TT 11: Majorana Physics

Time: Monday 15:00–18:45 Location: H4

TT 11.1 Mon 15:00 H4

Kitaev spin liquid at quantum criticality and beyond — •Dirk Wulferding[1,2], Youngsu Choi[3], Yann Gallais[4], Peter Lemmens[1,2], Seunghwan Do[5], and Kwang-Yong Choi[3] — [1]IPKM, TU-BS, Braunschweig, Germany — [2]LENA, TU-BS, Braunschweig, Germany — [3]Chung-Ang Univ., Seoul, Korea — [4]Univ. Paris-Diderot, Paris, France — [5]MPK / POSTECH, Pohang, Korea

The honeycomb lattice α-RuCl$_3$ is among the most promising candidates to realize a Kitaev spin liquid [1] that hosts Majorana fermions. In applied magnetic fields, the low temperature zig-zag antiferromagnetic order is suppressed, and α-RuCl$_3$ approaches quantum criticality at $H_c = 6.5$ T [2,3]. Our Raman study reveals distinct changes in low energy magnetic excitations as a function of applied fields. Based on a detailed temperature analysis [4,5] we comment on the fate of Majorana fermionic excitations and multiparticle quasiparticles at and beyond the quantum critical point.

Work supported by QUANOMET NL-4 and DFG LE967/16-1.

[1] Sandilands et al., PRL 114, 147201 (2014)
[2] Wang et al., PRL 119, 227202 (2017)
[3] Wolter et al., PRB 96, 041405(R) (2017)
[4] Glamazda et al., PRB 95, 174429 (2017)
[5] Glamazda et al., Nat. Commun. 7, 12286 (2016)

TT 11.2 Mon 15:15 H4

Probing Majorana bound states with an optical quantum dot — •Lena Bittermann[1], Daniel Frombach[1], Christophe De Beule[1], and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, TU Braunschweig — [2]Laboratory for Emerging Nanometrology Braunschweig

Majorana bound states (MBSs) arise at the ends of a semiconducting nanowire in proximity to a superconductor when a sufficiently strong magnetic field is applied. Ever since signatures of MBSs were discovered, there has been a lot of research exploring their properties. Nevertheless, their spin structure [1] has only recently gotten attention. By coupling a quantum dot to one of the ends of the wire [2], the spin and non-local properties can be investigated [3].

Here, we propose a setup where we use an optical quantum dot as a spectroscopic tool. At first we solve the low-energy model for the wire coupled to the quantum dot and calculate the corresponding transition rates for creation of photons via optical recombination. Furthermore, we use a master equation formalism to obtain the steady-state occupation probabilities. By analyzing the resulting photon emission spectrum, we can draw conclusions on the spin polarization of the MBSs for different recombination processes.

[1] D. Sticlet, C. Bena and P. Simon, PRL 108, 096802 (2012)
[2] M. T. Deng et al., Science 354, 1557 (2016)
[3] E. Prada, R. Aguado and P. San-Jose, PRB 96, 085418 (2017)

TT 11.3 Mon 15:30 H4

Fano resonaces in spinfull Majorana bound state - quantum dot hybrid system — •Alexander Schuray[1] and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, TU Braunschweig — [2]Laboratory for Emerging Nanometrology Braunschweig

The emergence of Majorana bound states (MBS) as topologically protected zero energy modes in hybrid superconductor-semiconductor devices spark a lot of research activities in the last couple of years [1]. Recently, it was reported that these hybrid devices can be coupled to a quantum dot [2]. In devices in which MBS are coupled to a quantum dot (QD) on one side and a normal conducting lead on the other side Fano resonances arise. These resonances can be used to identify and quantify the couplings to the MBS [3]. Here, we want to present our recent research in which we extend our previous work on a spinless MBS-QD system [3] to the spinful case including Coulomb interaction on the QD on a mean field level. We use full counting statistics to calculate the transport properties and support our analytical findings by numerical calculations using Kwant [4].

[1] R. Aguado, Riv. Nuovo Cimento 40, 523 (2017)
[2] M.T. Deng et al., Phys. Rev. B 98, 085125 (2018)
[3] A. Schuray, L. Weithofer, and P. Recher, Phys. Rev. B 96, 085417 (2017)
[4] C. W. Groth et al., New J. Phys. 16, 063065 (2014)

Invited Talk TT 11.4 Mon 15:45 H4

Majorana states in carbon nanotubes — •Magdalena Marganska[1], Lars Milz[1], Wataru Izumida[2], Christoph Strunk[3], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93 053 Regensburg, Germany — [2]Department of Physics, Tohoku University, Sendai 980 8578, Japan — [3]Institute for Experimental and Applied Physics, University of Regensburg, 93 053 Regensburg, Germany

One of the two most popular schemes for the realization of Majorana fermions uses proximitized semiconducting nanowires with spin-orbit coupling. With proper combination of magnetic field and gate voltage they can be driven into a topological phase, hosting zero energy Majorana bound states (MBS). Carbon nanotubes have similar properties and can be used in the same setup. They are however a hundred times thinner than the nanowires, which makes them truly one-dimensional systems, with only one relevant transverse mode for spin and valley degrees of freedom. Further, this allows us to perform a full microscopic tight-binding numerical simulation. Its results then serve as the reference for the construction of effective models in the reciprocal space.

In agreement with our numerics, the topological phase diagram predicts the presence of Majorana states at magnetic fields and chemical potentials which are encouraging for the planned experiments. The MBS themselves and their spin canting angle are revealed as complex entities, with a helical spatial profile made up from contributions from six different regions in the reciprocal space. This influences the coupling of the MBS to the outside world.

TT 11.5 Mon 16:15 H4

Transport properties of nanowire networks hosting Majorana bound states in presence of Coulomb energy — •Johan Ekström[1], Patrik Recher[2], and Thomas Schmidt[1] — [1]Physics and Materials Science Research Unit, University of Luxembourg, 1511 Luxembourg, Luxembourg — [2]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany

We investigate the electron transport through Coulomb blockaded structures hosting Majorana bound states (MBS). In particular we are interested in higher-order processes beyond local and crossed Andreev reflection. A nanowire in the topologically non-trivial regime hosts a pair of MBSs, one localized on each end of the wire. In more complex wire structures, for example wire junctions, MBSs can manifest themselves at the edges as well as at crossing points. This gives rise to transport processes that are not observed in simple nanowires. We present a general way of how the different transport processes can be obtained and understood by using a master equation where the tunneling Hamiltonian is taken into account perturbatively.

TT 11.6 Mon 16:30 H4

Interacting majorana chain in presence of disorder — •Jonas Karcher[1], Michael Sonner[1], and Alexander Mirlin[1,2] — [1]KIT, Karlsruhe, Deutschland — [2]NRC Kurchatov Institute, St. Petersburg, Russia

We investigate a majorana chain model with potential applications to the description of Kitaev edges. The model exhibits various topological phases which are separated by critical lines. Since the non-interacting system belongs to class BDI one would expect these lines to remain critical in presence of disorder if the interaction is sufficiently weak . Recent numerical studies using DMRG confirm this for attractive interactions. For strong repulsive interactions, these studies find that the system localizes. Our preliminary results show localization also for weak repulsive interaction. We want to understand the mechanism that drives the system into localization despite topological protection. To reach this goal we employ both DMRG calculations and diverse analytical RG-schemes. Our results from DMRG suggest spontaneous breaking of the translation symmetry. This cannot be understood from the weak disorder and weak interaction RG around the clean noninteracting fixed point (FP), where the interaction is irrelevant. Hence we investigate the stability of the infinite randomness FP against weak interaction. The wave functions exhibit (multi)fractality. Correlators are again computed analytically using a SUSY transfer matrix techniques. This approach is augmented by results from exact diagonalization. From their scaling behaviour we want to deduce the interaction RG flow.

TT 11.7 Mon 16:45 H4

Quasiparticle poisoning in the RSJ model for Josephson Junctions — •Daniel Frombach[1] and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, TU Braunschweig — [2]Laboratory for Emerging Nanometrology Braunschweig

The fractional 4π Josephson effect, a specific feature of Majorana bound states, is based on a conserved fermion parity of the junction. Effects which break the fermion parity conservation, processes known as quasiparticle poisoning, however reduce the 4π periodic effect to the usual 2π periodicity. The timescale on which these effects occur has been estimated [1] and is generally system specific.

Here we analyze the quasiparticle poisoning by directly including it into a RSJ description of the fractional Josephson junction. We discuss possible measuring schemes for the poisoning rates as well as signatures of topology even in the presence of quasiparticle poisoning.

[1] D. Rainis and D. Loss, Phys. Rev. B 85, 174533 (2012)

15 min. break.

TT 11.8 Mon 17:15 H4

Topological Mechanics from Supersymmetry — •Jan Attig[1], Krishanu Roychowdhury[2,3], Michael Lawler[2,4], and Simon Trebst[1] — [1]Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany — [2]Laboratory of Atomic And Solid State Physics, Cornell University, Ithaca, NY 14853, USA — [3]Department of Physics, Stockholm University, SE-106 91 Stockholm, Sweden — [4]Department of Physics, Binghamton University, Binghamton, NY, 13902, USA

In the field of topological mechanics, the identification of a mechanical system's rigidity matrix with an electronic tight-binding model allows to infer topological properties of the mechanical system from the associated electronic band structure. In this talk, I will provide a broader perspective on this relation by introducing an approach to systematically construct topological mechanical systems for an entire class of free Majorana fermion models through an exact supersymmetry (SUSY) that relates the bosonic (mechanical) and fermionic (e.g. electronic) degrees of freedom. As examples we discuss mechanical analogues of the Kitaev honeycomb model and of a second-order topological insulator with floppy corner modes. On a conceptual level, our SUSY construction naturally defines hitherto unexplored topological invariants for bosonic (mechanical) systems, such as bosonic Wilson loop operators that are formulated in terms of a SUSY-related fermionic Berry curvature.

TT 11.9 Mon 17:30 H4

Time-resolved Majorana-fermion dynamics in topological superconducting wires — •Riku Tuovinen[1], Michael A. Sentef[1], Robert van Leeuwen[2], Enrico Perfetto[3], and Gianluca Stefanucci[3] — [1]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany — [2]Department of Physics, University of Jyväskylä, 40014 Jyväskylä, Finland — [3]Dipartimento di Fisica, Università di Roma Tor Vergata, 00133 Rome, Italy

In the emerging field of topological quantum computing, topologically protected states can be utilized to minimize quantum decoherence [1]. We use a recently developed method for time-dependent quantum transport [2], and we consider a superconducting wire - hosting a Majorana zero mode at its edges [3] - connected to metallic leads. We investigate how the Majorana zero mode builds up in the transient regime [4], and we discuss how these ultrafast transport properties could also be observed experimentally.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. 83, 1057 (2011)
[2] R. Tuovinen, E. Perfetto, G. Stefanucci, and R. van Leeuwen, Phys. Rev. B 89, 085131 (2014)
[3] E. M. Stoudenmire, J. Alicea, O. A. Starykh, and M. P. A. Fisher, Phys. Rev. B 84, 014503 (2011)
[4] R. Tuovinen, M. A. Sentef, R. van Leeuwen, E. Perfetto, and G. Stefanucci, in preparation

TT 11.10 Mon 17:45 H4

Simulating topological tensor networks with Majorana qubits — •Carolin Wille[1], Reinhold Egger[2], Jens Eisert[1], and Alexander Altland[3] — [1]FU Berlin — [2]Heinrich-Heine-Universität Düsseldorf — [3]Universität zu Köln

The realization of topological quantum phases of matter remains a key challenge to condensed matter physics and quantum information science. In this work, we demonstrate that progress in this direction can be made by combining concepts of tensor network theory with Majorana device technology. Considering the topological double semion string-net phase as an example, we exploit the fact that the representation of topological phases by tensor networks can be significantly simpler than their description by lattice Hamiltonians. The building blocks defining the tensor network are tailored to realization via simple units of capacitively coupled Majorana bound states. In the case under consideration, this defines a remarkably simple blueprint of a synthetic double semion string-net, and one may be optimistic that the required device technology will be available soon. Our results indicate that the implementation of tensor network structures via mesoscopic quantum devices may define a powerful novel avenue to the realization of synthetic topological quantum matter in general.

TT 11.11 Mon 18:00 H4

Topological Ordering in the Majorana Toric Code — •Alexander Ziesen[1], Fabian Hassler[1], and Ananda Roy[1,2] — [1]JARA Institute for Quantum Information, RWTH Aachen University — [2]Institut de Physique Théorique, CEA Saclay

At zero temperature, a two-dimensional lattice of Majorana zero modes on mesoscopic superconducting islands exhibits a $\mathbb{Z}_2$ topologically-ordered phase, similar to the ground state of the toric code. Recently, a Landau field theory was proposed for the system that describes its phases and the different phase-transitions separating them. While the field theories for the different phase-transitions were obtained in the earlier work, the signatures of topological ordering in the different phases were not investigated in detail. This is the goal of the current work. We describe a lattice gauge theory of the Majorana toric code in terms of a $U(1)$ matter field coupled to an emergent $\mathbb{Z}_2$ gauge field. Subsequently, we use a generalized Wilson-loop order-parameter, namely, the equal-time Fredenhagen-Marcu order parameter, to distinguish between the different phases. Our findings confirm the previously-obtained field theory results. In contrast to the earlier work where the topological ordering of the different phases was inferred indirectly from the Landau field theory, our method directly detects the topological ordering in the system and is thus, an independent check for the earlier results.

TT 11.12 Mon 18:15 H4

Phase-dependent heat transport in topological superconductors — •Alexander G. Bauer and Björn Sothmann — Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

Recently, phase-coherent heat transport in superconducting tunnel junctions has received great interest. On the one hand, it allows for the realization of caloritronic circuits [1]. On the other hand, this can serve as a probe of fundamental properties of quantum matter [2]. Here, we investigate heat transport in junctions made from topological superconductors. We demonstrate that the thermal conductance can probe Majorana physics and enables us to distinguish between helical and chiral superconducting pairing.

[1] F. Giazotto and M. J. Martinez-Perez, Nature **492**, 401 (2012).
[2] B. Sothmann and E. M. Hankiewicz, Phys. Rev. B **94**, 081407 (2016).

TT 11.13 Mon 18:30 H4

Chiral Majorana fermions in graphene — •Petra Högl[1], Tobias Frank[1], Denis Kochan[1], Martin Gmitra[2], and Jaroslav Fabian[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Theoretical Physics and Astrophysics, Pavol Jozef Šafárik University, 04001 Košice, Slovakia

Chiral Majorana fermions are massless self-conjugate fermions which arise as propagating edge states of 2d topological superconductors. Recently, a scheme for topological quantum computation based on chiral Majorana fermions has been proposed [1]. We show the appearance of chiral Majorana edge modes in graphene by computing zigzag and armchair ribbon spectra. For this we use an effective model of graphene which takes into account proximity induced spin-orbit coupling and exchange field. This leads to a quantum anomalous Hall state which turns into a topological superconductor by adding superconducting proximity coupling. We prove the topological nature of the system by analyzing the Chern number of the 2d bulk.

This work has been supported by DFG SFB 1277 (Project B07) *and EU Seventh Framework Programme under Grant Agreement No. 604391 Graphene Flagship.*

[1] B. Lian, X.-Q. Sun, A. Vaezi, X.-L. Qi, S.-C. Zhang, PNAS 115, 10938 (2018)