TT 10: Topology: Majorana Physics I

Time: Monday 15:00–18:00 Location: H 2053

TT 10.1 Mon 15:00 H 2053

Characterization of Majorana bound states with Entanglement measures — •Vimalesh Vimal[1] and Jorge Cayao[2] — [1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden — [2]Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden

We consider a pair of Majorana bound states coupled to quantum dots and investigate the dynamics of quantum correlations quantifying their entanglement. In particular, for an initial state with maximally entangled quantum dots, a maximally entangled state between Majorana states and one of the quantum dots can be created periodically in time which strongly dependent on the Majorana nonlocality. A similar result is also obtained for a separable initial state, but the dynamics then develop oscillations that have different local and global frequencies when Majorana states have finite energy. Therefore, the entanglement dynamics have the potential to identify the emergence of Majorana states and also show that topological systems can serve as a source of entanglement.

TT 10.2 Mon 15:15 H 2053

Autocorrelation times of Majorana Zero Modes at finite Temperature — •Niklas Tausendpfund[1,2], Matteo Rizzi[1,2], and Aditi Mitra[3] — [1]Peter Grünberg Institut 8, Forschungszentrum Jülich, Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Köln, Germany — [3]New York University

Majorana zero modes provide a promising platform for robust quantum information storage due to their topological nature. For the non-interacting Kitaev chain, it is known that information imprinted in the edge modes has an infinite lifetime at arbitrary temperatures. The situation changes drastically with the introduction of interactions, leading to a long, but finite, lifetime at infinite temperature. In this work we study the influence of temperature on the lifetime of information stored in interacting Majorana zero modes.

TT 10.3 Mon 15:30 H 2053

Transport-based fusion that distinguishes between Majorana and Andreev bound states — •Maximilian Nitsch[1], Rubén Seoane Souto[1,2], Stephanie Matern[1], and Martin Leijnse[1] — [1]Lund University, S-22100 Lund, Sweden — [2]Materials Science Institute of Madrid, Spanish Research Council (CSIC), 28049 Madrid, Spain.

It has proven difficult to distinguish between topological Majorana bound states and nontopological Andreev bound states and to measure the unique properties of the former. In this work, we aim to alleviate this problem by proposing and theoretically analyzing a new type of fusion protocol based on transport measurements in a Majorana box coupled to normal leads. The protocol is based on switching between different nanowire pairs being tunnel coupled to one of the leads. For a Majorana system, this leads to switching between different states associated with parity blockade. The charge being transmitted at each switch provides a measurement of the Majorana fusion rules. Importantly, the result is different for a system with nontopological Andreev bound states. The proposed protocol only requires measuring a DC current combined with fast gate-control of the tunnel couplings.

TT 10.4 Mon 15:45 H 2053

Braiding of Majorana box qubits in open quantum systems — •Kunmin Wu, Sadeq S. Kadijani, Johan Ekström, and Thomas Schmidt — Department of Physics and Materials Science, University of Luxembourg, 1511 Luxembourg, Luxembourg

We propose a braiding protocol in an open quantum system consisting of three coupled Majorana boxes harboring Majorana bound states (MBSs). Each MBS is coupled to a quantum dot placed in a Markovian bosonic bath. In the limit of weak coupling, the dissipation in the Majorana sector will be governed by a master equation of Lindblad form. The existence of a dark state subspace makes it possible to engineer nontrivial steady states by controlling the tunnel coupling between quantum dots and MBSs. Since braiding requires a degenerate ground state subspace with a given fermionic parity, we find that at least three Majorana boxes are needed. We start with a dark state stabilization protocol and subsequently propose a device geometry which allows the implementation of a braiding protocol. In this braiding process, the tunnel couplings are changed adiabatically and periodically, forcing the steady state to undergo a rotation on the Bloch sphere with a nontrivial winding number. Our proposal provides a template for performing braiding operations within decoherence-free subspaces in a fermionic system.

TT 10.5 Mon 16:00 H 2053

Exploring Vortex Dynamics in Superconductor-Ferromagnet Heterostructures: From Domain Wall Interactions to Adiabatic Braiding of Majorana Modes — •Jonas Nothhelfer[1], Sebastián A. Díaz[2], Stephan Kessler[3], Tobias Meng[4], Matteo Rizzi[5,6], Kjetil M. D. Hals[7], and Karin Everschor-Sitte[1] — [1]University of Duisburg-Essen — [2]University of Konstanz — [3]Johannes Gutenberg University of Mainz — [4]Technische Universität Dresden — [5]Forschungszentrum Jülich — [6]University of Cologne — [7]University of Agder, Norway

In superconductor-magnet heterostructures, interface-induced spin-orbit coupling can play a vital role in the dynamics of textures in the superconductor and the magnet. We show that magnetic textures like domain walls and skyrmions exhibit a rich interaction spectrum with superconducting vortices. We find that the Rashba spin-orbit coupling induces magnetoelectric interactions between vortices and domain walls, with the domain wall's helicity determining the interaction: Néel walls push or pull the vortices, and vortices glide along Bloch walls. Furthermore, we show that hybrid excitations of superconducting vortices and magnetic skyrmions can bind Majorana modes that enable quantum computing. By adiabatically braiding these hybrid topological structures, we explicitly confirm the non-Abelian statistics of Majorana zero modes through self-consistent numerical simulations. Our findings provide a crucial basis for controlling superconducting vortices and using them for quantum computing.

[1] Díaz et al. arXiv:2310.06866
[2] Nothhelfer et al. Phys. Rev. B 105 (2022) 224509

TT 10.6 Mon 16:15 H 2053

How symmetry and topology bring order into the mess of vortex core states — •Thomas Gozlinski[1,2], Qili Li[1], Rolf Heid[1], Ryohei Nemoto[3], Roland Willa[1], Toyo Kazu Yamada[3], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology (KIT) — [2]Ludwig-Maximilians-Universität München (LMU) — [3]Chiba University, Japan

One popular approach of engineering Majorana bound states has been the combination of an s-wave superconductor and a topological insulator which is proposed to support Majorana zero modes in its vortex cores [1]. In principle, this state should be detectable as a zero bias conductance peak (ZBCP) in a scanning tunneling experiment. However, not every ZBCP is due to a Majorana bound state. In vortex cores, Caroli-de Gennes-Matricon (CdGM) states [2] are ubiquitous and can be mistaken for Majorana bound states. We use high-resolution scanning tunneling spectroscopy and semi-classical Eilenberger simulations to break down the complexity of the local density of states (LDOS) patterns these CdGM states can form [3]. We start from the simplest case of a single-flux-quantum vortex in an s-wave superconductor and successively increase the complexity through Fermi surface anisotropy, multi-band superconductivity and higher flux quantum numbers to understand the LDOS patterns observed in our experiment.

[1] L. Fu, C.L. Kane, Phys. Rev. Lett. **100** (2008) 096407
[2] C. Caroli, P.G. De Gennes, J. Matricon, Phys. Lett. **9** (1964) 307
[3] T. Gozlinski et al., Sci. Adv. **9** (2023) eadh9163

15 min. break

TT 10.7 Mon 16:45 H 2053

Hybrid light-matter states in topological superconductors coupled to cavity photons — •Olesia Dmytruk[1] and Marco Schirò[2] — [1]CPHT, CNRS, École polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France — [2]JEIP, UAR 3573 CNRS, Collège de France, PSL Research University, 11 Place Marcelin Berthelot, 75321 Paris Cedex 05, France

Using photonic cavities to probe and to control properties of the materials is a novel research direction of condensed matter physics. Topological materials play particularly important role in this direction due to their robustness and their possible application in quantum technologies. We study a topological superconductor that hosts Majorana bound states strongly coupled to cavity photons. We consider two models for topological behaviour: a prototype Kitaev chain and experimentally relevant semiconducting-superconducting nanowire. We find that the cavity photonic spectral function directly related to polariton spectrum of the hybrid system depends on the parity of the Majorana bound states in the topological phase. Moreover, we demonstrate that the peaks in cavity spectral function appear at different energy scales for the electronic chain in the trivial and topological phases. Therefore, cavity spectral function could be used to probe Majorana bound states in topological superconductors.

[1] O. Dmytruk, M. Schirò, arXiv:2310.01296

TT 10.8 Mon 17:00 H 2053

Quest for topological bands in magnetic chains on superconductors — •András Lászlóffy[1], Bendegúz Nyári[2], Nóra Kucska[1], László Szunyogh[2], and Balázs Újfalussy[1] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Budapest, Hungary

In magnetic chains placed 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. Simple models are suitable to understand which effects assist the formation of topological band structure, but provide no recipe how this works out in real situations. 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. We demonstrate that by scaling the magnetic moment in the spin spirals, several, however, narrow regions can be found where the system is topological. 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 changing the crystallographic direction of the chain and the magnetic configuration.

TT 10.9 Mon 17:15 H 2053

Manipulation of Majorana bound states – Stability, Topological fragmentation, and Braiding — •Balázs Ujfalussy[1], András Lászlóffy[1], Gábor Csire[2], Nóra Kucska[1], Bendegúz Nyári[3], and László Szunyogh[3] — [1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — [2]Materials Center Leoben Forschung GmbH, Roseggerstraße 12, 8700 Leoben, Austria — [3]Budapest University of Technology and Economics, Budapest, Hungary

In this talk, we provide a detailed and quantitative theoretical description of the effects of manipulating spins in an iron chain deposited on top of Au/Nb heterostructure in the superconducting state and hosting a Majorana Zero Mode by applying a first-principles computational approach. By studying the superconducting order parameter and the quasiparticle charge density of states (CDOS), we perform computational experiments in spin spiral chains that shed light on several concerns and difficulties during practical applications and add new aspects to the interpretation of recent experiments. We explore the stability of topological zero energy states, the formation of and distinction between topologically trivial and non-trivial zero energy edge states, the emergence of topological fragmentation, and the shift of Majorana Zero Modes along the superconducting nanowires These findings open avenues toward the implementation of a braiding operation.

TT 10.10 Mon 17:30 H 2053

Kitaev chain in an alternating quantum dot −− Andreev bound state array — •Sebastian Miles, David van Driel, Michael Wimmer, and Chun-Xiao Liu — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft 2600 GA, The Netherlands

We propose to implement a Kitaev chain based on an array of alternating normal and superconductor hybrid quantum dots embedded in semiconductors. In particular, the orbitals in the dot and the Andreev bound states in the hybrid are now on equal footing and both emerge as low-energy degrees of freedom in the Kitaev chain, with the couplings being induced by direct tunneling. Due to the electron and hole components in the Andreev bound state, this coupling is simultaneously of the normal and Andreev types, with their ratio being tunable by varying one or several of the experimentally accessible physical parameters, e.g., strength and direction of the Zeeman field, as well as changing proximity effect on the normal quantum dots. As such, it becomes feasible to realize a two-site Kitaev chain in a simple setup with only one normal quantum dot and one hybrid segment. Interestingly, when scaling up the system to a three-site Kitaev chain, next-nearest-neighbor couplings emerge as a result of high-order tunneling, lifting the Majorana zero energy at the sweet spot. This energy splitting is mitigated in a longer chain, approaching topological protection. Our proposal has two immediate advantages: obtaining a larger energy gap from direct tunneling and creating a Kitaev chain using a reduced number of quantum dots and hybrid segments.

TT 10.11 Mon 17:45 H 2053

Quantum scars and caustics in Majorana billiards — •Johanna Zijderveld[1], Mert Bozkurt[1,2], Michael Wimmer[1,2], and Inanç Adagideli[3,4] — [1]Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, The Netherlands — [2]QuTech, Delft University of Technology, 2600 GA Delft, The Netherlands — [3]Faculty of Engineering and Natural Sciences, Sabanci University, Orhanli-Tuzla, Istanbul, Turkey — [4]MESA+ Institute for Nanotechnology, University of Twente, The Netherlands

Majorana billiards are finitely sized and arbitrarily shaped topological superconductors which feature fermion parity switches. We investigate the influence of the shape of a topological superconductor on the localization of Majorana wavefunctions. Examining both p-wave and s-wave topological superconductors, we confirm that Majorana wavefunction features shape-dependent effects such as quantum scarring and caustics from semiclassical physics. With chiral symmetry, we find a mapping between wavefunctions of a regular $p^2/2m$ Hamiltonian and Majorana wavefunctions, which offers insight into this existence of partially localized quantum scars in Majorana billiards. Furthermore, we examine how the Majorana wavefunction changes due to a local perturbation in a region of neglibible wavefunction amplitude. In topological superconductors without chiral symmetry, we observe that the convexity of the billiard determines caustic-like features in the Majorana wavefunctions.