TT 1: Topology: Majorana Physics

Time: Monday 9:30–13:15 Location: H10

Invited Talk TT 1.1 Mon 9:30 H10

Stability of Floquet Majorana box qubits — •Anne Matthies — Institute for Theoretical Physics, University of Cologne, Germany

A topological superconductor in one dimension can host Majorana zero modes at its edge. By driving the system periodically, so-called π modes (also named Floquet-Majoranas) can arise. These are topologically protected modes with the quasi-energy π/T, where T is the period of the drive. We consider the role of π modes in the presence of long-range Coulomb interactions and therefore study a Cooper pair box made of two Josephson coupled superconducting topological quantum wires. Time-dependent gate voltages periodically drive the system and can induce π modes. The presence of four Majoranas and four π Majoranas in our setup allows us to define three topological qubits in a fixed fermion parity sector within one single box. We investigate how to obtain and control the π modes and study their stability in the presence of interactions. The stability of the Floquet-Majorana box qubit depends crucially on the initialization of the Floquet state. If the system is prepared by adiabatically increasing the amplitude of the oscillating gate voltage, the topological Floquet phase is always inherently unstable. The instability arises due to resonant quasi-particle creation mediated by interactions. However, a stable Floquet phase can be reached by using a two-step protocol. First, the amplitude of the oscillating gate voltage is adiabatically increased, while the frequency of the oscillation is small. Then, the oscillation frequency is increased slowly. With this frequency-sweep protocol, we can achieve a stable Floquet device despite interactions.
[1] PRL 128, 127702

TT 1.2 Mon 10:00 H10

Quantized phase-coherent heat transport of counterpropagating Majorana modes — Alexander G. Bauer[1], Benedikt Scharf[2], Laurens W. Molenkamp[3], Ewelina M. Hankiewicz[2], and •Björn Sothmann[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany — [2]Institute of Theoretical Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [3]Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We demonstrate that phase-coherent heat transport constitutes a powerful tool to probe Majorana physics in topological Josephson junctions. We predict that the thermal conductance transverse to the direction of the superconducting phase bias is universally quantized by half the thermal conductance quantum at phase difference $\phi = \pi$. This is a direct consequence of the parity-protected counterpropagating Majorana modes which are hosted at the superconducting interfaces. Away from $\phi = \pi$, we find a strong suppression of the thermal conductance due to the opening of a gap in the Andreev spectrum. This behavior is very robust with respect to the presence of magnetic fields. It is in direct contrast to the thermal conductance of a trivial Josephson junction which is suppressed at any phase difference ϕ.
[1] A. G. Bauer, B. Scharf, L. W. Molenkamp, E. M. Hankiewicz, B. Sothmann, Phys. Rev. B **104**, L201410 (2021)

TT 1.3 Mon 10:15 H10

Cookbook for perfect topological Majorana fermions — •Prathyush P. Poduval[1,2], Thomas L. Schmidt[1], and Andreas Haller[1] — [1]University of Luxembourg, Luxembourg, Luxembourg — [2]Indian Institute of Science, Bangalore, India

It has been demonstrated that Majorana corner modes of higher order topological insulators (HOTI) can be rotated by magnetic and superconducting pairing fields which pump the corner modes through the edges, and effectively realise a two-fold particle exchange [1]. These results are based on exact diagonalization of quadratic Hamiltonians that predict extended corner Majorana modes. Here, we show analytically that the topological phase of the 2D Majorana HOTI model can be adiabatically deformed to a scenario we dub "sweet spot limit", with perfectly localized Majorana corner modes. The existence of sweet spot limits are important for obtaining analytical solutions and also for possible experimental realizations with constraints on the total number of lattice nodes. Our findings are based on a systematic corner mode construction, which we apply to known lattice models in one and two spatial dimensions. The key idea is to obtain the typical lattice dimerization picture of the Hamiltonian matrix elements in a simultaneous eigenbasis of Majorana fermions and the symmetry operator which protects the corner modes. Based on our findings, we propose a novel 3D model featuring perfectly localized Majorana corner modes which avoids the dimensional obstruction encountered in 2D and may pave the way towards braiding.
[1] Phys. Rev. Res. 2, 032068

TT 1.4 Mon 10:30 H10

Edge $\mathbb{Z}_3$ parafermions in fermionic lattices. — •Raphael L R C Teixeira[1,2] and Luis G G V Dias da Silva[1] — [1]Instituto de Fisica - Universidade de Sao Paulo, Sao Paulo Brazil — [2]Department of Physics and Materials Science Université du Luxembourg, Luxembourg, Luxembourg

Parafermions modes are non-Abelian anyons which were introduced as $\mathbb{Z}_N$ generalizations of $\mathbb{Z}_2$ Majorana states. In particular, $\mathbb{Z}_3$ parafermions can be used to produce Fibonacci anyons, laying a path towards universal topological quantum computation. Due to their fractional nature, much of theoretical work on $\mathbb{Z}_3$ parafermions has relied on bosonization methods or parafermionic operators. In this work, we introduce a representation of $\mathbb{Z}_3$ parafermions in terms of purely fermionic models operators in the single-occupancy basis ($t-J$ regime). We establish the equivalency of a family of 1D-lattice fermionic models written in the $t-J$ model basis supporting free $\mathbb{Z}_3$ parafermonic modes at its ends. By using density matrix renormalization group calculations, we are able to characterize the topological phase transition and study the effect of local operators (doping and magnetic fields) on the spatial localization of the parafermionic modes and their stability. Moreover, we discuss the necessary ingredients towards realizing $\mathbb{Z}_3$ parafermions in strongly interacting electronic systems.

TT 1.5 Mon 10:45 H10

2π domain walls for tunable Majorana devices — •Daniel Hauck[1], Stefan Rex[2,3], and Markus Garst[1] — [1]Karlsruhe Institute of Technology, Institute for Theoretical Solid State Physics, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [3]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe

Superconductor-magnet hybrid structures provide a platform for investigating topological phases with localized Majorana states. Such states have previously been predicted for elongated Skyrmions in the magnetic layer. Here we consider 2π domain walls which are easier to realize and tweak experimentally. We show that localized Majorana states can be found in these systems and investigate possible ranges of parameters. This establishes 2π domain walls as tunable elements for the realization of Majorana devices.

TT 1.6 Mon 11:00 H10

Fraunhofer pattern in the presence of Majorana modes — •Fernando Dominguez[1], Elena G. Novik[2], and Patrik Recher[1,3] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany — [3]Laboratory for Emerging Nanometrology, 38106 Braunschweig, Germany

We investigate signatures of the presence of Majorana bound states that can arise in the Fraunhofer pattern of Josephson junctions made of Top.Sc/Qu.Spin Hall /Top.Sc. In this setup,the presence of Majorana bound states at the NS interfaces introduces electron-hole reflections with parallel spin, which due to spin-momentum locking, are forced to take place between opposite edges. In contrast to local electron-hole reflections (with opposite spin), the presence of such non-local processes do not accumulate a geometrical phase and therefore, they can change drastically or partially the periodicity of the Fraunhofer pattern. In order to observe such a change in the Fraunhofer pattern, the quantum spin-Hall edges have to be coupled either directly or through the bulk. Here, we propose two different scenarios where this can occur and provide numerical results from a scattering and tight-binding models.

15 min. break

TT 1.7 Mon 11:30 H10

Photonic noise as a probe of Majorana bound states — •Lena Bittermann[1], Fernando Dominguez[1], and Patrik Recher[1,2] — [1]Institut für Mathematische Physik, Technische Universität Braunschweig, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

We propose a route to detect Majorana bound states (MBSs) by coupling a topological superconductor to a quantum dot (QD) in a pn-junction. Here, two MBSs are coherently coupled to electrons on the QD, which recombine with holes in situ to photons. Importantly, the polarization of the emitted photons provides direct information on the spin structure [1,2] and nonlocality [2,3] of the MBSs. Here, we focus on the shot noise of the emitted photons which allows to clearly distinguish the cases of well separated MBSs at zero energy from overlapping MBSs. In addition, we show that quasiparticle poisoning changes the shot noise from super-Poissonian to sub-Poissonian. Furthermore, this setup can be extended by coupling a second QD close to the second MBS which gives rise to more resonances in the shot noise leading to additional signatures of the MBSs.

[1] D. Sticlet, C. Bena, P. Simon, PRL 108, 096802 (2012)
[2] E. Prada, R. Aguado, P. San-Jose, PRB 96, 085418 (2017)
[3] A. Schuray, L. Weithofer, P. Recher, PRB 96, 085417 (2017)

TT 1.8 Mon 11:45 H10

Zero energy modes of artificial spin chains from ab initio calculations — •Bendegúz Nyári[1], András Lászlóffy[2], László Szunyogh[1], and Balázs Újfalussy[2] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, Hungary — [2]Wigner Research Centre for Physics, Institute for Solid State Physics and Optics, Hungary

The conditions under which Majorana zero modes (MZM) appear and their physical properties in realistic materials have been of high interest over the past few years triggered by their possible applications as fault tolerant quantum bits. The MZMs are topological states corresponding to triplet pairing at zero energy emerging in an inner gap inside the superconducting gap. However, experimentally it is very challenging to identify MZMs based solely on the spectral properties. Ab inito calculations are able to reproduce the measured spectral quantities and provide additional information on the nature of the in-gap states reported in corresponding experiments.

In this work we present ab initio calculations in the superconducting state of the in-gap density of states and the singlet and triplet order parameters for Fe chains on Nb(110) surface covered by one monolayer of Au. The Fe chains are also assumed to be in various artificial spin-spiral states. In a wide range of the spin-spiral wavelength we find an inner gap with states at zero-energy and large triplet pairing order parameter. A similar behavior to previous studies based on tight-binding models further supports the conjecture that there are MZMs in this system.

TT 1.9 Mon 12:00 H10

Quantitative theory of of Yu-Shiba-Rusinov states of magnetic adatoms on Nb(110) surface and various overlayers — •Balazs Ujfalussy[1], Andras Laszloffy[1], Bendeguz Nyari[2], Kyungwha Park[3], and Laszlo Szunyogh[2] — [1]Wigner Research Centre for Physics, Budapest, Hungary — [2]Budapest University of Technology, Budapest, Hungary — [3]Department of Physics, Virginia Tech, Blacksburg, Virginia, USA

We present a fully relativistic first-principles-based theoretical approach for the calculation of the spectral properties of Fe, Co, Cr and Mn adatoms on the surface of Nb(110) substrate in the superconducting state, providing a material-specific framework for the investigation of the Yu-Shiba-Rusinov (YSR) states. We study the effect of spin-orbit coupling, the strength of the exchange field and induced moments. Furthermore, we attempt to explain certain features of the STM experiments, and to link some properties to the normal state density of states. In order to study the effect of the substrate, we provide results for the YSR states in the case of impurities on various Nb(110)/overlayer systems as well. We also study the formation of a zero-bias peak for single adatoms and dimers.

TT 1.10 Mon 12:15 H10

Matrix modelling of potential disorder effects on in-gap spectra of a vortex on a proximitized topological insulator surface — •Alexander Ziesen and Fabian Hassler — RWTH Aachen University, Aachen, Germany

We study a heterostructure of a three-dimensional topological insulator and an *s*-wave superconductor. If a single superconducting flux quantum is trapped on the proximitized surface of the topological insulator, it is theoretically predicted that a Majorana zero mode is hosted in this vortex core. To enable the usage of this non-Abelian anyon for quantum computation, it is essential to maximize the spectral gap between the Majorana zero mode and the first excited in-gap state. For clean systems tuned close to the charge neutrality point of the topological insulator and vortex radii close to the superconducting coherence length, this excitation gap is predicted to be comparable to the superconducting gap. On the other hand, for strongly disordered topological insulators, supersymmetric σ-models of symmetry class BD predict a finite, but experimentally barely resolvable excitation gap. In this work, we build the bridge between both limits with a matrix description of an effective two-dimensional surface model for strong proximization and potential disorder. With it, we quantify the amount of disorder tolerable in the system to allow for experimental resolution.

TT 1.11 Mon 12:30 H10

Steering Majorana braiding via skyrmion-vortex pairs: a scalable platform — Jonas Nothhelfer[1], •Sebastián A. Díaz[1], Stephan Kessler[2], Tobias Meng[3], Matteo Rizzi[4,5], Kjetil M. D. Hals[6], and Karin Everschor-Sitte[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]Johannes Gutenberg University of Mainz, Mainz, Germany — [3]Technische Universität Dresden, Dresden, Germany — [4]Forschungszentrum Jülich, Jülich, Germany — [5]University of Cologne, Cologne, Germany — [6]University of Agder, Grimstad, Norway

Majorana zero modes are quasiparticles that hold promise as building blocks for topological quantum computing. However, the litmus test for their detection, the observation of exotic non-abelian statistics revealed by braiding, has so far eluded experimental efforts. Here we take advantage of the fact that skyrmion-vortex pairs in superconductor-ferromagnet heterostructures harboring Majorana zero modes can be easily manipulated in two spatial dimensions. We adiabatically braid the hybrid topological structures and explicitly confirm the non-abelian statistics of the Majorana zero modes numerically using a self-consistent calculation of the superconducting order parameter. Our proposal of controlling skyrmion-vortex pairs provides the necessary leeway toward a scalable topological quantum computing platform.

[1] J. Nothhelfer, S. A. Díaz, S. Kessler, T. Meng, M. Rizzi, K. M. D. Hals, K. Everschor-Sitte, arXiv:2110.13983

TT 1.12 Mon 12:45 H10

Sachdev-Ye-Kitaev circuits for braiding and charging Majorana zero modes — •Jan Behrends[1] and Benjamin Béri[1,2] — [1]TCM Group, Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [2]DAMTP, University of Cambridge, Wilberforce Road, Cambridge CB3 0WA, United Kingdom

The Sachdev-Ye-Kitaev (SYK) model is an all-to-all interacting Majorana fermion model for many-body quantum chaos and the holographic correspondence. Here we construct fermionic all-to-all Floquet quantum circuits of random four-body gates designed to capture key features of SYK dynamics. Our circuits can be built using local ingredients in Majorana devices, namely, charging-mediated interactions and braiding Majorana zero modes. This offers an analog-digital route to SYK quantum simulations that reconciles all-to-all interactions with the topological protection of Majorana zero modes, a key feature missing in existing proposals for analog SYK simulation. We also describe how dynamical, including out-of-time-ordered, correlation functions can be measured in such analog-digital implementations by employing foreseen capabilities in Majorana devices.

TT 1.13 Mon 13:00 H10

Symplectic topological Kondo effect — •Elio Koenig[1], Jukka Vayrynen[2], and Guangjie Li[2] — [1]Max-Planck-Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany — [2]Purdue University, West Lafayette, IN 47907-2036, USA

The topological Kondo effect describes the stable, strongly coupled, non-Fermi liquid state obtained by screening a topological quantum dot, a so-called Majorana Cooper pair box, by means of external metallic leads. The symmetry group describing this exotic Kondo effect is the orthogonal group of rotations of real Majorana fermions. In this talk, I am going to present a symplectic topological Kondo effect, which, crucially, does not rely on the presence of Majorana modes. As I present in detail, this system can be implemented by coupling leads to a quantum dot consisting of a floating conventional s-wave superconductor coupled to spinful fermionic zero modes, as obtained e.g., in arrays of 1D topological insulators. Combining the solution of this problem at strong coupling with known results from Bethe Ansatz and conformal field theory demonstrates that this model harbors emergent anyonic excitations, including Fibonacci anyons, depending on the number of external leads. Importantly, the non-trivial physics is stable to anisotropies in the coupling to different leads.