TT 32: Focus Session: Chiral Topological Superconductors and Majorana Fermions

Chiral topological superconductors provide a paradigm of unconventional superconductivity. Such systems break time-reversal symmetry and exhibit rather exotic properties: they feature dispersive Majorana modes around their sample edge, and quantum vortices might host Majorana zero modes which display non-Abelian braiding statistics. This symposium aims to provide an overview of the current experimental and theoretical status as well as future directions of both chiral bulk superconductors and Shiba lattice systems presented by some of the leading experts in the field.

Organization: Katharina Franke, FU Berlin; Stephan Rachel, University of Melbourne

Time: Tuesday 9:30–12:45 Location: H 0104

Invited Talk TT 32.1 Tue 9:30 H 0104

Spin-Triplet Superconductivity in the Ruthenate — •Yoshiteru Maeno — Department of Physics, Kyoto University, Kyoto, Japan

The superconducting symmetry of Sr_2RuO_4 has been widely recognized as spin-triplet, chiral p-wave, based on a number of experimental observations as well as theoretical examinations. Although there are unresolved issues to explain, such as the strong suppression of the upper critical field and the first-order transition for the in-plane magnetic fields, there does not seem to be an alternative spin-singlet scenario at present capable of explaining all the key experiments [1].

In this talk, some important facts to consider towards refining the proper spin-triplet scenario are presented, such as the multicomponent order parameter characteristics of the intrinsic "1.5-K phase". This talk also addresses the issue of topological superconductivity of Sr_2RuO_4. Depending on the direction of the Cooper-pair d-vector, spinfull Dirac electron edge modes or spinless Majorana edge modes are expected.

This talk is mainly based on the collaborations and discussions with S. Kashiwaya, M. Sato, C. Hicks, A.P. Mackenzie, S. Yonezawa, Y. Yasui, K. Lahabi, and J. Aarts.

[1] A.P. Mackenzie et al., npj Quantum Materials (2017) 2:40.

Invited Talk TT 32.2 Tue 10:00 H 0104

Paths Towards Chiral d-wave Superconductivity — •Ronny Thomale — Universität Würzburg, Am Hubland, 97074 Würzburg

Starting by the discovery of integer quantum Hall effect in 1980, chiral topological states of matter have been in the focus of contemporary experimental and theoretical research. Astonishingly, despite significant effort and promising progress e.g. regarding the analysis of strontium ruthenate, unambiguous evidence for a chiral superconducting state of matter has remained an open problem until today. In this talk, we wish to sketch latest efforts to accomplish such an objective, and argue that hexagonal unconventional superconductors appear as one most interesting direction to realise chiral superconductivity which, from a mean field perspective, amounts to realising a Chern insulator of Bogoliubov quasiparticles.

Invited Talk TT 32.3 Tue 10:30 H 0104

Towards the Design of Majorana Bound States in Artificially Constructed Magnetic Atom Chains on Elemental Superconductors — •Roland Wiesendanger — Dept. of Physics, University of Hamburg, Hamburg, Germany

We demonstrate the fully-controlled bottom-up fabrication of artificial 1D atomic chains from individual magnetic Fe adatoms on high spin-orbit coupled superconducting Re(0001) substrates by STM-based atom-manipulation techniques at T=350 mK. Spin-polarized STM measurements indicate the presence of non-collinear spin textures, i.e. spin spiral ground states, stabilized by interfacial Dzyaloshinskii-Moriya interactions. Tunneling spectra measured spatially resolved on the Fe-atom chain on Re(0001) reveal the evolution of the local density of states inside the superconducting gap as well as the development of zero-energy bound states at the ends of the chain, which are distinguishable from trivial end states by systematically increasing the number of atoms within the Fe-atom chain. The experimental results will be compared with model-type calculations supporting the interpretation of the spectroscopic signatures at the ends of the chains as Majorana bound states. Such Majorana states can encode topological qubits and ultimately provide a new direction in topological quantum computation.

15 min. break.

Invited Talk TT 32.4 Tue 11:15 H 0104

Design of Majorana Modes: From Magnetic Skyrmions to Dimensional Tuning — •Dirk Morr — University of Illinois at Chicago, Chicago, USA

The experimental observation of Majorana bound states in topological superconductors represents a major breakthrough in realizing their applications in topological quantum computing and has stimulated the search for new possibilities to create and manipulate Majorana states at the nanoscale.

In this talk, I discuss the design of Majorana edge states in magnetic-superconducting hybrid structures and the ability to manipulate them through changes in the shape of the system or the creation of the magnetic skyrmions. I show that the tunneling conductance into Majorana edge states is quantized and proportional to the Chern number, C, while the chirality of the supercurrent carried by the Majorana modes reflects the sign of C, providing important insight into the nature of topological phases. Moreover I demonstrate the existence and unconventional spatial structure of superconducting triplet correlations which can be both time reversal (TR) breaking and TR preserving within the same system. Finally, I show that it is possible to continuously tune hybrid systems between 2D and 1D topological phases, and thus to change the character of the associated Majorana modes.

Invited Talk TT 32.5 Tue 11:45 H 0104

Experimental Hints of Topological Superconductivity in Hybrid Ferromagnet-Superconductor Systems — Gerbold Ménard[1], Sébastien Guissart[2], Christophe Brun[1], Raphaël Leriche[1], Mircea Trif[2], François Debontridder[1], Dominique Demaille[1], Dimitri Roditchev[3], Pascal Simon[2], and •Tristan Cren[1] — [1]Institut des Nanosciences de Paris, CNRS & Sorbonne University, Paris, France — [2]Laboratoire de Physique des Solides, CNRS & Paris-Saclay University, Orsay, France — [3]Laboratoire de physique et d'étude des matériaux, ESPCI, Paris, France

Just like insulators can present topological phases characterized by Dirac edge states, superconductors can exhibit topological phases characterized by Majorana edge states. One-dimensional topological superconductors are predicted to host zero energy Majorana fermions at their extremities. Zero bias anomalies localized at the edge of proximity induced superconducting wires were recently interpreted as fingerprints of the emergence of topological superconductivity [1,2]. By contrast, 2D superconductors have a one-dimensional boundary which would naturally lead to propagating Majorana edge states characterized by a Dirac-like dispersion. These dispersive Majorana edge states were recently observed in a Pb monolayer coupled to a nanomagnet [3]. The topological order was confirmed by the observation of Majorana bound states in vortex cores in this system.

[1] V. Mourik et al., Science 336, 1003 (2012)
[2] S. Nadj-Perge et al., Science 346, 602 (2014)
[3] G. C. Ménard, et al., Nature Comm. (2017)

TT 32.6 Tue 12:15 H 0104

Magnetic impurities on superconducting surfaces — •Nicolas Lorente — Centro de Física de Materiales and Materials Physics Center, CSIC-EHU Donostia International Physics Center, San Sebastián, Spain

A magnetic impurity on a superconducting surface can create a bound state. The state is localized to the magnetic impurity but it extends well into the superconductor and along the surface. Its energy is within the superconductor's gap. This state is a complex state caused by the weakening of Cooper pairs due to the magnetic exchange field produced by the impurity. If another magnetic impurity is approached, the Shiba states can start interacting. If their spins are aligned, they can form bonding and antibonding states. As the number of impurities increases forming a chain of impurities, the Shiba states also increase forming Shiba bands. Under certain conditions, some of these bands can cross the Fermi energy, closing the superconducting gap. This can give rise to changes in the topological electronic structure of the system. As a consequence, if the chain is not infinite, bound states at the edges of the chain are actually Majorana fermions. I will show model calculations analyzing the case of Cr chains on a β-Bi_2Pd superconductor.

TT 32.7 Tue 12:30 H 0104

Search for topological superconductivity in the proximitized, quantum-spin-Hall edge state of bismuth bilayers — •Berthold Jaeck[1], Yonglong Xie[1], Sangjun Jeon[1], Aris Alexandradinata[2], B. Andrei Bernevig[1], and Ali Yazdani[1] — [1]Department of Physics, Princeton University, Princeton, NJ 08544, USA — [2]Department of Physics, Yale University, New Haven, CT 06520, USA

Two-dimensional topological insulators host helical, one-dimensional (1D) modes that are protected by time-reversal symmetry. Proximity induced superconductivity on such edge modes is predicted to be topological in nature and provide a platform for realization of Majorana zero modes. Previously, scanning tunneling microscopy (STM) studies have found evidence for topological edge modes in bismuth (Bi) bilayers on the surface of bulk Bi(111) (1). By epitaxially growing thin films on the surface of Nb, we have successfully induced superconductivity into (111) oriented Bi films. Using high-resolution STM spectroscopy and quasi-particle interference mapping, we characterize the nature of both the normal and the superconducting properties of Bi bilayer edge modes. We find the 1D edge mode to develop a hard superconducting gap that appears to be spectroscopically distinct from the 2D surface gap of the bilayer islands. We will describe these and other experiments designed to elucidate the nature of superconductivity and search for signatures of topological superconductivity in these 1D topological edge states.

[1] I. Drozdov et al., Nature Phys. 10 (2014) 664.