TT 15: Topology: Majorana Physics

Time: Monday 15:00–18:30 Location: HSZ/0105

TT 15.1 Mon 15:00 HSZ/0105

Negative hybridization: a potential cure for braiding with imperfect Majorana modes — Cole Peeters, Themba Hodge, and •Stephan Rachel — School of Physics, University of Melbourne, Australia

Majorana zero modes, the elementary building blocks for the quantum bits of topological quantum computers, are known to suffer from hybridization when they get too close to each other. In that case, their wavefunctions start to overlap and the energy of the Majorana zero modes is pushed to finite energies. This breaking of the ground-state degeneracy leads to an accumulation of error during a braid–the fundamental process which encodes topological quantum gates. Here we show that, in certain situations, the energy splitting of the Majorana wavefunctions can become *negative* which can be utilized to reduce the average hybridization energy of the total braid. We discuss two instructive examples where *negative hybridization* improves the braiding performance to the point where imperfect Majorana modes have their non-Abelian statistics restored, resulting in successfully operated quantum gates. The upshot is that negative hybridization as an intrinsic property of Majorana modes has the potential to bring a Majorana-based quantum computer closer to reality.

TT 15.2 Mon 15:15 HSZ/0105

Distinguishing Majorana bound states from accidental zero-energy modes with a microwave cavity — Sarath Prem[1], •Olesia Dmytruk[2], and Mircea Trif[1] — [1]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, PL-02668 Warsaw, Poland — [2]CPHT, CNRS, Ecole polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

Detecting Majorana bound states (MBSs) in hybrid nanowires is challenging as their transport measurement signatures can be mimicked by trivial zero-energy Andreev bound states (ABSs) or zero-energy quasi-Majorana bound states (QMBSs). We propose an alternative approach that relies on microwave absorption visibility that is extracted from parity-dependent cavity-nanowire susceptibility measurements. We study a one-dimensional Rashba spin-orbit nanowire with an s-wave superconductor-covered proximitized region and an uncovered quantum dot region subjected to a magnetic field with spatially varying capacitive coupling to a single-mode cavity. True MBSs yield a visibility extremum only when both Majorana modes at superconducting edges simultaneously couple to the cavity exhibiting their nonlocal characteristics. In contrast, the zero-energy ABSs or QMBSs show a visibility extremum even when the cavity couples only locally to part of the nanowire. Owing to the recent experiments on poor man's Majoranas, we show that the visibility retains the nonlocal detection features.

[1] S. Prem, O. Dmytruk, and M. Trif, arXiv:2509.13194

TT 15.3 Mon 15:30 HSZ/0105

Scaling up a quantum dot Kitaev chain — Chun-Xiao Liu, Sebastian Miles, Alberto Bordin, Sebastiaan ten Haaf, Greg Mazur, Mert Bozkurt, and •Michael Wimmer — QuTech and Kavli institute of nanoscience, TU Delft, The Netherlands

Superconducting quantum dot devices can be used to implement a Kitaev chain, and tuned reliably into a topological phase. Recent experiments have succesfully implemented two- and three-site Kitaev chains [1,2]. In this talk, I discuss challenges of scaling up to longer chains and how to overcome them. To this end, I will show that the relative phase between sites in a quantum dot Kitaev chain can be adjusted by electrostatic means only. Finally, I will compare our theory to recent experiments.

[1] T. Dvir *et al.*, Nature **614** (2023) 445
[2] S.L.D. ten Haaf *et al.*, Nature **641** (2025) 890

TT 15.4 Mon 15:45 HSZ/0105

Experiments on hybrid topological insulator superconductor nanostructures — •Jakob Schluck, Ella Nikodem, and Yoichi Ando — Institute of Physics II, University of Cologne

Hybrid structures of topological insulators and conventional s-wave superconductors are predicted to generate topological superconductivity, which can host Majorana zero modes [1]. These quasiparticle excitations display non-Abelian exchange statistics and hold great potential for quantum computation [2]. Recently, we studied for the first time the phase-tunable density of states in topological insulator Josephson junctions via tunneling measurements [3]. The periodic gap closing and reopening can be interpreted as a signature of a topological phase transition. Furthermore, we established a new platform for experiments on topological superconductivity, the topological nano-SQUID [4]. By contacting top and bottom surface of the topological insulator simultaneously, we realize a scenario, where an in-plane magnetic field is sufficient to reliably reach the topological regime. In my talk, I will focus on the ongoing experimental efforts building on these achievements.

[1] L. Fu and C. L. Kane, Phys. Rev. Lett. 100 (2008) 096407
[2] C. Nayak et al., Rev. Mod. Phys. 80 (2008) 1083
[3] J. Schluck et al., arXiv:2406.08265v2
[4] E. Nikodem et al., arXiv:2412.07993v3

TT 15.5 Mon 16:00 HSZ/0105

Characterization of side-contacted topological-insulator-nanowire junctions — •Ella Nikodem, Jakob Schluck, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln

Superconducting hybrid devices based on topological insulator (TI) nanowires are a promising platform for realizing topological superconductivity and hosting Majorana zero modes (MZMs). We report our recent efforts to realize high-quality Josephson junctions based on etched BiSbTeSe2 nanowires laterally sandwiched with superconducting Nb. This device architecture enables full surface proximitization and forms an intrinsic columnar nano-SQUID, in which the top and bottom surfaces act as parallel SNS junctions. Upon threading a magnetic flux, we observe two key phenomena: (1) robust SQUID-like oscillations of the critical current with the periodicity of the superconducting flux quantum, confirming surface-dominated supercurrent [1]; and (2) a large gate- and field-tunable Josephson diode effect [2]. Conceptually, this device geometry allows for individual tuning of the phase difference of the top and bottom junctions, enabling the creation of a discrete vortex at the end of the nanowire that hosts a MZM [3]. This is substantiated by theoretical considerations based on both a phenomenological approach and full 3D tight-binding simulations. Preliminary tunnel spectroscopy results further pave the way towards detecting Majorana bound states in this platform.

[1] E. Nikodem et al., https://arxiv.org/abs/2412.07993
[2] E. Nikodem et al., Sci. Adv. 11 (2025) eadw4898
[3] L. Fu and C. Kane, Phys. Rev. Lett. 100 (2008) 096407

TT 15.6 Mon 16:15 HSZ/0105

Towards microwave measurements of topological insulator nano-SQUID devices — •Jorge Esteban Bolio, Lucas Marten Janssen, Ella Nikodem, Jakob Schluck, Christian Dickel, and Yoichi Ando — Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany

A topological insulator (TI) nanowire side contacted by superconducting leads gives rise to a TI nano-SQUID formed by the two parallel S-N-S Josephson junctions of the top and bottom surface. This platform is expected to exhibit a robust topological phase. While DC measurements in this platform have been performed [1,2], microwave measurements can also illuminate the junction quality and open a path for fast and robust detection of Majorana zero-modes (MZMs) [3]. We describe the integration of the TI nano-SQUID into a 3D transmon setup, and report our progress in the development of a dual nano-SQUID device where the overlap between two MZMs could be gate controlled.

[1] Nikodem et al. arXiv:2412.07993 (2024)
[2] Nikodem et al. Sci. Adv. 11 (2025) eadw4898
[3] E. Ginossar & E. Grosfeld, Nat. Commun. 5 (2014) 4772

TT 15.7 Mon 16:30 HSZ/0105

Poor man's Majorana bound states in quantum dot based Kitaev chain coupled to a photonic cavity — •Francesco Buonemani[1], Alvaro Gomez-Leon[2], Marco Schiro[3], and Olesia Dmytruk[1] — [1]CPHT, CNRS, Ecole polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France — [2]Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain — [3]JEIP, UAR 3573 CNRS, College de France, PSL Research University, 11, place Marcelin Berthelot, 75231 Paris Cedex 05, France

Majorana bound states (MBSs) in topological superconductors, given their robustness against external perturbations, are the ideal building blocks for quantum computation. In light of this, poor man's Majorana bound states (PMMBSs), isolated zero-energy bound states, promise to engineer Majorana bound states in a highly tunable setup consisting of a chain of quantum dots that are connected via superconductors.

We analyze the interaction between the minimal microscopic dot chain with proximity-induced superconductivity for PMMBSs and a single mode photonic cavity. We showed how the coupling to the light in the microscopic model leads to a different phenomenology compared to the case where the coupling was introduced in the two-site Kitaev chain model. Thus, we demonstrated that even starting from the microscopic quantum dot model coupled to photons, it is possible to control the sweet spot condition, for the emergence of PMMBSs, through the cavity parameters.

15 min. break

TT 15.8 Mon 17:00 HSZ/0105

Proximity-induced superconducting states in high Chern number quantum anomalous Hall heterostructures — Alejandro S. Gómez[1,2], Rafael A. Molina[3], Pablo Burset[1,2,4], and •Yuriko Baba[2,3] — [1]Universidad Autónoma de Madrid, Madrid, Spain — [2]IFIMAC-UAM, Madrid, Spain — [3]Instituto de Estructura de la Materia IEM-CSIC, Madrid, Spain — [4]Instituto Nicolás Cabrera-UAM, Madrid, Spain

Multilayer stackings of magnetically doped and undoped topological insulators can host multiple chiral channels forming a high Chern number quantum anomalous Hall (QAH) state [1]. This topological state does not require an external magnetic field. Therefore, a single channel QAH proximized by an s-wave superconductor has been proposed as a promising platform to achieve topological superconductivity and chiral Majorana modes [2,3]. In this work, we generalize these proposals to the case of heterostructures with multiple chiral states proximitized by a superconductor. We theoretically study the topological phases of the bulk system and the appearance of zero-energy states due to the bulk-boundary correspondence in the band inversion regime. Finally, we discuss the nature and topological protection of the zero-energy states against disorder and finite-size confinement effects.

[1] Y.F. Zhao et al. Nature 588 (2020) 419
[2] X.L. Qi, T.L. Hughes, S.C. Zhang Phys. Rev. B 82 (2010) 184516
[3] A. Udayet al., Nat. Phys. 20 (2024) 1589

TT 15.9 Mon 17:15 HSZ/0105

Braiding of Majorana wave packets at surfaces of noncentrosymmetric superconductors — •Georg Heedt[1], Clara Johanna Lapp[1,2], Julia Monika Link[1,2], and Carsten Timm[1,2] — [1]TU Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

Broken inversion symmetry in noncentrosymmetric superconductors causes singlet-triplet mixing of Cooper pairs. If the triplet pairing is sufficiently strong flat zero-energy Majorana surface bands are expected. We describe such a system in terms of a finite concentration of localized Majorana wave packets, which may be promising for quantum computation. Moving Majorana wave packets along closed paths leads to braiding of Majorana modes. We determine the non-Abelian phase associated with this braiding. To that end, we construct an exact time-dependent many-particle Hamiltonian that describes the desired motion and show that the phase can efficiently be evaluated in an effective single-particle picture.

TT 15.10 Mon 17:30 HSZ/0105

Phase dynamics and parity effects in quantum spin Hall Josephson junctions with coupled edges — •Cajetan Heinz[1], Patrik Recher[1,2], and Fernando Dominguez[3] — [1]Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, D-38106 Braunschweig, Germany — [3]Universität Würzburg, D-97074 Würzburg, Germany

We investigate a novel backscattering mechanism in quantum spin Hall N'SNSN' Josephson junctions in the presence of time-reversal symmetry. This extended geometry allows for the interplay between two types of Andreev bound states (ABS): the usual phase-dependent ABS localized at the edges of the central SNS junction *and* phase-independent ABS localized at the edges of the N'S regions. Crucially, the latter arise at discrete energies E_n and mediate a backscattering process between opposite edges of the SNS junction, opening gaps whenever both types of ABS are at resonance. In this scenario, the 4π-periodic ABS decouples from the rest of the 2π-periodic spectrum. Using the parameters extracted from the microscopic calculation, we construct an RSJ model that incorporates the 4π-periodic ABS, the remaining 2π-periodic part of the spectrum and the quasi-particle continuum. Here, two types of parity changes can arise: transitions between the 4π- and 2π-periodic ABS, and parity leakage from the 2π-periodic ABS into the continuum. Our results show different dynamical regimes depending on the rate of non-adiabatic transitions, ranging from Shapiro steps at integer multiples of $\hbar\omega_{ac}/2e$, over non-integer steps, to steps only at even integers, with ω_{ac} as the external ac driving frequency.

TT 15.11 Mon 17:45 HSZ/0105

Manipulating the topological spin of Majoranas — •Stijn de Wit[1], Emre Duman[2], Mert Bozkurt[3], Alexander Brinkman[1], and Inanc Adagideli[1,2] — [1]MESA+ Institute for Nanotechnology, University of Twente, The Netherlands — [2]Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul, Turkey — [3]QuTech, Delft University of Technology, Delft 2600 GA, The Netherlands

The non-Abelian exchange statistics of Majorana zero modes make them interesting for both technological applications and fundamental research. Unlike their non-Abelian counterpart, the Abelian contribution is often neglected in the discussion of Majorana braiding. We consider Majoranas bound to vortices in topological superconductors. Here, the Abelian exchange phase originates from the Majoranas so-called topological spin, and it is interpreted as an Aharonov-Casher phase arising from a vortex encircling an e/4 charge. In this work, we show how this fractional charge and hence the topological spin of Majoranas can be manipulated, introducing an additional knob for braiding operations in topological quantum computing. Final, we propose a vortex interference experiment to probe the presence of this fractional e/4 charge.

TT 15.12 Mon 18:00 HSZ/0105

Ab Initio Exploration of Material Platforms for Majorana Zero Modes in Magnetic Chains on Superconductors — •András Lászlóffy[1,2], Bendegúz Nyári[3], Levente Rózsa[2], László Szunyogh[3], and Balázs Újfalussy[2] — [1]Pázmány Péter Catholic University, Budapest, Hungary — [2]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [3]Budapest University of Technology and Economics, Budapest, Hungary

In magnetic chains on superconductors, Shiba bands are formed within the superconducting gap. Spin-orbit coupling or a spin-spiral configuration can lead to the hybridization of Shiba bands which can open a topologically non-trivial gap around the Fermi energy. To have a quantitative and realistic description of these systems, we solve the Kohn-Sham-Dirac Bogoliubov-de Gennes equations within the Korringa-Kohn-Rostoker multiple scattering theory. Elementary superconducting surfaces rarely support the appearance of a topological superconducting state, since either the superconducting gap or the spin-orbit coupling strength is small.[1] By adding a non-magnetic overlayer between the superconductor and the chain, we explore the topological properties of a large variety of systems in terms of varying the type of magnetic atoms in the chain and its crystallographic direction. We demonstrate that the formation of a spin spiral state has a larger impact on the robustness of the topologically non-trivial band structure than the enhanced spin-orbit coupling.

[1] Nyári et. al., PRB 112 (2025) 115414

TT 15.13 Mon 18:15 HSZ/0105

Ab initio band structure of magnetic chains on superconductors — •Bendegúz Nyári[1,3], András Lászlóffy[2], Balázs Újfalussy[2], László Szunyogh[3], and Levente Rózsa[2,3] — [1]HUN-REN-BME Condensed Matter Research Group — [2]HUN-REN Wigner Research Centre for Physics — [3]Budapest University of Technolofy and Economics

The detection of band topology and the reliability of Majorana Zero Mode (MZM) observations based only on real space quantities is a long standing problem. Due to the bulk edge correspondence the appearance of MZMs in a finite chain is related to the properties of the band structure, or more precisely the topological invariant, however these quantities can not be measured directly. In this work I present an ab initio approach which provides direct access to the band structure of magnetic chains on superconductors. The method relies on a 1D embedding scheme and includes the effect of the infinite host to the chain. The method was applied to Mn chains on Nb(110) and Ta(110) where the topological properties and symmetry aspects of the band structure were studied together showing the coexistence of trivial and non-trivial bands in the band structure [1].

[1] B. Nyári et al., Phys. Rev. B 112 (2025) 115414