in print, arXiv:1703.03736

Marcelo Goffman (CEA, Saclay, France)

Circuit Quantum Electrodynamics to address Andreev States

In this tutorial, I will introduce circuit quantum electrodynamics as a tool to detect and manipulate Andreev states engineered in superconducting weak links. In particular, I will present in detail experiments on the simplest case: a single-atom weak link, where only two spin-degenerate Andreev levels takes place. The last part of this tutorial will be devoted to discuss how this technique could be useful to address the topological case.

INVITED CONTRIBUTIONS

Sophie Guéron (Université Paris Sud Orsay, France)

Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry

Reducing the size of a conductor usually decreases its conductivity because of the enhanced effect of disorder in low dimensions, leading to diffusive transport and to weak, or even strong localization. Notable exceptions occur when topology provides protection against disorder. For instance in the recently discovered two-dimensional Topological Insulators, perfect spin-momentum locking should forbid backscattering along the edge states, and lead to ballistic conduction. In this talk, I will present a direct signature of ballistic 1D transport along the topological surfaces of a single crystal bismuth nanowire connected to superconducting electrodes. This signature was obtained by exploiting the extreme sensitivity of the supercurrent-versus-phase relation (CPR). The sharp sawtooth-shaped CPR we find demonstrates that transport occurs ballistically along two edges of the nanowire, and confirms the predicted nearly perfect transmission of Cooper pairs through Quantum Spin Hall edge states. In addition, we show that a magnetic field can induce 0-pi transitions and phi_0-junction behavior, providing a way to manipulate the phase of the supercurrent-carrying edge states and generate spin supercurrents.

Reference:

Murani et al, Ballistic edge states in Bismuth nanowires revealed by SQUID interferometry
Nature Communications 8, Article number: 15941 (2017), doi:10.1038/ncomms15941

Jelena Klinovaja (University of Basel, Switzerland)

Majorana fermions and parafermions in low-dimensional systems

Topological phases in quantum condensed matter systems have been at the center of attention over the past decade and have become one of the most rapidly developing subjects. I will review recent progress on topological states in low-dimensional systems such as Majorana fermions and parafermions. The focus of my talk will be on Rashba nanowires with proximity gap which can be brought into the topological phase by tuning external magnetic field or chemical potential. I will discuss spin and charge of the bulk quasiparticle states when passing through the topological transition for open and closed systems. The spin of bulk states around the topological gap reverses its sign when crossing the transition due to band inversion, independent of the presence of Majorana fermions in the system. This spin reversal can be considered as a bulk signature of topological superconductivity that can be accessed experimentally and is robust against random static and magnetic disorder. I will discuss how such signatures can be measured experimentally with STM tips [2] or in transport measurements via a quantum dot tunnel-coupled to the nanowire [3,4]. I am also going to discuss proximity effect both for 1D and 2D both analytically and numerically [5].

[1] P. Szumniak, D. Chevallier, D. Loss, and J. Klinovaja, arXiv:1703.00265.
[2] D. Chevallier and J. Klinovaja Phys. Rev. B 94, 035417 (2016).
[3] S. Hoffman, D. Chevallier, D. Loss, and J. Klinovaja, arXiv:1705.03002.
[4] S. Hoffman, C. Schrade, J. Klinovaja, and D. Loss, Phys. Rev. B 94, 045316 (2016).
[5] C. R. Reeg, J. Klinovaja, and D. Loss, arXiv:1701.07107.

INVITED CONTRIBUTIONS

Rosa López (University of Baleares, Spain)

Thermoelectrical transport in Majorana-Kondo systems

TBA

Fabrizio Nichele (Niels Bohr Institute, Copenhagen, Denmark)

Majorana modes in superconducting InAs/Al two-dimensional heterostructures

Majorana zero modes have received widespread attention due to their potential to support topologically protected quantum computing. Emerging as zero-energy states in one-dimensional semiconductors with induced superconductivity, Zeeman coupling, and spin-orbit interaction, Majorana modes have been primarily investigated in individual InSb or InAs nanowires, including recently realized epitaxial hybrid nanowires. Tests of non-Abelian statistics of Majoranas involve braiding or interferometric measurement, requiring branched geometries, which are challenging to realizing using nanowire growth. Scaling to large networks using arrays of assembled nanowire also appears difficult.

I will present investigations of Majorana zero modes in devices obtained from a two-dimensional heterostructure using top-down lithography and gating. Measurements indicate a hard superconducting gap, ballistic tunneling probes and in-plane critical fields up to 3 T. In the presence of an in-plane magnetic field aligned along the wire, zero energy states robust in field emerge out of coalescing Andreev bound states, indicative of Majorana zero modes.

We study the scaling of zero-bias conductance peaks as a function of magnetic field, tunnel coupling, and temperature. Results are consistent with theory for Majorana modes, including a peak conductance that is proportional to tunnel coupling, saturates at 2,e-2./ħ, decreases as expected with field-dependent gap, and collapses onto a simple scaling function in the dimensionless ratio of temperature and tunnel coupling.

These results suggest that the small ZBPs previously reported are not necessarily incompatible with MZMs if they were obtained in a regime where the ratio of temperature to broadening was small. Scalable top-down fabrication of high quality Majorana devices readily allows complex geometries and large networks, paving the way toward applications of Majorana devices.

Yuval Oreg (Weizmann Institute of Science, Israel)

Superconducting topological phases, theory and application

In this talk, I will give a brief overview of topological phases of the field of the 2006 Nobel laureates. Particularly, theories of superconducting topological phases in general and their practical realization in 1D will be discussed. I will describe the current experimental progress in the fabrication and the observation of Majorana Zero Mode at the ends of topological superconducting wires and their emergence as a key element for future quantum topological computation. Finally, I will discuss theoretical and experimental challenges in the quest for novel topological states of matter.

INVITED CONTRIBUTIONS

Patrik Recher (TU Braunschweig, Germany)

Topological Insulators: Classification and transport signatures

Topological insulators are insulators in the bulk but possess robust metallic surface states protected by time-reversal symmetry. The robustness of these states is routed in the topology of the system characterized by a topological index, a global property of the bandstructure, that can only take integer values. This is in contrast to phases of matter that are described by a local order parameter that can take continuous values. In my tutorial, I will introduce the concept of topological insulators and its characterization. Using the so called bulk-boundary correspondence we can predict interesting massless and spin-helical Dirac surface states that have unique transport properties and applications in fields reaching from spintronics to topological quantum computing. I will also present experimentally relevant solid state systems in two and three dimensions which are topological insulators.

Shinsei Ryu (University of Chicago, USA)

Many-body topological invariants for topological insulators and superconductors

Topological insulators and superconductors are fermionic symmetry-protected topological phases. Namely, they are topologically distinct from trivial states of matter in the presence of some symmetries. For example, topological insulators are topological only in the presence of time-reversal symmetry. Topological properties of such fermionic symmetry-protected topologically phases are commonly discussed by using single-particle Bloch wave functions. While such single-particle formulations have been tremendously successful, there still remains a question to address the effect of interactions. In this talk, I will describe a fully many-body formulation of topological invariants for various symmetry-protected topological phases of matter, which does not refer to single particle wave functions at all.

Pablo San-Jose (ICMM-CSIC, Madrid, Spain)

Overview of MathQ, a Mathematica simulator for quantum systems

MathQ is a Mathematica package designed to build discrete models of electronic systems and to compute a variety of physical properties, such as electronic structure, quantum transport and band topology. In this tutorial I will present an overview of MathQ, with practical examples relevant to the field of topological electronic systems.

INVITED CONTRIBUTIONS

Jörg Schäfer (University of Würzburg, Germany)

Novel Quantum Spin Hall Paradigm in 2D Honeycomb Layers: Bismuthene

This lecture will address the physics of quantum spin Hall (QSH) systems in (quasi-) 2D systems. Such materials promise revolutionary devices based on dissipationless spin currents in conducting edge channels. However, for systems such as HgTe, the decisive bottleneck preventing applications is the small bulk energy gap of less than 30 meV, requiring cryogenic operation temperatures. To address this challenge, an alternative route is to synthesize wide-gap 2D honeycomb layers. Technologically, and in contrast to hypothetical free-standing material, this requires the use of an adequate insulating substrate – which becomes vital part of the system description. This allows to realize suitable lattice parameters for the overlayer, and to use high-Z elements to exploit the effect of large spin-orbit coupling.

We will address the considerations for the experimental fabrication of such systems, and explain the ingredients that have lead to the recent realization of the Bi-based honeycomb layer, i.e., bismuthene, on a SiC substrate [1]. By combining experiment and theory, we explain that this material combination represents a new QSH paradigm. In contrast to the previous mechanisms at work in graphene and HgTe, respectively, the approach specifically exploits the on-site atomic spin-orbit coupling as a third avenue. Consistent with theory, one detects a huge bulk gap of ~0.8 eV and conductive edge states [1]. These results demonstrate a concept for a wide-gap QSH scenario, where the chemical potential resides in the global system gap, promising robust edge channel conductance even at room temperature.

[1] F. Reis et al., J. Schäfer, Science, online publication (29 June 2017), doi: 10.1126/science.aai8142

Felix von Oppen (Freie University of Berlin, Germany)

Color code quantum computation with Majorana bound states*

This talk will discuss how to combine the Majorana-based hardware of a topological quantum computer with topological error correction. Specifically, we establish color codes as providing a natural setting in which advantages offered by topological hardware can be seamlessly combined with a topological error-correcting software for full-fledged fault-tolerant quantum computing. Most importantly, color codes have a set of transversal gates which coincides with the set of topologically protected gates in Majorana-based systems, namely the Clifford gates. This allows one to exploit the protected Clifford gates at the level of the physical qubits when performing the corresponding logical gates at the code level. We illustrate our scheme by providing complete descriptions of possible architectures based on topological superconductor networks.

[*] D. Litinski, M. S. Kesselring, J. Eisert, F. von Oppen, Combining Topological Hardware and Topological Software: Color Code Quantum Computing with Topological Superconductor Networks, arXiv: 1704.01589 (2017).

INVITED CONTRIBUTIONS

Hao Zhang (Qutech, Delft University of Technology, Netherlands)

Quantized Majorana conductance plateau

Majorana zero modes hold great promise for topological quantum computing. A tunneling current from a metallic probe into a Majorana zero mode gives rise to a zero bias conductance peak. The Majorana peak height is predicted to be robust and quantized at the universal conductance value, 2e2/h. This quantized height is topologically protected from disorder, and not affected by the tunnel coupling change, i.e. a quantized conductance plateau. However, all previous reports of Majorana signatures show zero bias peaks with height either much less than 2e2/h, or not robust at 2e2/h. I will present quantized zero bias conductance peaks in Majorana nanowires. The peak height sticks to 2e2/h when tuning the tunnel coupling, resolving a quantized Majorana conductance plateau.

I will also talk about various trivial zero bias peaks in Majorana nanowires, most of them originate from Andreev bound states. These ABS-induced ZBPs can mimic many reported Majorana signatures (e.g. giving a quantized ZBP). I will discuss several ways to experimentally differentiate these trivial ZBPs from the topological case.

[1] Epitaxy of advanced nanowire quantum devices. Nature 548, 434-438 (2017)

[2] Ballistic superconductivity in semiconductor nanowires. 8, 16025 (2017)

[3] Ballistic Majorana Nanowire Devices. arXiv:1603.04069 (2016)

ORAL CONTRIBUTIONS

Liliana Arrachea (University of Buenos Aires, Argentina)

Fractional spin and Josephson effect in time-reversal-invariant topological superconductors

Alberto Camjayi, Liliana Arrachea, Armando Aligia, and Felix von Oppen

Time reversal invariant topological superconducting (TRITOPS) wires are known to host a frac- tional spin /4 at their ends. We investigate how this fractional spin affects the Josephson current in a TRITOPS-quantum dot-TRITOPS Josephson junction, describing the wire in a model which can be tuned between a topological and a nontopological phase. We compute the equilibrium Joseph- son current of the full model by continuous-time Monte Carlo simulations and interpret the results within an effective low-energy theory. We show that in the topological phase, the 0-to-π transition is quenched via formation of a spin singlet from the quantum dot spin and the fractional spins associated with the two adjacent topological superconductors.

To appear in Phys. Rev. Lett: arXiv: 1612.07410

Szabolcs Csonka (University of Budapest, Hungary)

Non-local probing of superconducting quantum dots via Yu-Shiba-Rusinov-state in Cooper pair splitter

The spin-singlet Cooper-pairs formed in a superconductor (SC) are a natural source of entangled electron pairs, which are required building blocks of a solid state based quantum computer. The Cooper-pair splitter (CPS) serves to generate the entangled pairs via crossed Andreev reflection (CAR), with the aid of two quantum dots (QDs) placed in between the SC and two normal leads. Depending on the ratio of relevant energy scales, several different transport regimes can be reached in the same geometry with different dominating physical phenomena. The conventional splitting process is proposed in the regime where the coupling of the QDs to the SC is weaker than to the normal leads. The opposite regime favors the appearance of the superconducting correlations on the QDs, e.g. formation of Yu-Shiba-Rusinov (YSR) states.

Here a new type non-local conductance signal is presented measured in an InAs nanowire based CPS device which operates in the strongly coupled SC-QD regime. Generally when one of the QDs is brought into resonance with the SC, the conductance of the other QD increases due the CAR process. In our measurements this increment is still present when the tunnel coupling between the tuned QD and the corresponding normal lead is turned off, and so the current via this channel is quenched.

The effect is explained with the presence of the YSR state on the tuned dot, which couples the dot states to a subgap quasiparticle in the SC. If the SC lead is narrower than the superconducting coherence length, the quasiparticle has considerable amplitude to leave to the probe dot, resulting in the appearance of the tuned QD's level structure in the conductance of the probe dot.

ORAL CONTRIBUTIONS

Tudor Stanescu (West Virginia University, USA)

Low-energy conductance of semiconductor-superconductor hybrid structures

Andreev bound states consisting of partially overlapping Majorana modes represent a generic low-energy feature that emerges in non-homogeneous semiconductor nanowires coupled to superconductors, such as quantum dot-nanowire systems, in the presence of a Zeeman field. We find that these Andreev bound states have a high probability of producing near-zero energy midgap states as the Zeeman splitting and/or the chemical potential are increased. The emergence of these low-energy modes, which is manifested as a "sticking together" of the Andreev bound states, is not correlated with any topological quantum phase transition that the system may undergo as the Zeeman field and other control parameters are varied. We show that using tunnelling conductance measurements it is virtually impossible to distinguish non-Abelian Majorana zero modes from weakly overlapping Majorana bound states emerging in the topologically-trivial regime. Consequently, when interpreting tunnelling conductance measurements one must keep in mind that the midgap sticking-together behavior of Andreev bound states does not represent definitive evidence for topological superconductivity with non-Abelian Majorana bound states. We also find that treating the parent superconductor as an active component of the system, rather than a passive source of Cooper pairs, has qualitative consequences regarding the low-energy behavior of the differential conductance. In particular, the presence of sub-gap states in the parent superconductor leads to characteristic particle-hole asymmetric features and to the breakdown of the quantization of the zero-bias peak associated with the presence of Majorana zero modes.

Martin Stehno (University of Würzburg, Germany)

The fractional Josephson effect in topological insulators: concepts and experiments

Mid-gap Andreev bound states (MBS) are expected to emerge in the energy spectrum of Josephson junctions with topological insulator (TI) weak links. Owing to the resonant character of tunnelling via such states, the current-phase relation acquires a 4 pi-periodic component as single electrons are shuttled across the device, instead of Cooper pairs. The corresponding AC Josephson current component has the fractional frequency eV/ħ.

In this seminar, we discuss experimental signatures of the fractional Josephson effect. Missing Shapiro steps in the current-voltage characteristic of TI Josephson junctions under microwave irradiation, and the emission of Josephson radiation with fractional frequency are key observations hinting at the presence of MBS in such devices. Direct measurements of the current-phase relation yield additional information about the Andreev bound states in the junction. We review recent experiments on HgTe-based 2D and 3D TI Josephson devices.

ORAL CONTRIBUTIONS

Hermann Suderow (Autonomous University of Madrid, Spain)

Millikelvin scanning tunneling spectroscopy: electronic features of semimetals and putative topological superconductors at very low energies

Scanning tunneling microscopy and spectroscopy (STM/S) down to 100 mK is an efficient tool to study superconductors and semimetals. The local electronic density of states is obtained at atomic level with a resolution in energy of a few tens of micro eV. Friedel-like oscillations are observed close to defects like vacancies or interstitials. Real space maps of the electronic density of states close to defects provide thus a visual account from which we can measure the wavelength of the electronic wavefunctions at the energy corresponding to the applied bias voltage. The Fourier transform of the real space maps provides the constant energy contour of the electronic dispersion relation. By making maps at different energies, below and above the Fermi level, we can in principle trace the full bandstructure. In this talk, I will review visualization experiments of scattering effects in superconductors and semimetals. I will focus on the type-II Weyl semimetal WTe2, where we directly observe the signature of edge states associated to the Weyl points, in form of incomplete constant energy contours. I will also discuss our recent efforts in the putative chiral d-wave superconductor URu2Si2 and review peculiar observations in the density of states at the surface of beta-Bi2Pd.

POSTER CONTRIBUTIONS - SESSION A	
A1	Arrighi Aloïs *Thermoelectric properties of Topological Insulators*
A2	Awoga Oladunjoye *Disorder robustness and protection of Majorana bound states in ferromagnetic chains on conventional superconductors*
A3	Benito Marías Enrique *Analytical analysis of Fermi Arcs in a Slab geometry*
A4	Bommer Jouri *Anisotropic magnetic field dependence of the superconducting gap in hybrid superconductor-nanowire devices*
A5	Bovenzi Nicandro *Twisted Fermi surface of a thin-film Weyl semimetal*
A6	Caio Marcello Davide *Non-Equilibrium Dynamics of Chern Insulators*
A7	Calzona Alessio *Energy and momentum distribution of fractional excitations in helical systems*
A8	Carroll Chris *Novel gap Closure from Magnetic Textures in Superconductors*
A9	Casas Barrera Oscar Eduardo *Green function approach for topological insulators coupled to magnetic or superconducting regions*
A10	Cayao Jorge *Andreev spectrum and supercurrents in SNS junctions made of nanowires*
A11	De Teresa José María *Magnetotransport in 1D superconducting nanowires*
A12	Díaz Escribano Samuel *Effect of electrostatic environment in Majorana nanowires*
A13	Esin Iliya *Steady states and edge state transport in topological Floquet-Bloch systems*
A14	Figueroa Adriana I. Magnetic proximity effects in topological insulator/magnetic insulator heterostructures
A15	Frombach Daniel *Josephson effect in topologically confined channels*
A16	Ginting Dianta *Enhancement of Thermoelectric Performance in the Vicinity of Breakdown of Topological Crystalline Insulator by PbSe alloying in (Pb0.5Sn0.5Te)1-x(PbSe)x*

POSTER CONTRIBUTIONS - SESSION A	
A17	Gau Matthias *Topological Kondo Effects in Majorana-Cooper box devices*
A18	Haller Roy *Detection of topological superconductivity via phase tunable noise in Josephson junctions*
A19	Hansen Esben Bork *Transport Signatures of Quasiparticle Poisoning in a Majorana Island*
A20	He Wenyu *Nodal Topological Superconductivity in Monolayer NbSe2*
A21	Hell Michael *Two-dimensional platform for networks of Majorana bound states*
A22	Ilic Stefan *Enhancement of the Pauli limit in disordered transition metal dichalcogenide monolayers*
A23	Irfan Muhammad *Geometry dependence of Fraunhofer pattern in Josephson Junction*
A24	Jünger Christian *Cooper pair splitting on superconductor-InAs double nanowire junction*
A25	Kauppila Ville *Quasiparticle poisoning statistics in Andreev qubits*
A26	Keidel Felix *Tunable Hybridization of Majorana bound states at the quantum spin Hall edge*
A27	Kotulla Markus *Confinement of 3D Topological Insulators*

POSTER CONTRIBUTIONS - SESSION B	
B1	Lau Alexander *Coexistence of Fermi arcs and Dirac cones on the surface of time-reversal invariant Weyl semimetals*
B2	Lera Natalia *Topological phonons in isostatic lattices*
B3	Macaluso Elia *Hard Wall Confinements for ν = 1/2 Fractional Quantum Hall Liquids in Disk-shaped and Ring-shaped Geometries*

POSTER CONTRIBUTIONS - SESSION B	
B4	Mascot Eric *Quantized charge transport in chiral Majorana edge modes*
B5	Niyazov Ramil *Tunneling into and between helical edge states in Fermionic approach: Conductances and asymmetry*
B6	Oladejo Semiu Oladipupo *Finite geometries and Finite quantum systems: Duality between lines in phase space and mutually unbiased bases in Hilbert space*
B7	Park Sunghun *Zeeman effect on Andreev levels in a superconductor-semiconductor-superconductor Josephson junction with Rashba spin-orbit coupling*
B8	Pekerten Baris *Disorder-induced topological transitions in multichannel Majorana wires*
B9	Peñaranda del Río Fernando Wave function non-locality in smoothly confined Majorana wires
B10	Pérez Daniel *1D Photonic Topological Insulator: Phase Transitions and Edge States*
B11	Pöyhönen Kim *Tunable topological superconductivity from a lattice of finite-size magnets*
B12	Rodríguez-Vega Martin *Universal fluctuations in a topological Floquet insulator at low frequencies*
B13	Rubio García Álvaro *Topological order in the Haldane model with on-site spin interactions*
B14	Sangia Soraya *Proximity-induced superconductivity in bismuth nanostripes*
B15	Saxena Ruchi *Emergent topological phases in periodically driven SO-coupled materials and their exotic bulk-edge correspondence*
B16	Schulz Ferdinand *Transport properties of hybrid systems based on bilayer quantum spin Hall structures*
B17	Schuray Alexander *Fano resonances in transport through Majorana networks*
B18	Seoane Souto Ruben *Counting statistics revealing quasi-particle trapping in superconducting nanojunctions*
B19	SK Firoz Islam *Enhancement of crossed Andreev reflection in normal-superconductor-normal junction in a thin topological insulator*

POSTER CONTRIBUTIONS - SESSION B	
B20	Tomaszewski Damian *Aharonov-Bohm and Aharonov-Casher effects for nonlocal and local Cooper pairs*
B21	Ulčakar Lara *System dynamics of time-dependent Hamiltonian crossing a topological phase transition*
B22	Van Beek Ian *Non-Kondo many-body physics in a Majorana-based Kondo type system*
B23	Van der Wurff Erik *Large anomalous magnetic moment in three-dimensional Dirac and Weyl semimetals*
B24	Vila Tusell Marc *Spin-orbit-mediated spin relaxation in ballistic graphene materials*
B25	Weinreich Jan *Non-equilibrium phase transitions in a Floquet topological*
B26	Westström Alex *Designer curved-space geometry for relativistic fermions in Weyl metamaterials*
B27	Zhou Benjamin, Tomg *The origin of bias independent conductance plateaus and zero bias conductance peaks in Bi2Se3/ NbSe2 hybrid structures*

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