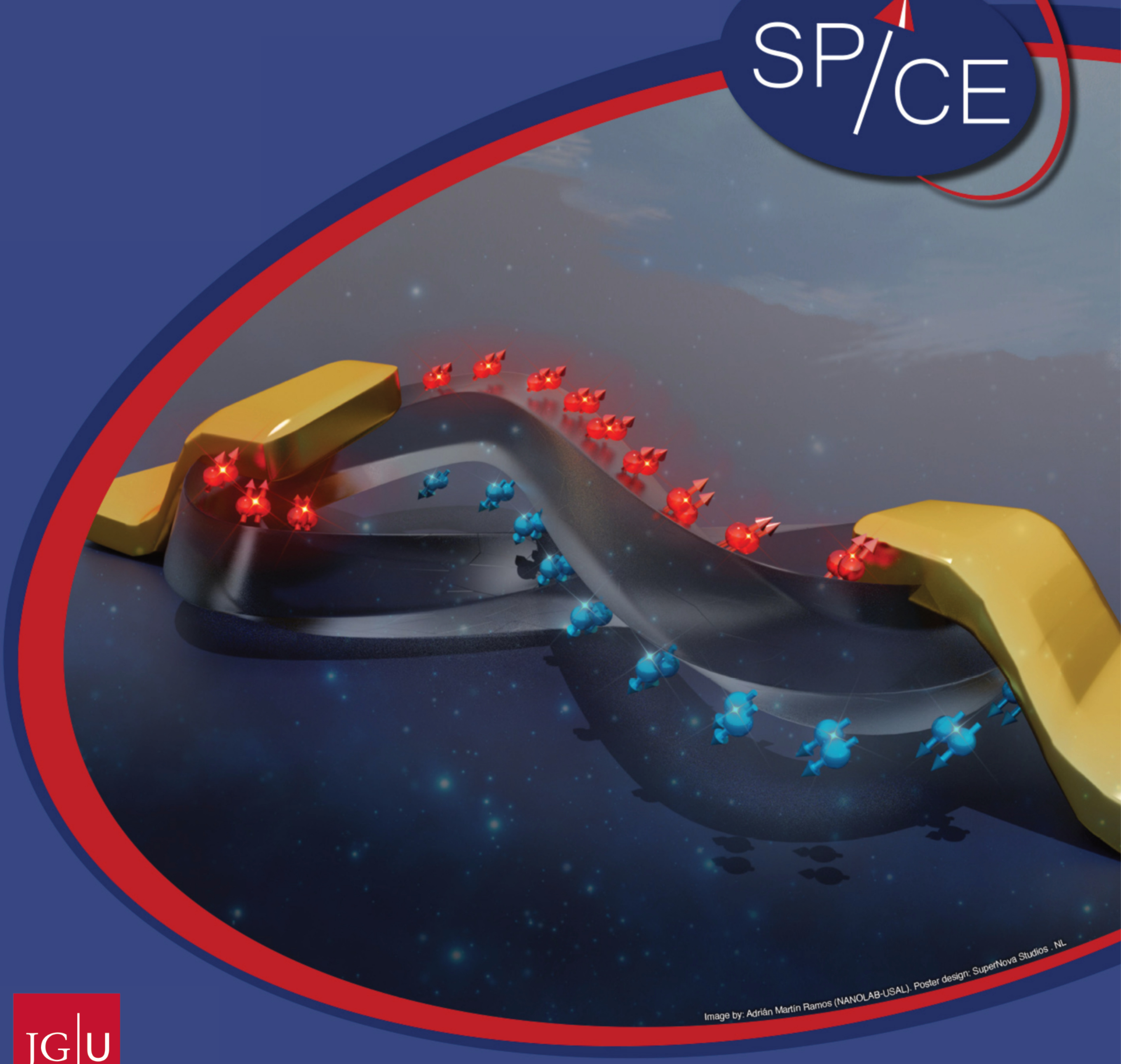
SPICE Online Workshop

October 19th - 22th 2020, Mainz, Germany

TOPOLOGICAL SUPERCONDUCTIVITY IN QUANTUM MATERIALS



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TOPOLOGICAL SUPERCONDUCTIVITY IN QUANTUM MATERIALS

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Program

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10:20 – 10:50	**Peter LILJEROTH, Aalto University** Topological superconductivity in a van der Waals heterostructure
10:50 - 11:10	**Coffee Break**
11:10 – 11:40	**Takasada SHIBAUCHI, University of Tokyo** Possible transition to a topological ultranodal pair state in FeSe1-xSx superconductors
11:50 – 12:20	**Christian SCHOENENBERGER, University of Basel** One-dimensional states residing on edges and steps in few-layer WTe2
12:20 – 13:30	**Poster Session**

Afternoon Session – Monday, October 19th

14:00 – 15:00	**Dimitri EFETOV, Institute of Photonic Sciences** Angle Bilayer Graphene – Superconductors, Orbital Magnets, Correlated States and beyond
15:10 – 15:40	**Javier VILLEGAS, CNRS-Thales** Propagation and interference of d-wave superconducting pairs in graphene
15:50 – 16:20	**Jeanie LAU, Ohio State University** Flat Bands in Flatlands
16:30 – 17:00	**Eli ZELDOV, Weizmann Institute of Science** Mapping the twist-angle disorder and unconventional Landau levels in magic angle graphene

Morning Session – Tuesday, October 20th

09:00 – 10:00	**Jelena KLINOVAJA, University of Basel** Second Order Topological Superconductivity: Majorana and parafermion corner states
10:10 – 10:40	**Ramon AGUADO, ICMM-CSIC** Microwave spectroscopy of hybrid superconductor- semiconductor qubits with Majorana zero modes
10:40 – 11:00	**Coffee Break**
11:00 – 11:30	**Bohm Jung YANG, Seoul National University** Topological superconductivity of centrosymmetric magnetic metals
11:40 – 12:40	**Jagadeesh MOODERA, Massachusetts Institute of Technology** Topological superconductivity in gold leads to Majorana Zero Mode Pair
12:40 – 13:30	**Poster Session**

Afternoon Session – Tuesday, October 20th

14:00 – 14:30	**Yasuhiro ASANO, Hokkaido University** Josephson Effect of two-band/orbital superconductors
14:40 – 15:10	**Mario Cuoco, University of Salerno** Topological phases combining superconductivity and magnetism
15:20 – 15:50	**Alexander GOLUBOV, University of Twente** Resonant p-wave oscillations of Josephson current in Nb-Bi2Te2.3Se0.7-Nb topological junctions
16:00 – 16:30	**Eun-Ah KIM, Cornell University** Two-dimensional Topological Superconductivity
16:40 – 17:10	**Paola GENTILE, University of Salerno** Geometrically driven effects in curved superconducting nanostructures
17:20 – 17:50	**Valerii VINOKOUR** Topological Nature of High Temperature Superconductivity

Morning Session – Wednesday, October 21st

09:30 – 10:30	**Satoshi IKEGAYA, Max Planck Institute for Solid State Research** Fingerprints of Majorana modes beyond the zero-bias conductance peak
10:30 – 10:50	**Coffee Break**
10:50 – 11:20	**Shane CYBART, University of California Riverside** Helium Ion Beam Modification of High Transition Temperature Superconductors
11:30 – 12:00	**Sachio KOMORI, University of Cambridge** Magnetic exchange through s- and d-wave superconductors
12:10 – 12:40	**Shingo YONEZAWA, Kyoto University** Domain control in the topological nematic superconductor SrxBi2Se3
12:40 – 13:50	**Poster Session**

Afternoon Session – Wednesday, October 21st

14:00 – 15:00	**Ron NAAMAN, Weizmann Institute of Science** Chiral Molecules as Topological Devices- The Chiral Induced Spin Selectivity Effect
15:10 – 15:40	**Oded MILLO, Hebrew University of Jerusalem** Unconventional superconductivity and magnetic-related states induced in a conventional superconductor by nonmagnetic chiral molecules
15:50 – 16:20	**Manfred SIGRIST, ETH Zurich** Domain walls and critical currents in chiral superconductors

Morning Session – Thursday, October 22nd

09:00 – 10:00	**Ady STERN, Weizmann Institute of Science** The Josephson effect as a tool for creating topological superconductivity
10:10 – 10:40	**Yukio TANAKA, Nagoya University** Odd-frequency pairing in topological superconductors
10:40 – 11:00	**Coffee Break**
11:00 – 11:30	**Clifford HICKS, Max-Planck-Institute for Chemical Physics of Solids** Evaluation of chiral superconductivity in Sr2RuO4
11:40 – 12:10	**Edwin HERRERA, UAM Madrid** One-dimensional moiré charge density wave in the hidden order state of URu2Si2 induced by fracture
12:20 – 12:50	**Jacobo SANTAMARIA, Complutense University of Madrid** Long range unconventional Josephson effect across a half metallic ferro-magnet
12:50 – 13:00	**Closing Remarks**

Speaker Abstracts

Monday, October 19th, 09:10

Tuning the exchange and potential scattering strength of individual magnetic adsorbates on superconductors

Katharina FRANKE
Free University of Berlin

Magnetic impurities in conventional superconductors induce a pair-breaking potential, which leads to bound states inside the superconducting energy gap. These states are called Yu-Shiba-Rusinov (YSR) states, and can be probed by scanning tunneling spectroscopy at the atomic scale. The energy of these states depends on the strength of both exchange and potential scattering. The individual YSR states can be regarded as the building blocks for topological superconductivity in adatom chains on conventional superconductors.

Here, we explore different strategies to tune the energy of the YSR states. In the first case, we tune the strength of the magnetic exchange scattering to the Cooper pairs. Upon tip approach we are able to continuously vary the energy of YSR states induced by Fe-porphin molecules on Pb(111) across the Fermi energy. This model system further allows to study the quantum phase transition between a screened and unscreened spin [1].

In the second case, we make use of the charge-density wave (CDW) of NbSe2, which coexists with superconductivity, to tune the energy of YSR states of individual Fe atoms. All atoms are placed in the same atomic adsorption site, but at different positions with respect to the CDW. The YSR states exhibit different energies and different oscillatory patterns. We ascribe the shift in energies to the variation of the density of states as well as to changes in the potential scattering strength [2]. These results are important for designing topological nanostructures.

[1] L. Farinacci, G. Ahmadi, G. Reecht, M. Ruby, N. Bogdanoff, O. Peters, B. W. Heinrich, F. von Oppen, K. J. Franke, Phys. Rev. Lett. 121, 196803 (2018).

[2] E. Liebhaber, S. Acero Gonzalez, R. Baba, G. Reecht. B. W. Heinrich, S. Rohlf, K. Rossnagel, F. von Oppen, K. J. Franke, Nano Lett. 20, 339 (2020).

Monday, October 19th, 10:20

Topological superconductivity in a van der Waals heterostructure

Peter LILJEROTH
Aalto University

There has been a surge of interest in designer materials that would realize electronic responses not found in naturally occurring materials. For example, it is not clear if topological superconductivity [1], which is a key ingredient in topological quantum computing, exist in any single material. These limitations can be overcome in designer van der Waals (vdW) heterostructures, where the desired physics emerges from the engineered interactions between the different components.

Molecular-beam epitaxy (MBE) growth allows the construction of vertical heterostructures with clean and high-quality interfaces [2]. We use MBE to grow islands of ferromagnetic CrBr3 [3] on a superconducting NbSe2 substrate. This combines out of plane ferromagnetism with Rashba spin-orbit interactions and s-wave superconductivity and allows us to realizate topological superconductivity in a van der Waals heterostructure [4]. We characterize the resulting one-dimensional edge modes using low-temperature scanning tunneling microscopy (STM) and spectroscopy (STS). The use of vdW heterostructures with uniform and high-quality interfaces is promising for future device structures and further control of topological superconductivity through external stimuli (e.g. electrostatic gating).

[1] M. Sato, and Y. Ando, Topological superconductors: a review. Rep. Prog. Phys. 80, 076501 (2017)

[2] S. Kezilebieke, M. N. Huda, P. Dreher, I. Manninen, Y. Zhou, J. Sainio, R. Mansell, M.M. Ugeda, S. van Dijken, H.-P. Komsa, P. Liljeroth, Electronic and Magnetic Characterization of Epitaxial VSe2 Monolayers on Superconducting NbSe2, Commun. Phys. 3, 116 (2020)

[3] W. Chen, Z. Sun, Z. Wang, L. Gu, X. Xu, S. Wu, C. Gao, Direct observation of van der Waals stacking–dependent interlayer magnetism. Science 366, 983 (2019)

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Monday, October 19th, 11:10

Possible transition to a topological ultranodal pair state in FeSe1-xSx superconductors

Takasada SHIBAUCHI
University of Tokyo

The FeSe1-xSx superconductors involving non-magnetic nematic phase and its quantum criticality provide a unique platform to investigate the relationship between nematicity and superconductivity [1]. It has been shown that across the nematic quantum critical point, the superconducting properties change drastically [2,3], and the non-nematic tetragonal FeSe1-xSx (x>0.17) exhibits substantial low-energy states despite the high-quality of crystals. Here we have perform the muon spin rotation (μSR) measurements on FeSe1-xSx (x=0, 0.20, 0.22) and observed the spontaneous internal field below the superconducting transition temperature Tc, providing strong evidence for time-reversal breaking (TRSB) state in bulk FeSe1-xSx [4]. We also find that the superfluid density in the tetragonal crystals is suppressed from the expected value, indicating the presence of non-superconducting carriers. These results in FeSe1-xSx are consistent with the recently proposed topological phase transition to a novel ultranodal pair state with Bogoliubov Fermi surface [5].

[1] See, for a review, T. Shibauchi, T. Hanaguri, and Y. Matsuda, J. Phys. Soc. Jpn. (in press); arXiv:2005.07315 (2020)

[2] Y. Sato et al., Proc. Natl. Acad. Sci. USA 115, 1227-1231 (2018)

[3] T. Hanaguri et al., Sci. Adv. 4, eaar6419 (2018)

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Monday, October 19th, 11:50

One-dimensional states residing on edges and steps in few-layer WTe2

Christian SCHOENENBERGER
University of Basel

WTe2 is a layered material with rich topological properties. As a bulk crystal it is a type-II Weyl semimetal and as a monolayer a two-dimensional topological insulator. Recently, it has been predicted that higher order topological insulator states can appear in WTe2. An observation of 1D, highly conductive channels, known in this case as hinge states, is hindered by the bulk conductivity of WTe2. Here, we employ the Josephson effect to disentangle the contribution of the hinge states from the bulk in electronic transport. We observe 1D current carrying states on edges and steps in few-layer WTe2. The width of the states is deduced to be below 100 nm. A supercurrent in them can be measured over distances up to 3 μm and in perpendicular magnetic field up to 2 T. Moreover, the dependence of the supercurrent with field is compatible with the asymmetric Josephson effect predicted to occur in topological systems with broken inversion symmetry. We note, that superconductivity is induced into WTe2 at the interface to the contacts made from Pd, which is a normal metal. The induced superconductivity has a critical temperature of about 1.2 K. By studying the superconductivity in perpendicular magnetic field, we obtain the coherence length and the London penetration depth. These parameters hint to a possible origin of superconductivity due to the formation of flat bands. Furthermore, the critical in-plane magnetic field exceeds the Pauli limit, suggesting a non-trivial nature of the superconducting state.

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Monday, October 19th, 14:00

Angle Bilayer Graphene – Superconductors, Orbital Magnets, Correlated States and beyond

Dimitri EFETOV
Institute of Photonic Sciences

When twisted close to a magic relative orientation angle near 1 degree, bilayer graphene has flat moire superlattice minibands that have emerged as a rich and highly tunable source of strong correlation physics, notably the appearance of superconductivity close to interaction-induced insulating states. Here we report on the fabrication of bilayer graphene devices with exceptionally uniform twist angles. We show that the reduction in twist angle disorder reveals insulating states at all integer occupancies of the four-fold spin/valley degenerate flat conduction and valence bands, i.e. at moire band filling factors nu = 0, +(-) 1, +(-) 2, +(-) 3, and reveals new superconductivity regions below critical temperatures as high as 3 K close to - 2 filling. In addition we find novel orbital magnetic states with non-zero Chern numbers. Our study shows that symmetry-broken states, interaction driven insulators, and superconducting domes are common across the entire moire flat bands, including near charge neutrality. We further will discuss recent experiments including screened interactions, fragile topology and the first applications of this amazing new materials platform.

Monday, October 19th, 15:10

Propagation and interference of d-wave superconducting pairs in graphene

Javier VILLEGAS
CNRS-Thales

Following earlier work in which we demonstrated the Klein-like tunneling of d-wave superconducting paints intro graphene [1], here we present experiments that show the longrange preparation of d-wave correlations in that material. For this, we fabricated devices that behave as a proximitized Fabry-Pérot cavitiy, where d-wave Andreev pairs interferences are produced. The interferences manifest themselves in series of pronounced conductance oscillations analogous to those produced by De Gennes-Saint James resonances in conventional superconductor/ metal junctions. Their observation imply that the d-wave Andreev pairs propagate over distances of a few hundred nm in the CVD graphene used for the experiments [2]. We will end up by discussing ongoing experiments in applied magnetic field, which also produces an intriguing series of conductance oscillations in the superconducting state of the junctions.

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Monday, October 19th, 15:50

Flat Bands in Flatlands

Jeanie LAU
Ohio State University

In a flat band system, the charge carriers' energy-momentum relation is very weakly dispersive. The resultant large density of states and the dominance of Coulomb potential energy relative to the kinetic energy often favor the formation of strongly correlated electron states, such as ferromagnetism, nematicity, antiferromagnetism, superconductivity, and charge density waves. The advent of two-dimensional (2D) materials and their heterostructures has ushered in a new era for exploring, tuning and engineering of flat band system. Here I will present our results on transport measurements of high quality few-layer 2D material devices, including intrinsic magnetism and helical edge states in few-layer graphene, and observation of both superconductivity and the Mott-like insulating state in a tBLG device with a twist angle of ~0.93°.

Monday, October 19th, 16:30

Mapping the twist-angle disorder and unconventional Landau levels in magic angle graphene

Eli ZELDOV
Weizmann Institute of Science

The emergence of flat bands and of strongly correlated and superconducting phases in twisted bilayer graphene crucially depends on the interlayer twist angle upon approaching the magic angle. Utilizing a scanning nanoSQUID-on-tip, we attain tomographic imaging of the Landau levels and derive nanoscale high precision maps of the twist-angle disorder in high quality hBN encapsulated devices, which reveal substantial twist-angle gradients and a network of jumps [1]. We show that the twist-angle gradients generate large gate tunable in-plane electric fields, unscreened even in the metallic regions, which drastically alter the quantum Hall state by forming edge channels in the bulk of the samples. The correlated states are found to be particularly fragile with respect to twist-angle disorder. We establish the twist-angle disorder as a fundamentally new kind of disorder, which alters the local band structure and may significantly affect the correlated and superconducting states.

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Tuesday, October 20th, 09:00

Second Order Topological Superconductivity: Majorana and parafermion corner states

Jelena KLINOVAJA
University of Basel

Recently, a lot of interest has been raised by the generalization of conventional TIs/TSCs to so-called higher order TIs/TSCs. While a conventional d-dimensional TI/TSC exhibits (d − 1)-dimensional gapless boundary modes, a d-dimensional n-th order TI/TSC hosts gapless modes at its (d − n)-dimensional boundaries. In my talk, I will consider a Josephson junction bilayer consisting of two tunnel-coupled two-dimensional electron gas layers with Rashba spin-orbit interaction, proximitized by a top and bottom s-wave superconductor with phase difference φ close to π [1-3]. In the presence of a finite weak in-plane Zeeman field, the bilayer can be driven into a second order topological superconducting phase, hosting two Majorana corner states (MCSs). If φ=π, in a rectangular geometry, these zero-energy bound states are located at two opposite corners determined by the direction of the Zeeman field. If the phase difference φ deviates from π by a critical value, one of the two MCSs gets relocated to an adjacent corner. As the phase difference φ increases further, the system becomes trivially gapped. The obtained MCSs are robust against static and magnetic disorder.

In the second part of my talk, I will switch from non-interacting systems [4,5], in which one neglects effects of strong electron-electron interactions, to interacting systems and, thus, to exotic fractional phases. I will show that this is indeed possible and explicitly construct a two-dimensional (2D) fractional second-order TSC. I will consider a system of weakly coupled Rashba nanowires in the strong spin-orbit interaction (SOI) regime. The nanowires are arranged into two tunnel-coupled layers proximitized by a top and bottom superconductor such that the superconducting phase difference between them is π. In such a system, strong electron- electron interactions can stabilize a helical topological superconducting phase hosting Kramers partners of Z_2m parafermion edge modes, where m is an odd integer determined by the position of the chemical potential. Furthermore, upon turning on a weak in-plane magnetic field, the system is driven into a second- order topological superconducting phase hosting zero-energy Z_2m parafermion bound states localized at two opposite corners of a rectangular sample.

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Tuesday, October 20th, 10:10

Microwave spectroscopy of hybrid superconductor- semiconductor qubits with Majorana zero modes

Ramon AGUADO
ICMM-CSIC

Recent experimental efforts have focused on replacing the weak link in the Josephson Junction (JJ) of a superconducting qubit by electrostatically-gateable technologies compatible with high magnetic fields [1]. Such alternatives are crucial in order to reach a regime relevant for readout of topological qubits based on Majorana zero modes (MZMs) [2]. In my talk, I will focus on JJs based on semiconducting nanowires that can be driven to a topological superconductor phase with MZMs. A fully microscopic theoretical description of such hybrid semiconductor-superconducting qubit allows to unveil new physics originated from the coherent interaction between the MZMs and the superconducting qubit degrees of freedom [3]. The corresponding microwave spectroscopy presents nontrivial features, including a full mapping of zero energy crossings and fermionic parity switches in the nanowire owing to Majorana oscillations [4].

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[2] Majorana qubits for topological quantum computing, R. Aguado and Leo Kouwenhoven, Physics Today 73, 6, 44 (2020)

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Tuesday, October 20th, 11:00

Topological superconductivity of centrosymmetric magnetic metals

Bohm Jung YANG
Seoul National University

I am going to talk about the topological properties of the superconductivity that coexists with stable magnetism. In the first part of this talk, we propose a route to achieve odd-parity spin- triplet superconductivity in metallic collinear antiferromagnets with inversion symmetry. Owing to the existence of hidden antiunitary symmetry, which we call the effective time- reversal symmetry (eTRS), the Fermi surfaces of ordinary antiferromagnetic metals are generally spin-degenerate, and spin-singlet pairing is favored. However, by introducing a local inversion symmetry breaking perturbation that also breaks the eTRS, we can lift the degeneracy to obtain spin-polarized Fermi surfaces. In the weak-coupling limit, the spin- polarized Fermi surfaces constrain the electrons to form spin-triplet Cooper pairs with odd- parity. Furthermore, we find that the odd-parity superconducting states host nontrivial band topologies manifested as chiral topological superconductors, second-order topological superconductors, and nodal superconductors. In the second part, I am going to talk about topological superconductivity of spin-polarized fermions in ferromagnets. By generalizing the Fu-Berg-Sato criterion to account for higher order band topology, we show that doped nodal semimetals of spin-polarized fermions can host various types of magnetic higher-order topological superconductivity.

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[2] J. Ahn and B. –J. Yang, “Higher-order topological superconductivity of spin-polarized fermions”, arXiv:1906.02709; Physical Review Research 2, 012060(R) (2020)

Tuesday, October 20th, 11:40

Josephson Effect of two-band/orbital superconductors

Yasuhiro ASANO
Hokkaido University

We have been interested in physics of an odd-frequency Cooper pair. At this conference, we will discuss two phenomena of two-band (two-orbital) superconductors. At first, we discuss the Josephson effect between two two-band superconductors respecting time-reversal symmetry, where we assume a spin-singlet s-wave pair potential in each conduction band. The superconducting phase at the first band ! and that at the second band " characterize a two-band superconducting state. We consider a Josephson junction where an insulating barrier separates two such two-band superconductors. By applying the tunnel Hamiltonian description, the Josephson current is calculated in terms of the anomalous Green's function on either side of the junction. We find that the Josephson current consists of three components which depend on three types of phase differences across the junction: the phase difference at the first band !, the phase difference at the second band ", and the difference at the center-of-mass phase (! +")/2. A Cooper pair generated by the band hybridization carries the last current component.[1] Secondly, we also discuss the effects of random nonmagnetic impurities on superconducting transition temperature in a Cu doped Bi2Se3, for which four types of pair potentials have been proposed. Although all the candidates belong to s-wave symmetry, two orbital degrees of freedom in electronic structures enrich the symmetry variety of a Cooper pair such as even-orbital-parity and odd-orbital-parity. We consider realistic electronic structures of Cu-doped Bi2Se3 by using a tight-binding Hamiltonian on a hexagonal lattice and consider effects of impurity scatterings through the self-energy of the Green's function within the Born approximation. We find that even-orbital-parity spin-singlet superconductivity is basically robust even in the presence of impurities. The degree of the robustness depends on the electronic structures in the normal state and on the pairing symmetry in orbital space. On the other hand, two odd-orbital-parity spin- triplet order parameters are always fragile in the presence of potential disorder. We also discuss relations between our conclusions and the results of another theoretical studies on the same issue.

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[2] T. Sato and YA, Phys Rev. B 102, 024516 (2020)

Tuesday, October 20th, 12:20

Topological phases combining superconductivity and magnetism

Mario Cuoco
University of Salerno

In this talk I will present different routes to generate and manipulate topological phases due to the interplay between superconductivity and magnetism. The search for new variants of semimetals (SMs) recently highlighted the interplay of Dirac fermions physics and magnetism. Indeed, antiferromagnetic (AFM) SMs can be obtained where both time and inversion are broken while their combination is kept [1,2] or due to chiral- [2] and time-symmetry [2,3] combined with non-symmorphic transformations [2]. Here, we discuss materials, i.e. transition metal oxide systems, that can exhibit AFM-SM phase due to orbitally directional double- exchange effects [4, 2]. In this context, the impact of s-wave spin-singlet pairing on AFM-SMs with Dirac points or nodal loops at the Fermi level [5] is generally shown to convert the semimetal into various types of nodal topological superconductors. The changeover from fully gapped to gapless phases is dictated by symmetry properties of the AFM-superconducting state that set out the occurrence of a large variety of electronic topological transitions [4].

Finally, I will focus on various quantum platforms marked by spin-singlet or spin-triplet pairing interfaced with non-trivial magnetic patterns and discuss the nature of the emerging topological phases [6,7,8]. The coexistence of ferromagnetism or antiferromagnetism with spin-triplet superconductivity is also analysed and discussed with respect to relevant materials cases.

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Tuesday, October 20th, 14:00

Topological superconductivity in gold leads to Majorana Zero Mode Pair

Jagadeesh MOODERA
Massachusetts Institute of Technology

Surfaces and interfaces play a pivotally defining role for many of the topologically driven nontrivial quantum phenomena. A good example is the prediction of Majorana zero modes (MZMs or the Majorana pair) to occur in a topological superconductor (TSC) – viz., superconducting surface state of gold. [1] A fermion in a TSC can separate in space into two parts known as MZMs. Thus, Majorana pair are Fermionic states, each of which is an antiparticle of itself, and are required to always appear in pair together with its partner. According to the theoretical proposal of Potter and Lee, [1] under the right conditions, a superconducting gold nanowire with (111) crystalline surface with its large Rashba spin-orbit (S-O) splitting could host the Majorana pair. Utilizing the interplay between superconductivity, S-O coupling and Zeeman field we laid the foundation to realize MZM. [2] We have experimentally optimized a novel stable heterostructures, to achieve all these three interactions, to directly observe the MZM pair using a low temperature with high vector field scanning tunneling microscope, by probing the ferromagnetic EuS island over the gold surface. [3] With this two-dimensional stable metal platform, by means of the Shockley surface state (SS) of (111)-gold (Au) with induced superconductivity, we can envision a novel approach to building non-local qubits that are intrinsically fault-tolerant. In this talk I will be presenting our path towards the observation of MZMs.

Supported by John Templeton Foundation Grants No. 39944 and 60148, ONR Grants N00014-16-1-2657, N00014-20-1-2306 and NSF DMR 1700137.

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Tuesday, October 20th, 15:10

Resonant p-wave oscillations of Josephson current in Nb-Bi2Te2.3Se0.7-Nb topological junctions

Alexander GOLUBOV
University of Twente

Recent proposals of inducing p-wave superconductivity by sandwiching a conventional s- wave superconductor (S) with a topological insulator (TI) triggered a burst of research activity. Topological superconductors harness the inherent electron – hole symmetry of excitations in a superconductor with the helical nature of the electronic states in topological materials, that may lead to Majorana zero energy states. Various theoretical models focused on possible pairing symmetries of the proximity induced superconducting order in topological layers. Several experimental groups already realized S-TI interfaces and S-TI-S junctions, and studied the Josephson current across them. Few papers have reported unusual Shapiro steps consistent with the formation of the p-wave correlations. However, measurements that could provide the definitive evidence of the p-wave superconductivity should be phase-sensitive, to discriminate between the p- and other (s-, d-...) pairings symmetries.

In this work we report a new type of oscillations of the critical Josephson current in magnetic field observed in the Nb-Bi2Te2.3Se0.7-Nb junctions [1,2]. The ultra-short period ~ 1 Oe of these oscillations and their sharply peaked shape reflect the resonant transmission via Andreev bound states with the ultra-fine ~ 1 μeV interlevel spacing. We argue that the ultra- fine oscillations revealed in our S-TI-S devices is the direct consequence of the p-wave superconducting order induced at S-TI contacts.

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Tuesday, October 20th, 15:50

Two-dimensional Topological Superconductivity

Eun-Ah KIM
Cornell University

One could envision different strategies for designing topological superconductivity. One strategy would be to restrict the phase space in the kinetic energy by manipulating the band structure. Another strategy would be to restrict the pairing interaction. I will our proposals following each of these strategies. For the band-structure manipulation, I will discuss the prediction of p-wave superconductivity in p-doped TMD's with intermediate interaction. I will also discuss the competition for the surface state among multiple topological orders in FeSeTe. For the strategy of manipulating pairing interaction, I will discuss our proposal of using a metal-quantum paramagnet heterostructure.

Tuesday, October 20th, 16:30

Geometrically driven effects in curved superconducting nanostructures

Paola GENTILE
University of Salerno

The most recent advances in nanotechnology have demonstrated the possibility to create flexible semiconductor nanomaterials which are bent into curved, deformable objects ranging from semiconductor nanotubes, to nanohelices, etc. The consequences of the nanowire bending on the electronic quantum properties have been demonstrated to become of particular importance in systems with structure inversion asymmetry, where the interplay between nanoscale deformations and Rashba spin-orbit coupling (RSOC) [1] allows an all-geometrical and electrical control of electronic spin textures and spin transport properties [2,3], including the possibility to induce topological nontrivial phases [4-6]. In the presence of superconducting pairing, inversion symmetry breaking (ISB) makes neither spin nor parity good quantum numbers anymore. The ensuing mixing of even spin-singlet and odd spin- triplet channels leads to a series of novel features, from unconventional surface states to topological phases. Within this framework, we have explored the impact that nanoscale geometry has on superconducting properties of low-dimensional materials, showing that the interplay between RSOC and shape deformations can lead to novel paths for a geometric manipulation of the superconducting state, both for spin-singlet and spin-triplet quantum configurations [7], then significantly affecting the Josephson effect of weak links between Rashba coupled straight superconducting nanowires with geometric misalignment [8] as well as between nanowires of topological superconductors with non-trivial geometric curvature [9].

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Tuesday, October 20th, 17:10

Topological Nature of High Temperature Superconductivity

Valerii VINOKOUR
Argonne National Laboratory

An underlying mechanism of the high temperature superconductivity (HTS) and the nature of the adjacent phases remains the biggest mystery of condensed matter physics. It is believed that the key to understanding of HTS lies in revealing the origin of the enigmatic properties of the pseudogap state that settles in the underdoped region between the superconducting transition temperature Tc and the pseudogap temperature T* > Tc. The experiments indicate that the pseudogap state is a distinct thermodynamic phase that exhibits metallic transport, magnetoelectric effect and the nematicity. We develop a unified theory that offers a quantitative description of the pseudogap phase properties and describes the observed phase diagram. The proposed mechanism of the superconductivity is the emergence of the condensate of dyons, the composite particles carrying both electric and magnetic charge, in our case the Cooper pair bound with the magnetic monopole. In the HTS phase, the dyon condensate coexists with the fundamental Cooper pair condensate and the elevated Tc results from the stabilizing effect of the monopole condensate. We show that in the pseudogap phase charged magnetic monopole condensate realizes the oblique confinement of Cooper pairs. The universality of the HTS phase diagram for different materials reflects the unique topological mechanism responsible for formation of the emerging phases. Our findings provide a topological reason for the high critical temperature in HTS.

Wednesday, October 21st, 09:00

Fingerprints of Majorana modes beyond the zero-bias conductance peak

Satoshi IKEGAYA
Max Planck Institute for Solid State Research

The unambiguous detection of Majorana bound states (MBSs) in topological superconductors has been a central topic of condensed matter physics for recent years. So far, the presence of MBSs was demonstrated experimentally in a number of topologically nontrivial superconducting systems. In this connection, clear evidences of Majorana bound states are only obtained by the detection of zero-bias conductance peaks in tunneling transport measurements. In recent years, it became clear that various additional signatures of Majorana modes need to be investigated in order to complete our understanding.

In our presentation, we summarize two unambiguous fingerprints which can act as a ‘smoking gun’evidence. First we study the anomalous nonlocal conductance due to chiral Majorana edge states in a superconductor/ferromagnet hybrid as shown in Fig. 1(a). We obtain the important result that the chiral nature of the Majorana edge states causes an anomalously long-range and chirality-sensitive nonlocal transport in this device. This, in turn, enables us to identify conclusively the moving direction and further properties of the chiral Majorana edge states [1]. Secondly, we propose a novel experiment for achieving the first experimental observation of the anomalous proximity effect caused by Majorana bound states. In particular, we discuss the differential conductance of a semiconductor/superconductor hybrid as shown in Fig. 1(b), which contains a planar topological Josephson junction realized in recent experiments. The conductance spectrum changes drastically through the topological phase transition because the Majorana bound state appearing only in the topologically nontrivial phase can penetrate into the dirty normal segment and form the resonant transmission channel there [2]. In general, our results allow contrasting singlet and triplet superconductivity employing properties of Majorana modes beyond zero bias peaks.

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Wednesday, October 21st, 10:10

Domain walls and critical currents in chiral superconductors

Manfred SIGRIST
ETH Zurich

Chiral superconductors are two-fold degenerate and domains of opposite chirality can form, separated by domain walls. While there are experimental indications for domain formation in some unconventional superconductors assumed to realize chiral Cooper pairing, there has not been any unambiguous proof for their existence. In this talk we consider the impact domain walls in chiral superconductors can have on the critical currents. For this purpose we consider various domain wall orientations for both chiral p-wave and chiral d-wave superconductors. We demonstrate that selection rules and crystalline anisotropy play an essential role in connecting the two chiral domains coherently through the domain wall. In particular, we illustrate the case of a domain wall parallel to the basal plane for a chiral p-wave superconductor. The possibility to realize half-flux vortices in these domain walls will be analyzed and used as a tool to estimate the critical currents. The possibility of experimental verication will be discussed.

Wednesday, October 21st, 11:00

Helium Ion Beam Modification of High Transition Temperature Superconductors

Shane CYBART
University of California Riverside

In Feynman's infamous 1959 lecture entitled, "There's Plenty of Room at the Bottom " he inspired and foreshadowed the emergence of nanoengineering. He suggested that finely focused electron, and ion beams would aid our eyes and hands to precisely engineer structures at the atomic level. Currently, electron beam lithography systems and gallium focused ion beams are ubiquitous in nanotechnology and can routinely be used to create structures of the order of tens of nanometers. However, the ability to scale to the sub-10 nm has been a technological challenge until the development of gas field ion sources (GFIS) over the past decade. The GFIS source, utilizes a single crystal tungsten wire sharpened to just 3 atoms. Helium gas is field ionized by one of these atoms, creating a helium ion beam with diameter of only 0.25nm! This instrument is emerging as an important tool for sub-10nm structuring of materials. Helium ion beams have significant advantages. Helium is small and chemically inert which allows it to be used for direct modification of materials properties without etching away material or employing resists.

My research group has been utilizing GFIS for direct patterning of ceramic high-temperature superconducting materials for quantum electronics. The helium ion beam induces nanoscale disorder from irradiation into the crystalline structure which converts the electrical properties of the material from superconductor to insulator. Insulating feature sizes of less than 2nm have been successfully demonstrated and many unique novel devices have been realized. Much of this success is due to the irradiation sensitivity of electrical transport in high temperature superconductors. This sensitivity results from loosely bound oxygen atoms (~1-8ev) in the crystal lattice that are easily displaced into interstitial or anti-site defects. I will describe details of the GFIS materials modification process and highlight applications in quantum sensing, and high frequency detection.

Wednesday, October 21st, 11:40

Magnetic exchange through s- and d-wave superconductors

Sachio KOMORI
University of Cambridge

At a ferromagnet / superconductor interface, a magnetic exchange field can couple with the superconducting state. For the case of an s-wave (isotropic) superconductor, the coupling manifests as a spin-splitting of the superconducting density of states which decays in the superconductor over the Cooper pair coherence length which is tens of nanometers in Nb. In a d-wave (anisotropic) superconductor, the Cooper pair coherence length is spatially anisotropic and subnanometre in all directions meaning magnetic coupling is equivalently short ranged. In this talk I will present our recent experiments on investigating magnetic coupling at ferromagnet / superconductor interfaces with s-wave (Nb) and d-wave (YBa2Cu3O7) superconductors. For Nb, superconducting spin-transport based on triplet Cooper pairs is blocked in the singlet superconducting state and rapidly-suppressed in the normal state due to spin-orbit scattering [1]. In YBCO, magnetic exchange field are found to be long-ranged, penetrating tens of coherence lengths due to the quasiparticle nodal states [2]. The results demonstrate dynamic coupling between unconventional superconductivity and magnetism.

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Wednesday, October 21st, 12:20

Domain control in the topological nematic superconductor SrxBi2Se3

Shingo YONEZAWA
Kyoto University

Topological superconductivity, accompanying non-trivial topology in its superconducting wave function, has been one of the central topics in condensed-matter physics. During the recent extensive efforts to search for topological superconducting phenomena, nematic superconductivity, exhibiting spontaneous rotational symmetry breaking in bulk superconducting quantities, has been discovered in the topological-superconductor candidates AxBi2Se3 (A = Cu, Sr, Nb) [1]. In the in-plane field-angle dependence of various superconducting properties, such as the spin susceptibility [2], the specific heat [3], and the upper critical field [4], exhibit pronounced two-fold symmetric behavior although the underlying lattice has three-fold rotational symmetry.

More recently, we succeeded in controlling nematic superconductivity in SrxBi2Se3 via external uniaxial strain [5]. In the trigonal AxBi2Se3 material, six kinds of nematic domains can be realized. By applying uniaxial strain in situ using a piezo-based uniaxial-strain device [6], we reversibly controlled the superconducting nematic domain structure. Namely, the multi-domain state under zero strain can be changed into a nearly single-domain state under 1% uniaxial compression along the a axis. This result indicates strong coupling between nematic superconductivity and lattice distortion. Moreover, this is the first achievement of domain engineering using nematic superconductors.

In this talk, I overview experiments on nematic superconductivity, with a focus on our specific-heat study of CuxBi2Se3 [3]. I then explain our recent demonstration of uniaxial-strain control of nematic superconductivity in SrxBi2Se3 [5,6].

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Wednesday, October 21st, 14:00

Chiral Molecules as Topological Devices- The Chiral Induced Spin Selectivity Effect

Ron NAAMAN
Weizmann Institute of Science

Spin based properties, applications, and devices are commonly related to magnetic effects and to magnetic materials or materials with large spin orbit coupling. However, we found that chiral molecules act as spin filters for photoelectrons transmission, in electron transfer, and in electron transport.

The new effect, termed Chiral Induced Spin Selectivity(CISS) [1], was found, among others, in bio-molecules and in bio-systems as well as in inorganic chiral crystals. It has interesting implications for the production of new types of spintronics devices [2], in controlling magnetization [3], and on electron transfer and conduction. Recently we also found that charge polarization in chiral molecules is accompanied by spin polarization. This finding shed new light on spin dependent interaction between chiral molecules and between them and magnetic surfaces [4].

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Wednesday, October 21st, 15:10

Unconventional superconductivity and magnetic-related states induced in a conventional superconductor by nonmagnetic chiral molecules

Oded MILLO
Hebrew University of Jerusalem

Hybrid ferromagnetic/superconducting systems are well known for hosting intriguing phenomena such as emergent triplet superconductivity at their interfaces and the appearance of in-gap, spin-polarized Yu-Shiba-Rusinov (YSR) surface-states bound to magnetic impurities. In this work we demonstrate that similar phenomena can be induced on a surface of a conventional superconductor upon chemisorbing non-magnetic chiral molecules. By applying scanning tunneling spectroscopy, we show that the singlet-pairing s-wave order parameter of Nb, NbN and NbSe2 is significantly altered upon the adsorption of chiral polyalanine alpha-helix molecules on the surface. The tunneling spectra exhibit zero-bias conductance peaks embedded inside gaps or gap-like features, suggesting the emergence of a triplet-pairing component, corroborated by fits to theoretical spectra. Conductance spectra measured on devices comprising NbSe2 flakes over which these chiral molecules were adsorbed, exhibit, in some cases, in-gap states nearly symmetrically positioned around zero bias. These states shift apart with magnetic field, akin to YSR states, as corroborated by theoretical simulations. Other samples show evidence for a collective phenomenon of hybridized YSR-like states giving rise to unconventional, possibly triplet superconductivity, manifested in the conductance spectra by the appearance of a zero bias conductance peak that diminishes, but does not split, with magnetic field. The transition between these two scenarios appears to be governed by the density of adsorbed molecules. Chiral molecules were also found to have a unique signature on the TC of Nb and NbRe films when linking Au nanoparticles to them. Finally, low-energy muon spin rotation (LE-μSR) data demonstrate clear evidence for a strong modification of the screening supercurrent distribution deep inside a Nb film upon adsorption of chiral molecules, providing evidence for unconventional chiralinduced superconductivity. The adsorption-modified local magnetic field profile inside the (65 nm thick) Nb film monitored by LE-μSR, a measure of the screening modification, is well fitted to a model calculation where the chiral molecules layer is considered as an insulating spin-active interface that is proximity-coupled to the Nb film.

The work was done in collaboration with the following groups: Yossi Paltiel, Hen Alpern, Nir Sukenik, Tamar Shapira, Shira Yochelis (The Hebrew University of Jerusalem), Jason Robinson, Harry Bradshaw (University of Cambridge), Angelo Di Bernardo, Elke Scheer (Konstanz University), Jacob Linder (Norwegian University of Science and Technology).

Thursday, October 22nd, 09:00

The Josephson effect as a tool for creating topological superconductivity

Ady STERN
Weizmann Institute of Science

In this talk I will describe how the Josephson effect may be employed to realize one dimensional topological superconductivity. I will describe the basic idea, the experimental observations, the relation to topological superconductivity based on quantum wires, a surprising effect of disorder, and a scheme for braiding Majorana zero modes in Josephson junctions.

Thursday, October 22nd, 10:10

Odd-frequency pairing in topological superconductors

Yukio TANAKA
Nagoya University

It is known that odd-frequency pairing ubiquitously presents in superconductor junctions [1]. Especially, in the presence of zero energy surface Andreev bound state (ZESABS) realized in topological superconductors, the odd-frequency pairing is amplified near the surface or interface. One of the remarkable property generated by odd-frequency pairing is anomalous proximity effect in diffusive normal metal (DN) / superconductor junction where quasiparticle density of states in DN has a zero energy peak (ZEP) of LDOS due to the penetration of odd-frequency spin-triplet s-wave pairing [2,3]. It has been shown that proximity coupled nano-wire junction [4] is an idealistic system to study anomalous proximity effect due to odd-frequency triplet-s wave pairing [5].

We have further clarified the relation between induced odd-frequency pairing and the bulk quantity defined by Green's function[6]. Odd-frequency Cooper pairs with chiral symmetry emerging at the edges are a useful physical quantity. We have shown that the odd-frequency Cooper pair amplitudes can be expressed by a winding number extended to a nonzero frequency and can be evaluated from the spectral features of the bulk. We have found that the odd-frequency Cooper pair amplitudes are classified into two categories: the amplitudes in the first category have the singular functional form proportional to 1/z (where z is a complex frequency) that reflects the presence of ZESABS, whereas the amplitudes in the second category have the regular form proportional to z.

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Recently, we have found that the presence of ZESABS generates new type of thermopower.

We have shown that the thermoelectric effect in ferromagnet / superconductor junctions can be entirely dominated by ingap Andreev reflection processes. Consequently, the electric current from a temperature bias changes sign in the presence of ZESABS and resulting odd-frequency pairing [7].

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Thursday, October 22nd, 11:00

Evaluation of chiral superconductivity in Sr2RuO4

Clifford HICKS
Max-Planck-Institute for Chemical Physics of Solids

Several previous experimental results give evidence that the superconductivity of Sr2RuO4 is chiral. These include measurements of the Kerr effect, critical currents across junctions between Sr2RuO4 and conventional superconductors, sound velocities, and muon spin relaxation. Through recent NMR Knight shift measurements it is now understood that the pairing is most likely spin-singlet [1,2], and on the tetragonal lattice of Sr2RuO4 the combination of singlet pairing and chirality compels consideration of an unlikely order parameter: dxz ± idyz. It is unlikely because it has a horizontal line noad at kz=0, and Sr2RuO4 has a very low c-axis conductivity. Therefore, a firm determination of whether or not the superconductivity of Sr2RuO4 is chiral is highly important, as it may imply a new form of pairing. Here, I present evidence from experiments under uniaxial stress applied along the [100] direction. Tc rises rapidly [3]. By lifting the tetragonal symmetry of the lattice, uniaxial stress is expected to induce a splitting between Tc and the onset temperature of chirality, TTRSB. In muon spin rotation experiments under uniaxial stress, a large splitting is observed: TTRSB is found to remain low while Tc i ncreases [4]. However, in heat capacity measurements, no second heat capacity anomaly is observed; the upper limit on any heat capacity anomaly at TTRSB is ~5% of that at Tc [5]. In scanning SQUID magnetometry studies [6], a cusp in the strain dependence of Tc, implied by transition splitting, is not observed. In this talk I will discuss possibilities to reconcile these results.

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Thursday, October 22nd, 11:40

One-dimensional moiré charge density wave in the hidden order state of URu2Si2 induced by fracture

Edwin HERRERA
UAM Madrid

URu2Si2 is a heavy fermion system which crystallizes in a tetragonal structure and where superconductivity emerges inside the misterious hidden order phase. The latter consists of a still unknown type of order that appears together with a strong entropy reduction below 17.5 K. URu2Si2 becomes superconducting below 1.5 K. The hidden order phase is characterized by dynamical spin modes at q0=(0 0 1) and q1=(0.6 0 0). These quench into an antiferromagnetic order under pressure (q0=(0 0 1)) and at high magnetic fields (q1=(0.6 0 0)). Here I will show recent Scanning Tunneling Microscopy experiments (STM) at very low temperatures (0.1 K). I will report on the discovery of a charge modulation with a wavevector that is a moiré combination of the atomic lattice periodicity and q1, produced by fracturing the crystal in presence of the dynamical spin mode at q1. Our results suggest that charge interactions are a fundamental ingredient that competes with hidden order in URu2Si2 and advance controlled fracture as powerful means to obtain ground states derived from strong electronic correlations [1]. Furthermore, I will show results at surfaces with large amounts of atomically flat steps showing the U fourfold lattice. There we find a new heavy fermion 2D-electron gas type of surface state with an effective mass 17 times the free electron mass. We discuss lateral quantization of such 2D heavy electrons and the interaction of the surface band with bulk superconductivity.

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Thursday, October 22nd, 12:20

Long range unconventional Josephson effect across a half metallic ferromagnet

Jacobo SANTAMARIA
Complutense University of Madrid

The Josephson effect results from the coupling of two superconductors across a non- superconducting spacer to yield a quantum coherent state. In ferromagnets, singlet (opposite- spin) Cooper pairs decay over very short distances, and thus Josephson coupling requires a nanometric spacer. This is unless equal-spin triplet pairs are generated which, theoretically, can couple superconductors across much longer distances. Despite many experimental hints of triplet superconductivity, long range triplet Josephson effects have remained elusive. In this talk I will discuss a micron-range Josephson coupling across the half-metallic ferromagnet

La0.7Sr0.3MnO3 combined with the high-temperature superconductor YBa2Cu3O7 in planar junctions. These display the Josephson physics' hallmarks: critical current oscillations due to flux quantization and quantum phase locking under microwave excitation. The marriage of high- temperature quantum coherent transport and full spin polarization brings unique opportunities for the practical realization of superconducting spintronics, and enables novel strategies for quantum computing.

Poster Abstracts

In-gap states emerging from magnetic nanostructures deposited on superconductors

Uriel ACEVES
Forschungszentrum Jülich

Recently, the importance of superconductivity reflourished in the context of topo- logical superconductivity, an essential field for state-of-the-art realizations of quan- tum computing. Electronic states emerging inside the superconducting gap play a vital role there, such as the topologically trivial Shiba-Yu-Rusinov states, Andreev bound states, and non-trivial Majorana bound states usually induced by impurities. This field can give rise to unforeseen breakthroughs in basic research and future technologies when interconnected to standard spintronic applications. Theoretical frameworks based on a realistic description of the electronic structure of supercon- ducting materials interfaced with magnetic systems are necessary to understand and predict related phenomena. This is the goal of my work.

In my poster I present the basic theory behind a self-consistent multi-orbital su- perconducting tight-binding scheme and its implementation in our software TITAN. With it, we explored the impact of the self consistency in the magnitude of the ef- fective gap. While most of the scanning tunneling microscopy studies were devoted to in-gap bound states induced by the presence of impurities, here we investigate the potential emergence of in-gap bands enabled by interfacing a Fe monolayer de- posited on a Nb(110) substrate, favored by the large superconducting gap of Nb.

Tomography of zero-energy end modes in topological superconducting wires

Armando ALIGIA
Centro Atomico Bariloche, Argentina

We characterize the Majorana zero modes in topological hybrid superconductor-semiconductor wires with spin-orbit coupling and magnetic field, in terms of generalized Bloch coordinates φ, θ, δ, and analyze their transformation under SU(2) rotations. We show that, when the spin-orbit coupling and the magnetic field are perpendicular, φ and δ are universal in an appropriate coordinate system. We use these geometric properties to explain the behavior of the Josephson current-phase relation, in junctions of two wires with different orientations of the magnetic field and/or the spin-orbit coupling. We show how to extract from there, the angle θ, hence providing a full description of the Majorana modes. Simple analytical expressions describe accurately the numerical results.

Mesoscopic conductance fluctuations and noise in disordered Majorana wires

Daniil ANTONENKO
Skoltech / Landau Institute

Superconducting wires with broken time-reversal and spin-rotational symmetries can exhibit two distinct topological gapped phases and host bound Majorana states at the phase boundaries. When the wire is tuned to the transition between these two phases and the gap is closed, Majorana states become delocalized leading to a peculiar critical state of the system. We study transport properties of this critical state as a function of the length L of a disordered multichannel wire. Applying a non- linear supersymmetric sigma model of symmetry class D with two replicas, we identify the average conductance, its variance and the third cumulant in the whole range of L from the Ohmic limit of short wires to the regime of a broad conductance distribution when L exceeds the correlation length of the system. In addition, we calculate the average shot noise power and variance of the topological index for arbitrary L. The general approach developed in the paper can also be applied to study combined effects of disorder and topology in wires of other symmetries.

Anisotropy of the upper critical field of Sr2RuO4 under in-plane magnetic field and current

Ryo ARAKI
Department of Physics, Kyoto University

Since the discovery of the superconductivity of Sr2RuO4[1], many researchers have discussed the superconducting pairing symmetry. Though it has been long believed that the order parameter is represented by d-vector parallel to c-axis, recent NMR Knight-shift experiments using low-energy pulses have shown that the Knight shift decreases by about 60% below the transition temperature and pointed out that the superconductivity of Sr2RuO4 is probably in a spin-singlet state or triplet state with d-vector parallel to the ab plane[2].

Also, we can debate on the symmetry in the respect of behaviors of various physical quan- tities near the upper critical magnetic field, Hc2. For instance, measurements of the mag- netocaloric effect revealed that the superconducting transition becomes first order when the fields are parallel to the ab-plane at about 0.8 K or less [3]. This result suggests the super- conductivity is in singlet state or triplet state expressed by d-vector in the ab-plane.

The motive of our experiment is investigation of transport properties toward understanding of origin of the first order transition and the superconducting pairing symmetry. We measure the resistivity of the Sr2RuO4 sample processed by FIB in I and H parallel to the ab-plane. In our research so far, at 0.33 K under I = 100 μA, we observed the first order transition, the ordinary 4-fold rotational symmetry and the unusual 2-fold rotational symmetry[4]. In addition, we measured the resistivity sweeping the values of the in-plane field or temperature. I'll talk about these results and discuss the superconducting symmetry of Sr2RuO4 in this workshop.

One-Dimensional Moiré Superlattices and Magic Angle Physics in Collapsed Chiral Carbon Nanotubes

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The discovery of superconducting and correlated insulating behavior in twisted bilayer graphene (TBG) has shaken up the field of two-dimensional (2D) materials, reinvigorating the study of graphene-based systems [1]. We demonstrate that one-dimensional moiré patterns, analogous to those found in twisted bilayer graphene, can arise in collapsed chiral carbon nanotubes (CNT)

[2]. Resorting to a combination of approaches, namely, molecular dynamics to obtain the relaxed geometries and tight-binding calculations validated against ab-initio modeling, we find that magic angle physics occur in collapsed carbon nanotubes. Velocity reduction, flat bands, and localization in AA regions with diminishing moiré angle are revealed, showing a magic angle close to 1°.

Superconductivity in TBG was an unexpected phenomenon, so the quest for other systems which could be the 1D analogues of TBG is of great importance to elucidate the nature of superconductivity found therein. Moreover, nontrivial topological phases have been found in the magic angle regime and are closely related to flat bands [3]. Therefore, chiral collapsed carbon nanotubes stand out as promising candidates to explore topology and superconductivity in low dimensions, emerging as the one-dimensional analogues of twisted bilayer graphene.

Role of canting and depleted-triplet minima in superconducting spin valve structures

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The trilayer and pentalayer spin valve structures are revisited to determine the behavior of pair correlations and Josephson current when the magnetic layers are canted at arbitrary angle. The two systems display markedly different behaviors in the center magnetic layer. While the trilayer generates a triplet component that is weakly affected by canting, the pentalayer tunes in singlet pair correlations depending heavily on canting. We also show that a minimum with depleted $m = \pm 1$ triplet components, rather than a 0–π transition, may be observed in the current profile $I_c(d_F)$ of a trilayer spin valve. The depleted-triplet minimum is directly attributable to a decrease of $m = \pm 1$ triplet correlations with increased thickness of the central ferromagnet, accompanied by a hidden, simultaneous sign change of the Gor'kov functions contributed from the left and right superconductors. We introduce a toy model for superconducting-magnetic proximity systems to better illuminate the behavior of individual components of the Gor'kov function and compare with a full numerical calculation.

Infinite Magnetoresistance at a Rare Earth Ferromagnet / Superconductor Interface

Harry BRADSHAW
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An external magnetic field on a superconductor couples to the orbital motion of electrons, creating circulating currents and the Meissner effect, and couples to the spin of electrons which spin-splits the superconducting density of state (DoS). In a pioneering paper [1], Tedrow and Kumar demonstrated a spin-splitting of the superconducting DoS in Al in the absence of an external magnetic field by depositing Al onto a rare earth f-orbital ferromagnetic insulator (FI).

The spin-splitting in S on an FI and thus the magnitude of the magnetic exchange field (Ex) at the S/FI interface can be quantified via quasiparticle tunnelling DoS measurements. Alternatively, Ex can be indirectly quantified via critical temperature (Tc) measurements of an S/FI bilayer: at magnetic coercivity (Hc) the net magnetization of the FI is zero, which translates to a net reduction in Ex in S and an enhancement of Tc relative to magnetic saturation (Hs) - i.e. DTc = Tc (Hc)- Tc (Hs) > 0 and values can exceed 0.5 K in Al/EuS bilayers [2]. Such domain wall enhanced superconductivity is also achieved using metallic transition metal (s-d orbital) ferromagnets (F), but DTc values tend to be a few mK [3,4] and justified on the basis of diffusion of superconductivity into F. In this poster we demonstrate values of DTc that exceed 150 mK in Nb/Ho bilayers where Ho is an f-orbital ferromagnet with a metallic band structure. These results are in stark contrast to transition metal F, but show similarities to S/FI bilayers, indicating that the proximity effect in superconductor bilayers systems with rare earth ferromagnets is dominated by a coupling mechanism between the superconductivity and f-orbital moments.

Robustness of unconventional s-wave superconducting states against disorder

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The University of Otago

Unconventional superconductors are infamously unstable against the presence of nonmagnetic disorder, while the critical temperature of a conventional superconductor is insensitive to such disorder, as encapsulated in Anderson's theorem. Generalization of Anderson's theorem to superconductors with multiple bands has proven difficult. We investigate the robustness against disorder of superconductivity in systems with two bands [1]. In these multi-band systems, unconventional superconducting states are possible with momentum-independent (s-wave) pairing functions. We have developed a general framework, based on the self-consistent Born approximation, to understand the stability of orbitally non-trivial superconductors against disorder, and applied this framework to the candidate topological superconductor CuxBi2Se3. Unconventional s-wave states are found to be significantly more robust against disorder than the analogous single- band states. Additionally, superconductors with momentum-dependent gaps in multi-band systems inherit some robustness against disorder from the s-wave states with the same symmetry, in a significant deviation from the behavior exhibited in single-band superconductors.

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Topological skyrmion phases of matter

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We introduce topological phases of matter defined by skyrmions in the ground state spin—or pseudospin—expectation value textures in the Brillouin zone, the chiral and helical topological skyrmion phases of matter. These phases are protected by a symmetry present in all centrosymmetric superconductors and detectable by spin-ARPES. We study the physics both in simple toy mod- els and also a tight-binding model for spin-triplet superconductivity in transi- tion metal oxides. We find the latter model realizes each of these topological skyrmion phases. The chiral phase is furthermore realized for a parameter set characterizing Sr2RuO4 with spin-triplet superconductivity. We also find two types of topological phase transitions by which the skyrmion number can change. The second type occurs without the closing of energy gaps in a system described by a quadratic Hamiltonian without breaking the protecting symmetries when spin-orbit coupling is non-negligible. This contradicts the "flat band" limit as- sumption of the entanglement spectrum, Wilson loops, and the ten-fold way classification scheme of topological phases of matter.

Interlayer scattering in twisted double bilayer graphene

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Twisted graphene heterostructures recently emerged as a new platform for correlated states, such as superconductivity. Even though many theoretical models are proposed, the nature of this superconductivity remains unknown. To potentially shine light on the coupling mechanism of electrons in twisted graphene, we here investigate the interlayer scattering mechanisms in twisted double bilayer graphene. We choose to use an intermediate twist angle, where the heterostack behaves as a weakly coupled double quantum well [1,2]. We investigate the scattering between the two bilayers by studying magneto interlayer oscillations and find two regimes with enhanced interlayer scattering. Close to the Lifshitz transition, the temperature dependent resistivity reveals that scattering is dominated by electron-phonon processes. At the onset of the second sub band, interlayer scattering is observed likely due to electron-electron or impurity scattering.

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Non-trivial effects in “trivial” hybrid nanowire-superconductor devices

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Trivial superconductivity in Rashba nanowires can be masked as topological superconductivity. For example, zero-bias conductance peaks and re-entrant supercurrents against magnetic field can also show in trivial nanowires hosting quantum dots [1,2]. In the trivial case, these signatures are a consequence of the Yu-Shiba-Rusinov (YSR) spin-screening mechanism, in itself a complex phenomenon in which Cooper pairing, Coulomb blockade and exchange compete to determine the ground state. Understanding the full range of physical manifestations of the YSR mechanism in nanowires is of fundamental importance if a clear demarcation between trivial and topological effects is to be established.

We present electrical measurements at dilution-refrigerator temperatures on devices based on individual InAs nanowires with epitaxially-grown superconductors [3]. Single and double quantum dots can be confined in the nanowires, constituting realizations of the one and two- impurity YSR models [4,5,6]. The influence of the confined spins on the neighbouring superconductors is studied through their effect on the Josephson supercurrent and on the discrete subgap excitations. While our data can be described by standard YSR models up to some degree, unexpected features and/or additional complexity are also observed [4,5,6], which we hope will motivate future theoretical developments towards a more complete understanding of the full spectrum of trivial phenomenology in hybrid nanowire devices.

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Spontaneous emergence of Josephson junctions in homogeneous rings of single-crystal Sr2RuO4

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For more than two decades Sr2RuO4 was the leading candidate for chiral spin-triplet superconducting pairing. Due to recent NMR experiments revealing the suppressed spin susceptibility below the superconducting transition, other pairing symmetries have been proposed. A common factor between these proposals is the two-component nature of the order parameter that can break up the superconductor into superconducting domains. At the boundary between domains, the condensate is suppressed and can manifest itself as a Josephson junction. This poster shows the spontaneous appearance of these domain walls in microstructured ultra-pure (Tc of 1.5K) loops of Sr2RuO4 by the use of magnetic interferometry measurements and the detection of Shapiro steps under RF-radiation. These findings are consistent with the two-component picture. Applying an in-plane magnetic field reveals that a two-state system is formed that can be reproducibly switched using the application of current in the device.

Topological charge, spin and heat transistor

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Spin pumping consists in the injection of spin currents into a non-magnetic material due to the precession of an adjacent ferromagnet. In addition to the pumping of spin the precession always leads to pumping of heat, but in the presence of spin-orbital entanglement it also leads to a charge current. We investigate the pumping of charge, spin and heat in a device where a superconductor and a topological insulator are in proximity contact with a ferromagnetic insulator. We show that the device supports two robust operation regimes arising from topological effects. In one regime, the pumped charge, spin and heat are quantizated and related to each other due to a topological winding number of the reflection coefficient. In the second regime, a Majorana zero mode switches off the pumping of currents owing to the topologically protected perfect Andreev reflection. We show that the interplay of these two effects can be utilized so that the device operates as a robust charge, spin and heat transistor.

Orbital tunable 0-π transitions in Josephson junctions with noncentrosymmetric topological superconductors

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Josephson effects play a main role of the determination of pairing symmetry in solid state physics. At the oxide interface superconductor LaAlO3/SrTiO3 [1], that has two- dimensional electron gas with inversion symmetry breaking, strong spin-orbit coupling, and orbital degrees of freedom, to determine the pairing symmetry is one of the issues. In the recent experiment of the Josephson junction with the two pieces of LaAlO3/SrTiO3, zero-vias conductance peak and anomalous temperature dependence of the Josephson current have been observed and these results indicate the unconventional superconductivity at LaAlO3/SrTiO3 [2]. In addition, interorbital topological superconductivity with spin-triplet/orbital-singlet/s-wave state has been proposed in two- dimensional multiorbital superconductors with inversion symmetry and spin-orbit coupling [3].

In this study, we calculate the Josephson transport properties in a Josephson junction consisting of a conventional s-wave superconductor coupled to a multiorbital noncentrosymmetric superconductor marked by an orbitally driven inversion asymmetry and isotropic interorbital spin-triplet pairing, e.g. oxide interface [4]. We demonstrate that the local interorbital spin-triplet pairing is tied to the occurrence of sign-changing spin- singlet pair amplitude on different bands with d-wave symmetry. Such multi-band d-wave state is a unique superconducting configuration that drives unexpected Josephson effects with 0-□ transitions displaying a high degree of electronic control. Remarkably, we find that the phase state of a noncentrosymmetric/s-wave Josephson junction can be toggled between 0 and □ in multiple ways through a variation of electron filling, strength of the spin-orbital coupling, amplitude of the inversion asymmetry interaction, and junction transparency. These results highlight an intrinsic orbital and electrical tunability of the Josephson response and provide unique paths to unveil the nature of unconventional multiorbital superconductivity as well as inspire innovative designs of Josephson quantum devices.

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SQUID imaging of the intermediate state of the type-I superconductor PdTe2

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The Dirac semimetal PdTe2 becomes superconducting at a temperature Tc=1.6 K. Thermodynamic and muon spin rotation experiments support type-I superconductivity, which is unusual for a binary compound. A key property of a type-I superconductor is the intermediate state which presents a coexistence of superconducting and normal domains (flux structures) at magnetic fields lower than the thermodynamic critical field Hc. By means of scanning SQUID microscopy (SSM) we observe flux structures in the superconducting state of PdTe2. The flux structures are strongly history dependent with a transition from round shapes to laminar shapes as the magnetic field is increased (see Fig. 1). We observe Landau branching and derive the domain-wall width.

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Manipulation of time reversal symmetry breaking superconductivity in Sr2RuO4 by uniaxial stress

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Although the normal-state electronic structure of Sr2RuO4 is known with exceptional precision, even after two decades of research, the symmetry of it’s certainly unconventional superconducting state is under strong debate, e.g. the long time favored spin-triplet px + ipy state is ruled out by recent NMR experiments [1]. However, in general time-reversal-symmetry breaking (TRSB) superconductivity indicates complex two-component order parameters. Probing Sr2RuO4 under uniaxial stress offers the possibility to lift the degeneracy between such components [2]. One key prediction for Sr2RuO4, a splitting of the superconducting and TRSB transitions under uniaxial stress has not been observed so far. Here, we report results of muon spin relaxation (μSR) measurements on Sr2RuO4 placed under uniaxial stress [3]. We observed a large stress-induced splitting between the onset temperatures of superconductivity and TRSB. Moreover, at high stress beyond the van Hove singularity, a new spin density wave ordered phase is observed. In order to perform μSR measurements under uniaxial stress a custom strain device was developed [4].

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Robust Weak-Antilocalization effect in Bi2Se3 thin films

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Topological insulators (TIs) have emerged as a novel class of quantum materials with an insulating bulk, and spin-polarized metallic states at the surface that behave as Dirac fermions [1]. These surface states are topologically protected by time reversal symmetry and backscattering against non-magnetic impurities is suppressed. Their unique properties make them ideal platforms for the realization of innovative applications such as topological quantum computing [2] or spintronics [3]. Among the TIs discovered so far, Bi2Se3 has attracted much attention due to its simple surface band structure, consisting of a single Dirac cone at the centre of the Brillouin zone, and to its relatively large bulk band gap of 0.3 eV [4]. The fabrication of high-quality films is crucial for the study and control of surface transport in this material and for its incorporation into technological applications.

Although the existence of topological surface states in Bi2Se3 is systematically demonstrated through spectroscopic techniques such as Angle-Resolved Photoemission Spectroscopy (ARPES) [5], surface transport is usually obscured by the strong contribution of the bulk. However, the characteristic □ Berry phase carried by electrons in TIs gives rise to exotic phenomena. In the quantum diffusive regime, electrons can interfere with themselves, and when performing closed paths, this interference is destructive in TIs, representing a positive correction to conductivity known as Weak-Antilocalization (WAL) effect [6], observed in magnetoresistance measurements. WAL is determined by spin-orbit interactions in the material, as well as, the phase coherence length of carriers, and its study through magnetotransport experiments can provide plenty of information of the motion of electrons in Bi2Se3.

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In this work, we review the study of WAL in Bi2Se3 thin films during the years since it was observed for the first time in 2010 [7]. Thin films are ideal systems to explore this effect due to their geometry that confines the movement of electrons in a planar region, increasing the contribution of closed paths. Furthermore, confinement in thickness direction affects transport in a very interesting way and helps to increase surface contribution, which is crucial in TIs. In many cases, the analysis of WAL in magnetotransport can be used to determine film quality and provides a tool to discern surface transport, even though a quantitative study usually requires the observation of other phenomena such as quantum oscillations.

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s+is superconductivity in $Ba_{1-x}K_xFe_2As_2$

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In general, magnetism and superconductivity are antagonistic to each other. However, there are several families of superconductors in which superconductivity coexists with magnetism, and a few examples are known where the superconductivity itself induces spontaneous magnetism. The best known of these compounds are Sr_2RuO_4 and some non-centrosymmetric superconductors. Here, we report the finding of a narrow dome of an s + is superconducting phase with a broken time-reversal symmetry (BTRS) inside the broad s-wave superconducting region of the centrosymmetric multiband superconductor $Ba_{1-x}K_xFe_2As_2$ ($0.7 \lesssim x \lesssim 0.85$). We observe spontaneous magnetic fields inside this dome using the muon spin relaxation (μSR) technique. Furthermore, our detailed specific heat study reveals that the BTRS dome appears very close to a change in the topology of the Fermi surface. With this, we experimentally demonstrate the emergence of a novel quantum state due to topological changes of the electronic system. See figure 1, adopted from the following references [1, 2].

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Detection of hole pockets in the candidate type-II Weyl semimetal MoTe2 from Shubnikov-de Haas quantum oscillations

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Transition-metal dichalcogenides MoTe2 has been intensively studied owing to its intriguing physical properties such as the non-saturating, quadratic extremely large magnetoresistance (XMR). Td-MoTe2 is a candidate of type-II Weyl semimetal, in which the Weyl points arise from linear crossing at the boundary between electron and hole pockets. In addition, the 1T'-MoTe2 is predicted to host higher order topological state [1]. A recent focus on MoTe2 concerns the possibility to realize topological superconductivity. At ambient pressure, MoTe2 undergoes a superconducting transition at ~ 0.1 K and Tc can be significantly enhanced by applying pressure. The μSR study under pressure and the study on Td-phase MoTe2−xSx suggested the possible s+-superconducting gap [2,3].

For a thorough discussion of MoTe2, it is imperative to understand its electronic structure. The bulk electronic structure of Td-MoTe2 features large hole Fermi pockets at the Brillouin zone center (Γ) and two electron Fermi surfaces along the Γ − X direction. However, the large hole pockets, whose existence has important implications for the Weyl physics of Td-MoTe2, had never been conclusively detected in quantum oscillations. This raises doubt on the realizability of Majorana states in Td-MoTe2, because these exotic states rely on the existence of Weyl points, which originated from the same band structure predicted by DFT. Here, we report an unambiguous detection of these elusive hole pockets via Shubnikov-de Haas (SdH) quantum oscillations. At ambient pressure, the quantum oscillation frequencies for these pockets are 988 T and 1513 T and the quasiparticle effective masses m* are 1.50 me and 2.77 me, respectively, when the magnetic field is applied along the c-axis. This result indicating the importance of Coulomb interactions in this system. We further measure the SdH oscillations under pressure. At 13 kbar, we detected a peak at 1798 T with m* = 2.86 me. Relative to the oscillation data at a lower pressure, the amplitude of this peak experienced an enhancement, which can be attributed to the reduced curvature of the hole pockets under pressure. Combining with DFT + U calculations, our data shed light on why these important hole pockets had not been detected until now.

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Multiorbital odd-frequency pairing in a ferroelectric superconductor SrTiO3

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We demonstrate that SrTiO3 (STO) can be a platform for observing the bulk odd-frequency pair correlations owing to the multiorbital nature [1]. We consider a three-orbital tight-binding model for STO in the vicinity of a ferroelectric critical point such as Sr1-xCaxTiO3-y [2]. Assuming an intra-orbital spin-singlet s-wave superconducting order parameter, it is shown that the odd- frequency pair correlations are generated due to the intrinsic LS coupling which leads to the local orbital mixing. Furthermore, we show the existence of additional odd-frequency pair correlations in the ferroelectric superconducting phase [3,4], which is induced by an odd-parity orbital hybridization term proportional to the ferroelectric order parameter. We also perform a group theoretical classification of the odd-frequency pair amplitudes based on the fermionic and space group symmetries of the system. The classification table enables us to predict dominant components of the odd-frequency pair correlations based on the symmetry of the normal state Hamiltonian that we take into account. Furthermore, we show that experimental signatures of the odd-parity orbital hybridization, which is an essential ingredient for the ferroelectricity-induced odd-frequency pair correlations, can be observed in the spectral functions and density of states.

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Discovery of superconductivity in the line-nodal material CaSb2

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In the last decade, topological materials, which have non-trivial topology in the electronic state of the bulk, have been attracting much attention. The line-nodal material is a gapless topological material that has linear nodes. In contrast to the Dirac or Weyl semimetal, a line-nodal material has the conduction and valence bands touching along a line in the reciprocal space.

CaSb2, crystallizing in the P21/m space group, has recently been proposed theoretically as a candidate of the line-nodal material [1]. The most interesting point is that the line nodes of this material are protected by the non-symmorphic 21 symmetry of the crystal. Thus, the line nodes can exist stably even under spin-orbit interaction. This year, we discovered that CaSb2 exhibits superconductivity at approximately 1.7 K [2]. Theoretically, the possibility of topological superconductivity due to the degree of freedom of the antimony orbitals has also been pointed out [2]. In this poster presentation, we will explain superconducting properties of CaSb2, such as electrical resistivity (Figure) and magnetic susceptibility.

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Superconducting Sr_2RuO_4 thin film growth achieved by interface engineering

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The layered perovskite Sr2RuO4 has been studied intensively with possible topological superconductivity and potential application for quantum computing. [1] Recently, as the debate over the nature of the superconducting symmetry of Sr2RuO4 has intensified, new experimental approaches are required to clarify the underlying physics. [2] In this respect, Sr2RuO4 thin film is highly required by providing a platform for Josephson junctions or spin-valve devices with a well-controlled geometry, which is important for detailed studies of the superconducting state. [3] However, superconductivity in Sr2RuO4 thin films is extremely sensitive to structural defects owing to the unconventional nature of the paring symmetry and the long in-plane superconducting coherence length (ξab ~ 66 nm). [4] Especially, out-of-phase boundaries (OPBs) are considered as a significant obstacle that hindered the superconductivity of Sr2RuO4 thin films. [5]

In this presentation, we will introduce superconducting Sr2RuO4 thin films growth by pulsed laser deposition (PLD) technique. To suppress the OPBs, we controlled the film-substrate interface by employing intentionally induced intergrowth or layered perovskite-structure substrate. Consequently, our SRO214 thin films exhibited robust superconductivity up to 1.15 K, with sharp resistive transition width (ΔTc ~ 0.1 K). Our work suggests approaches to obtain superconducting Sr2RuO4 film by PLD, which provides broad opportunities to investigate the superconducting symmetry of Sr2RuO4.

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Two-channel anomalous Hall effect in SrRuO3

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Skyrmions are topologically non-trivial chiral magnetic bubbles which can be observed with the 'topological Hall effect'. 4 to 5 unit cell thick SrRuO3 films show an extra Hall peak often attributed to the topological Hall effect from skyrmions [1,2].

This poster shows evidence that these peaks instead result from the superposition of two anomalous Hall effects from 4 and 5 unit cell thick regions, and more generally this shows that a non-monotonic Hall signal is not unambiguous evidence of a topological Hall effect.

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Microwave Spectroscopy Reveals the Quantum Geometric Tensor of Topological Josephson Matter

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Quantization effects due to topological invariants such as Chern numbers have become very relevant in many systems, yet, key quantities as the quantum geometric tensor (QGT) [1] providing local information about quantum states remain experimentally difficult to access. Recently, it has been shown that multiterminal Josephson junctions (MJJs) constitute an ideal platform to synthesize topological systems in a controlled manner and that the time-averaged transconductance between two terminals is quantized in terms of the Chern number [2-5]. Although first experiments towards ballistic MJJs have been performed [6,7], a direct way to measure the local QGT of Andreev states has not been proposed yet. We address this theoretically by studing properties of Andreev states in topological Josephson matter and demonstrate that the QGT of Andreev states can be extracted by synthetically polarized microwaves [8]. The oscillator strength of the absorption rates provides direct evidence of topological quantum properties of the Andreev states.

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Oxygen Vacancy Engineering for Highly Tunable Ferromagnetic Properties: A Case of SrRuO3 Ultrathin Film with a SrTiO3 Capping Layer

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Oxide heterostructures have great potential for spintronics applications due to their well-defined heterointerfaces and vast functionalities. To integrate such compelling features into practical spintronics devices, effective control of the magnetic switching behavior is key. Here, continuous control of the magnetic coercive field in SrTiO3/SrRuO3 ultrathin heterostructures is achieved by oxygen vacancy (VO) engineering. Pulsed laser deposition of an oxygen-deficient SrTiO3 capping layer can trigger VO migration into the SrRuO3 layer while avoiding the formation of Ru vacancies. Moreover, by varying the thickness and growth conditions of the SrTiO3 capping layer, the value of the coercive field (HC) in the ferromagnetic SrRuO3 layer can be continuously tuned. The maximum enhancement of HC at 5 K is 3.2 T. Such a wide-range tunability of HC may originate from a VO-induced enhancement of perpendicular magnetic anisotropy and domain wall pinning. This study offers effective approaches for controlling physical properties of oxide heterostructures via VO engineering, which may facilitate the development of oxide-based functional devices.

Majorana vortex zero modes in superconducting topological crystalline insulators

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Majorana fermions bound to a superconducting vortex have received great attention in recent years, since these non-Abelian particles were predicted to be experimentally accessible in a hybrid system of three-dimensional (3D) topological insulators (TIs) and conventional s-wave superconductors (SCs) [1]. Recent experiments have reported evidence for Majorana fermions localized at vortex cores in superconducting TIs [2] and iron-based SCs [3].

Multiple Majorana vortex zero modes can emerge when the parent material in proximity to an s-wave superconductor is a 3D topological crystalline insulator (TCI) with surface Dirac cones protected by crystal symmetry [4]. Thus far a variety of TCIs have been predicted theoretically, while little has been known about Majorana vortex zero modes in superconducting TCIs, especially for newly-proposed TCIs having surface rotation anomaly, which realize a new class of topological surface states involving multiple Dirac cones.

We show that the proximity-induced s-wave superconductivity on the surface of

these TCIs yields a topological superconducting phase in which two Majorana zero modes are bound to a vortex, and that n-fold rotation symmetry ($n = 2, 4, 6$) enriches the topological classification of a superconducting vortex from $Z2$ to $Z2 \times Z2$ [5]. Using a model of a three- dimensional high-spin topological insulator with s-wave superconductivity and two-fold rotation symmetry, we show that, with increasing chemical potential, the number of Majorana zero modes at one end of a vortex changes as $2 \rightarrow 1 \rightarrow 0$ through two topological vortex phase transitions. In addition, we show that additional magnetic-mirror symmetry further enhances the topological classification to $Z \times Z$.

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Magic-angle superconducting graphene and the Roeser-Huber formula

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As shown in several previous publications, there is a relation between the superconducting transition temperature and some characteristic distance in the crystal lattice, which enables the calculation of the superconducting transition temperature, Tc, based only on the knowledge of the electronic configuration and of the crystallographic structure. This relation was found to apply for a large number of superconductors, including the high-temperature superconductors, the iron-based materials, alkali fullerides, metallic alloys, and element superconductors.

When we apply this scheme (Roeser-Huber formula) to Moiré-type superconductivity, i.e., magic-angle graphene and hexagonal boron nitride and WSe2, we find that the calculated Tc does not match the experimental observations, as the calculated Tc turns out to be much higher. So, with the characteristic distance of the resulting Moiré-pattern of two twisted graphene layers with the magic angle 1.1°, we find Tc ~ 6 K. Now, the question arises why the calculation produces larger Tc's. The given problem for experimentalists is the fact that for electric measurements always substrates are required to arrange the contacts. When now discussing superconductivity in atomically thin objects, also the substrates employed play a role when forming the Moiré -patterns. The consequence of such substrate-induced Moiré- patterns is that the resulting Moiré-pattern will show a larger distance, and thus, a lower Tc of the final structure will result.

Odd–Parity Spin–Triplet Superconductivity in Antiferromagnetic Metals Lacking Effective Time-Reversal Symmetries

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We propose a route to achieve odd-parity spin-triplet superconductivity in metallic collinear antiferromagnets with inversion symmetry. Owing to the existence of hidden antiunitary symmetry, which we call the effective time-reversal symmetry (eTRS), the Fermi surfaces of ordinary antiferromagnetic metals are generally spin-degenerate, and spin-singlet pairing is favored. However, by introducing a local inversion symmetry breaking perturbation that also breaks the eTRS, we can lift the degeneracy to obtain spin-polarized Fermi surfaces. In the weak-coupling limit, the spin-polarized Fermi surfaces constrain the electrons to form spin-triplet Cooper pairs with odd-parity. Interestingly, all the odd-parity superconducting ground states we obtained host nontrivial band topologies manifested as chiral topological superconductors, second-order topological superconductors, and nodal superconductors. We propose that double perovskite oxides with collinear and antiferromagnetically ordered local spins such as SrLaVMoO6, are promising candidate systems where our theoretical ideas can be applied to.

Electronic Transport in InSb Quantum Wells

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InSb is a III-V binary compound known for its low effective mass, giant effective g factor in the bulk, and its large spin-orbit interactions. Recently, InSb, as well as InAs, has received more and more attention in the community as a candidate to realize Majorana zero mode. In this poster, we present our latest transport experiments with InSb quantum wells. First, high mobility InSb quantum wells with tunable carrier densities are investigated by transport experiments in magnetic fields tilted with respect to the sample normal. We employ the coincidence method and the temperature dependence of the Shubnikov-de Haas oscillations and find a value for the effective g-factor of |□∗| = 35 ± 4 and a value for the effective mass of □∗ ≈ 0.017 □□, where □□ is the free electron mass. Second, we study an electrostatically defined quantum point contact in a high-mobility InSb two dimensional electron gas. Finally, an attempt to achieve high-quality shallow InSb QWs is shown. These quantum wells would be promising to be coupled with the superconductors for the Majorana physics research.

Spin-injection into spin-split superconductors via spin pumping

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High frequency pumping of pure spin currents from metallic ferromagnets into a non-magnetic metal has been widely applied in conventional (non-superconducting) spintronics [1]. There are only a few experimental reports of spin-injection into spin-split superconductors [2–4] despite theory for dynamic spin pumping into superconductor predicting Cooper pair conversion and the generation of superconducting spin current [5–8]. A time-dependent magnetic state should support the conversion of singlet state Cooper pairs in the superconductor into spin triplet Cooper pairs in which the spins are parallel [9]. Such a triplet superconducting state offers exciting opportunities for spintronics as the net spin of electron pairs can flow in the absence of dissipation. In this poster we present preliminary results on broadband ferromagnetic resonance spin-pumping from the ferromagnetic insulator EuS into proximity layers of Nb in the normal and superconducting states. The results indicate a suppression of spin-pumping efficiency in Nb in the superconducting state and critical temperature (Tc) measurements on " EuS/Nb/EuS control devices show a sensitivity of Tc to the spin-splitting field in Nb and thus " magnetisation-alignment of the EuS layers. Further film growth optimisation is required in order to improve the spin-conductance at the EuS/Nb interface and the effects of sulphur diffusion on the superconducting properties of Nb should be investigated.

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Imaging the current-driven metal–insulator transition in Ca2RuO4

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It was recently reported that a continuous electric current is a powerful control parameter to trigger changes in the electronic structure and metal–insulator transitions (MITs) in Ca2RuO4. However, the spatial evolution of the MIT and the implications of the unavoidable Joule heating have not been clarified yet, often hindered by the difficulty to assess the local sample temperature. We present infrared thermal imaging measurements performed on single-crystal Ca2RuO4 while controlling the MIT by electric current. The change in emissivity at the phase transition allows us to monitor the gradual formation and expansion of metallic phase upon increasing current. Our local temperature measurements indicate that, within our experimental resolution, the MIT always occurs at the same local transition temperatures, irrespectively if driven by temperature or by current. Our results highlight the importance of local heating, phase coexistence, and microscale inhomogeneity when studying strongly correlated materials under the flow of electric current.

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Designing Nonstandard Andreev-Bound-State Spectra in Majorana Devices

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We investigate the Andreev-bound-state (ABS) spectra of a topological Josephson junction, i.e. a junction consisting of two topological superconductors (TSCs) [1,2]. We consider the situation in which each TSC can harbors multiple Majorana bound states (MBSs) per edge by virtue of a chiral or unitary symmetry [3]. Interestingly in this regime, we find a rich diversity of nonstandard Andreev-bound-state (ABS) dispersions [2], which show multiple crossings protected by fermion parity, despite their 2-periodic character. These crossings additionally unlock the possibility of nontrivial topology in synthetic spaces, when considering networks of such 1D junctions. Indeed, a single junction with four interface MBSs and all MBS couplings fully controllable, or, networks of such coupled junctions with partial coupling tunability, open the door for topological band structures with Weyl points or nodes in synthetic dimensions [1]. Finally, we also study a three terminal topological Josephson junction [4]. Here, considering the 2D synthetic space spanned by the two independent superconducting phase differences, we demonstrate that the ABS spectra may contain either point or line nodes. We show that the resulting type of nodes depends on the number of preexisting interfacial MBSs, with nodal lines necessarily appearing when two TSCs harbor an unequal number of MBSs. When chiral symmetry is preserved, the lines are open and coincide with high-symmetry lines of synthetic space, while when it is violated the lines can also transform into loops and chains. These findings unveil novel paths to mechanisms for ABS engineering and single-out signatures relevant for the experimental detection and manipulation of MBSs.

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Andreev reflection through tunneling in a spinless chiral edge state

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The phenomenon of induced superconductivity in a spin-polarized chiral quantum Hall edge state through the superconducting proximity effect is being investigated due to the macroscopy and sta- bility of the involved quantum phenomena, which has lead to predicted applications in quantum technology. Recent experiments have observed the phenomenon through signatures of the mediating process of Andreev reflection, but lack support in theoretical works. We address this by modelling the system with a many-body Hamiltonian motivated by experiments, and integrate out the super- conductor to get an effective pairing Hamiltonian in the quantum Hall edge state. In addition to clarifying the qualitative appearance of nonlocal superconducting correlations in a chiral edge state, we predict the effect of quantitative experimental conditions on these correlations. In particular, it follows how two surface phenomena of the superconductor, namely Rashba spin orbit coupling and the Meissner effect, are essential for the Andreev reflection.

Dynamical torques from Shiba states in s-wave superconductors

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Magnetic impurities inserted in a s-wave superconductor give rise to spin-polarized in-gap states called Shiba states. We study the back-action of these induced states on the dynamics of the classical moments. We show that the Shiba state pertains to both reactive and dissipative torques acting on the precessing classical spin that can be detected through ferromagnetic resonance measurements. Moreover, we highlight the influence of the bulk states as well as the effect of the finite linewidth of the Shiba state on the magnetization dynamics. Finally, we demonstrate that the torques are a direct measure of the even and odd frequency triplet pairings generated by the dynamics of the magnetic impurity. Our approach offers non-invasive alternative to the STM techniques used to probe the Shiba states.

Superconductivity in SrAuSi3 with noncentrosymmetric crystal structure probed by μSR

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In a superconductor with noncentrosymmetric crystal structure, it is theoretically suggested that the novel superconducting state such as even and odd parity mixing due to antisymmetric spin-orbit coupling (ASOC) is realized. In particular, 5d transition-metal compounds possess strong SOC owing to large relativistic effect between nuclei and electrons and unique superconducting properties can be expected. In recent years, in noncentrosymmetric superconductors with 5d electron orbitals, time-reversal symmetry broken superconducting state with the full gap have been experimentally found in several systems [1].

Recently, SrAuSi3 including Au with 5d electron was discovered [2,3]. This compound has non-centrosymmetric crystal structure and superconductivity appears below TC~1.6K. From the temperature dependence of the specific heat and the magnetic penetration depth, the superconducting gap symmetry of SrAuSi3 is suggested to be full gap [3,4]. To clarify the superconducting properties, in particular time reversal symmetry, we have measured the temperature dependence of the internal field in SrAuSi3 using zero field muon spin relaxation measurement (ZF-μSR) at J-PARC. In the presentation, we will discuss the symmetry the superconducting state in SrAuSi3.

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Z2-enriched symmetry indicators for topological superconductors in the 1651 magnetic space groups

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While the symmetry-based diagnosis of topological insulators and semimetals [1] has enabled large-scale discovery of topological materials candidates, the extension of these approaches to the diagnosis of topological superconductors remains a major open question.

One important new ingredient in the analysis of topological superconductivity is the presence of Z2-valued Pfaffian invariants associated with certain high-symmetry momenta [2,3]. Such topological invariants lie beyond the conventional scope of symmetry representation theory for band structures, and as such they are nontrivial to incorporate into the systematic calculations of the symmetry indicators of band topology. Here, we overcome this challenge and report the full computation of the Z2 -enriched symmetry indicators for superconductors in all symmetry settings. Our results indicate that incorporating the Z2 band labels enhance the diagnostic power of the scheme in roughly 60% of the symmetry settings [4].

Our framework can also be readily integrated with first-principles calculations to elucidate on the possible properties of unconventional superconductivity in a given compound. As a demonstration, we analyze explicitly the interplay between pairing symmetry and topological superconductivity in the recently discovered superconductors CaPtAs and CaSb2 [4].

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Topological phonons in oxide perovskites controlled by light

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Perovskite oxides exhibit a rich variety of structural phases hosting different physical phenomena that generate multiple technological applications. We find that topological phonons – nodal rings, nodal lines, andWeyl points – are ubiquitous in oxide perovskites in terms of structures (tetragonal, orthorhombic, rhombohedral), compounds (BaTiO3, PbTiO3, SrTiO3), and external conditions (photoexcitation, strain, temperature). In particular, in the tetragonal phase of these compounds all types of topological phonons can simultaneously emerge when stabilized by photoexcitation, whereas the tetragonal phase stabilized by thermal fluctuations only hosts a more limited set of topological phonon states. Additionally, we find that the photoexcited carrier concentration can be used to tune the topological phonon states and induce topological transitions even without associated structural phase changes. Overall, we propose oxide perovskites as a versatile platform in which to study topological phonons and their manipulation with light [1].

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Artificial separation of trivial and topological superconducting domains

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Interplay between superconductivity, spin orbit coupling and magnetic field can lead to realization of the topological phase shift [1]. Existence of this topological phase allows for emergence of the bound states, which most famous example is the Majorana bound states that emerge at the boundary of the one dimensional nanostructure [2,3]. However, similar topological bound state can be also realized in two dimensional system [4]. Moreover, recent experimental works suggest possibility of realization of the topological superconducting domain in magnetic nanostructure coupled with bulk superconductor [5,6]. In such a case, boundary between trivial and topological phase are “marked” by nearly-zero in-gap bound state. The analysis of the topological phase diagram of such a system shows that a similar phase separation occurs by tuning the chemical potential of the nanoflake. Here, we study such a possibility in detail, analyzing the spatial extent of the edge modes circulating around the nanoflake and discussing some practical implementations. We also show how the chirality of Majorana edge states can be probed using scanning tunneling spectroscopy with a double tip setup [7].

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Splitting the Hinge Mode of Higher-Order Topological Insulators

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The surface of a higher order topological insulator comprises a two-dimensional topological insulator (TI) with broken inversion symmetry, whose mass is determined by the microscopic details of the surface such as surface potentials and termination. It hosts a helical mode pinned to selected hinges where the surface gap changes its sign. We study the effect of perturbations that break time reversal and particle conservation on this helical mode, such as a Zeeman field and a proximate superconductor. We find that in contrast to the helical modes of inversion symmetric TIs, which are gapped by these couplings, the helical modes at the hinges can remain gapless and spatially split. When this happens, the Zeeman field splits the helical mode into a chiral mode surrounding the magnetized region, and a superconductor results in a helical Majorana mode surrounding the superconducting region. The combination of the two might lead to the gapping of one of the chiral Majorana modes, and leave a single one-dimensional chiral Majorana mode around the superconducting island. We propose that the different topological states can be measured in electrical transport.

Charge Density waves in Twisted Double Bilayer Graphene

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When twisted to angles near 1°, graphene multilayers provide a new window on electron correlation physics by hosting gate-tuneable strongly-correlated states, including insulators, superconductors, and unusual magnets. Here we report the discovery of a new member of the family,[1] density-wave states, in double bilayer graphene [2,3] twisted to 2.37°. At this angle the moiré states retain much of their isolated bilayer character, allowing their bilayer projections to be separately controlled by gates [4]. We use this property to generate an energetic overlap between narrow isolated electron and hole bands with good nesting properties. Our measurements reveal the formation of ordered states with reconstructed Fermi surfaces, consistent with density-wave states, for equal electron and hole densities. These states can be tuned without introducing chemical dopants, thus opening the door to a new class of fundamental studies of density-waves and their interplay with superconductivity and other types of order, a central issue in quantum matter physics.

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Anomalous Thermal Hall Effect in Chiral Superconductors

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Chiral superconductors exhibit novel transport properties that depend on the topology of the order parameter, topology of the Fermi surface, the spectrum of bulk and edge Fermionic excitations, and the structure of the impurity potential. In the case of electronic heat transport, impurities induce an anomalous (zero-field) thermal Hall conductivity that is easily orders of magnitude larger than the quantized edge contribution. The effect originates from branch-conversion scattering of Bogoliubov quasiparticles by the chiral order parameter, induced by potential scattering. The former transfers angular momentum between the condensate and the excitations that transport heat. The anomalous thermal Hall conductivity is shown to depend to the structure of the electron-impurity potential, as well as the winding number, v, of the chiral order parameter, Δ(p) = |Δ(p)|eivφp. The results provide quantitative formulae for interpreting heat transport experiments seeking to identify broken T and P symmetries, as well as the topology of the order parameter for chiral superconductors.[1]

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Current–phase relation in a topological Josephson junction: Andreev bands vs. scattering states

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We consider a long topological Josephson junction formed on a conducting 2D surface of a 3D topological insulator (TI). The superconducting correlations are proximity-induced by s-wave superconductors covering the surface. The 1D spacing between the coverings is either unfilled or filled by a magnetic insulator. Generally, the Josephson current mediated by the TI surface is determined by scattering modes as well as by the states localized around the junction (Andreev bound states or Andreev bands). We considere two simple cases where it is possible to fully take into account both the contribution of the Andreev bound states (Andreev bands) and that of the continuum of scattering states. Both contributions turn out to be logarithmically divergent, but these divergen- cies compensate each other in the final result. Moreover, the contribution of the Andreev bands can show very unusual behavior, e.g., negative slope of the Josephson current at zero phase bias (π-junction) as well as kinks and zero-crossings at phase biases different from 0 and π. Yet, all these features are completely eliminated by the corresponding contribution of the scattering states. The current–phase relation remains close to sinusoidal with some deviations towards the saw-tooth shape. We have also analyzed the Josephson current in the limit of a very thin (narrow) junction and discussed the applicability of the Ambegaokar–Baratoff relation.

Atomic limit and inversion-symmetry indicators for topological superconductors

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Symmetry indicators have proven to be extremely helpful in identifying topologically non-trivial crystalline insulators using symmetry-group representations of their Bloch states [1].

An extension of this approach to superconducting systems requires defining an appropriate atomic limit for Bogoliubov-de-Gennes Hamiltonians. Here, we introduce such a notion of atomic limit and derive a Z2d -valued symmetry indicator for inversion-symmetric superconductors of d dimensions. This indicator allows for a refined topological classification including higher-order phases for systems in the superconducting symmetry classes D and DIII. We further elucidate the bulk- boundary correspondence of these phases using Dirac surface theories.

Requiring only the normal-state band structure and the superconducting order- parameter symmetry as an input, this indicator is well suited for a search of topological superconductors using first-principles calculations [2].

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Interplay of proximity effects in Nb/FePd heterostructures: domain-superconductivity, spin-triplet Cooper pair generation, and the impact on the ferromagnet

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Proximity effects in superconductor(S)/ferromagnet(F) thin film heterostructures are highly topical issues due to their potential application in superconducting spin valves or fluxonic devices [1, 2]. Superconducting, electric, and magnetic properties can be controlled by an external applied magnetic field [3] and emerge for example as stray-field generated domain- superconductivity or spin-triplet superconducting correlations.

These two phenomena arise from fundamentally different origins but can still be studied within one heterostructure system. Our goal is to investigate their interplay and tunability by an external magnetic field, and to obtain information on the inverse proximity effect: a change of magnetization of the F-layer. We use a heterostructure system of Nb(S)/FePd(F) with varying strength of PMA and a lateral domain structure, grown by molecular beam epitaxy.

On the one hand, macroscopic magnetoelectric transport measurements reveal a confined superconducting state due to the stray fields of L10-ordered FePd. On the other hand, direct proximity effects at the Nb/FePd interface with a non-collinear magnetization presumably lead to the generation of spin-triplet Cooper pair components with long penetration depth within the F- layer [4]. Grazing-Incidence Small-Angle Neutron Scattering (GISANS) probe exchange mechanisms on the microscopic scale and reveal a change in the ferromagnetic domain pattern by an onset of domain-wall-superconductivity.

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Competing proximity effect and spin accumulation in superconducting spin valves

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Current perpendicular-to-plane (CPP) superconducting spin-valves have previously demonstrated giant magnetoresistance, mediated via quasiparticle spin-transport at the superconducting gap edge[1]. Spin accumulation in these systems leads to an increase in resistance in the antiparallel magnetisation state relative to the parallel state due to a significant potential difference that drives spin-polarised quasiparticles into a non- equilibrium regime. In current in-plane (CIP) spin-valves out-of-plane potential differences are small and the superconductor proximity effect is dominant over spin-polarised quasiparticle transport. In CIP spin-valves the antiparallel state has lower resistance due to a reduced suppression of superconductivity by the opposing exchange fields from the ferromagnetic layers. Here, we report CPP Py/Nb/Py/FeMn superconducting spin-valves that demonstrate a Nb-thickness-dependent competition between spin accumulation and proximity effect behaviours in Nb. The results are central to the development superconducting memory and provide new insight into the coupling of superconductivity and non-equilibrium spin-transport.

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Anomalous inverse proximity effect in unconventional-superconductor junctions

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We study the inverse proximity effect of ferromagnet/superconductor junctions, in particular, the effects of the Andreev bound states due to the unconventional pairing. We obtained the magnetization penetrating into the superconductor based on the quasiclassical Eilenberger theory. We show that the direction of the induced magnetization is determined by the two factors: whether Andreev bound states are present at the junction interface and the sign of the spin-mixing angle. Namely, when the Andreev bound states appear at the interface, the direction of the induced magnetization is opposite to that without Andreev bound state. This anomalous inverse proximity effect can be measured by several experimental means that observed the conventional inverse proximity effect. Applying this novel effect, we can determine the pairing symmetry of a superconductor.

121/123Sb-NMR/NQR studies on the superconducting line-nodal material CaSb2

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The crystal structure of CaSb2 is non-symmorphic P21/m space group, as shown in Fig. 1. From the first-principles calculation, it is expected to be a line-nodal material, which has linear nodes in the bulk band structure [1]. In this system, these nodes are preserved even under spin-orbit coupling, because they are protected by non-symmorphic symmetry of the crystal, and a part of them intersects the Fermi level. The line-nodal material has attracted much attention as a new kind of topological materials, but a limited number of materials retain nodal lines under spin-orbit coupling. Thus, it has great importance to reveal the properties of CaSb2.

Moreover, recently Ikeda et al. have reported that CaSb2 exhibits superconductivity below 1.7 K [2]. In order to study the superconducting state of CaSb2 from a microscopic point of view, we performed 121/123Sb-nuclear magnetic resonance (NMR) and nuclear quadrupole resonance (NQR) measurements on a powdered sample. We estimated the NQR parameters from the NMR spectra and succeeded in observing NQR signals.

In this presentation, we will show the result of the nuclear spin-lattice relaxation rate (1/T1) measurement and discuss the superconducting gap symmetry of CaSb2 based on the 1/T1 result.

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Biaxial dilatometer using fiber Bragg grating for low temperatures

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The doped topological insulator MxBi2Se3 (M = Cu, Nb, Sr) is a nematic superconductor, in which in-plane field-angle-dependence of superconducting properties such as NMR Knight shift [1] and specific heat [2] break rotational symmetry of its crystalline lattice in plane. Recently, Kostylev et al. reported that nematic domain structure of SrxBi2Se3 can be controlled by applying uniaxial strain [3]. In addition, Cho et al. reported that thermal expansion of NbxBi2Se3 shows anisotropic jump at a temperature noticeably above the superconducting transition temperature [4]. These results suggest coupling between nematic superconductivity and lattice deformation.

We made a probe for a commercial refrigerator (Quantum Design, PPMS) to study structural changes associated with the nematic superconducting transition. This probe is equipped with fiber Bragg grating (FBG) strain sensors as a dilatometer. FBG is a grating on a core of an optical fiber working as strain gauge [5]. We can measure multi-axis strain with little heating and little influence by magnetic field. Therefore, FBG strain gauge is suitable to detect change of the crystalline symmetry at low temperatures under magnetic field.

Our probe can be cooled down from room temperature to 1.8 K and continuous biaxial strain measurement is possible. We tested the probe by measuring biaxial thermal expansion of SrTiO3 and clearly detected the anisotropy in thermal expansion associated with the structural transition from cubic to tetragonal. Strain resolution as high as ~10-7 is achieved after averaging. We also measured biaxial thermal expansion of SrxBi2Se3 around Tc. Thermal expansion in normal state was consistent with the result from Cho et al [4]. However, we detect no anisotropic jump around Tc.

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Non-topological zero bias peaks in full-shell nanowires induced by flux tunable Andreev states

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A semiconducting nanowire core fully wrapped by a superconducting shell has been proposed as an alternative geometry for obtaining Majorana modes without the need of fine tuning the chemical potential or an external magnetic field [1]. While this robustness seems to avoid interpretation ambiguities in terms of non-topological Andreev bound states, we here demonstrate that the appearance of subgap states is actually governed by the junction region in tunneling spectroscopy measurements, not the full-shell nanowire itself [2]. Short tunneling regions never show subgap states, while longer junctions always do. This can be understood in terms of quantum dots forming in the junction and hosting Andreev levels in the Yu-Shiba-Rusinov regime. Their intricate magnetic- field dependence, both through the Zeeman and the Little-Parks effects, may result in robust zero- bias peaks, a feature that could be easily misinterpreted as originating from Majoranas, but is unrelated to topology.

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Second Chern Number and Non-Abelian Berry Phase in Topological Superconducting Systems

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Topology ultimately unveils the roots of the perfect quantization observed in complex systems. The 2D quantum Hall effect is the celebrated archetype. Remarkably, topology can manifest itself even in higher-dimensional spaces in which control parameters play the role of extra, synthetic dimensions. However, so far, a very limited number of implementations of higher-dimensional topo- logical systems have been proposed, a notable example being the so-called 4D quantum Hall effect. Here we show that mesoscopic superconducting systems can implement higher-dimensional topology and represent a formidable platform to study a quantum system with a purely nontrivial second Chern number. We demonstrate that the integrated absorption intensity in designed microwave spectroscopy is quantized and the integer is directly related to the second Chern number. Finally, we show that these systems also admit a non-Abelian Berry phase. Hence, they also realize an enlightening paradigm of topological non-Abelian systems in higher dimensions.

Microscopic Theory of Topological Hall effect on the Surface of Topological Insulator

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Transport phenomena on the surface of three-dimensional topological insulators (TIs) are of interest from the viewpoint of spin transport phenomena in spintronics. In particular, spin- momentum locking, a characteristic feature of Dirac electrons, is expected to lead to highly efficient spin-charge conversion [1,2]. A characteristic transport phenomenon on the surface of TIs is the anomalous Hall effect in ferromagnetic TIs [3,4], which can be interpreted as the Hall effect due to the emergent magnetic field (Berry's curvature) induced by the topological structure of the wavenumber space. On the other hand, the topological Hall effect (THE) [5], which is induced by the spatial variation of the magnetic structure, can be interpreted as the Hall effect originating from the topological structure of real space. The THE has been studied mainly in ordinary ferromagnetic metals, however, there have been few studies on the surface of TIs, although its existence has been suggested experimentally[6]. A pioneering study of the THE on the surface of TIs is carried in a specific case assuming a skyrmion as the magnetization structure[7], but there are no studies on the general magnetization structure.

In this study, we calculate the THE on general magnetization structures on the surface of 3D TIs based on a microscopic model. First, from symmetry consideration, we investigate the forms of the magnetization structures allowed for the THE, and determine whether the transport coefficients are an even or odd function of chemical potential. We also calculate the nonzero THE based on linear response theory. We will compare our results with those of previous studies [7] and discuss the physical properties of THE.

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Majorana Electric Quadrupole Response in Topological Crystalline Superconductors

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Majorana fermions appear as gapless states on the surface of topological superconductors. In the absence of symmetry, they are stable to any perturbation. On the other hand, when a topological superconductor has time-reversal symmetry, Majorana fermions form Kramers pairs (Majorana Kramers pairs), and then they can respond to a magnetic field. Previous studies have revealed that Majorana Kramers pairs respond only to a magnetic field applied in a specific direction due to crystalline symmetries of the system [1]. Moreover, it has been clarified that Majorana Kramers pairs with a one-dimensional Z invariant defined from crystalline symmetry exhibit the magnetic dipole or octupole responses. The relationship between these responses and irreducible representations of pair potentials has also been classified [2,3].

In this study, we show that two Majorana Kramers pairs respond to electric (time-reversal-even) perturbations [4]. In particular, we analytically and numerically reveal that the electric-quadrupole response of a magnetic field, which is the second order of a magnetic field, appears when two one-dimensional Z invariants independent of each other take finite values simultaneously. The electric-quadrupole response is peculiar to Majorana Kramers pairs emergent on nonsymmorphic space group.

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Exploring spin supercurrent transport in lateral spin valve

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Spin transport studies in superconductors have traditionally involved quasiparticle injection at bias voltages around the superconducting gap energy.1,2 In comparison, spin supercurrent carried by spin-triplet Cooper pairs offers more potentials for energy efficient devices as the net spin of electron pairs flow in the absence of dissipation.3 Spin supercurrent transport has been recently demonstrated in spin pumping measurements that the pumped spin can transfer through a s-wave superconductor terminated by a spin sink with large spin orbit coupling.4 This could be explained as spin triplet channel opened in the superconducting state due to the presence of spin orbit coupling and exchange field.5,6 In this poster we present magnetoelectric transport results in X/Nb/Cu/CoFeAl lateral spin valve device where X denotes NiFe/Pt or Pt/CoFeB functional layer to induce the triplet state of Nb. However, enhanced spin absorption in superconducting state compared with normal state has not been observed yet in above structures, indicating the induced triplet pairing is insufficient and the density states ratio between superconducting and normal state is still low. Further optimisation of the functional layer to increase the triplet conversion should be investigated.

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Superconducting Proximity Effect on a Magnetic Topological Insulator Controlled by Magnetization

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Superconducting proximity effect (PE) on magnetized topological insulators (TIs) has the potential to induce unconventional Cooper pairs, some of which can host Majorana fermions whose antiparticles are themselves [1, 2]. Indeed, we observed some unique behaviors on Nb/Fe-doped Bi2Te2Se (FBTS)/ Nb Josephson junctions: e.g., a unique three-peak conductance, the Ic-T following inverse to the temperature, and the 4π-periodic Josephson supercurrent [3]. Furthermore, theory predicts that the magnetized TI systems can tune its PE from a topological to a non-topological state by magnetization and chemical potential [4].

In this study, we investigated the magnetization dependence of PE on FBTS. First, we fabricated an Nb/ FBTS Josephson junction (Fig.1 (a) and (b)) similar to the former ones [3] and confirmed that the junction also has the three unique behaviors mentioned above. Then, we evaluated Ic-H characteristics of the Josephson junction before/after applying large magnetic fields. The Ic-H patterns show typical Fraunhofer-like patterns with slight hysteresis (Fig. 1 (c)). After large magnetic fields (> 0.5 T), the patterns were drastically shift depending on the direction of the last large fields. This shift indicates that the critical currents are sensitive to the existing remnant magnetization. In additoin, we also observed a transition-like behavior in the conductance spectrum. We are plan to discuss those results in the aspect of the topological transition.

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Space-group approach to the wavefunction of a Cooper pair. Applications to topological superconductors UTe2 and Sr2RuO4

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The space-group approach to the wavefunction of a Cooper pair [1] is based on Bradley- Davies extension of Mackey theorem on the space groups [2] and Anderson ansatz for a Cooper pair [3]. The results of this first-principle approach in the majority of cases coincide with the results of phenomenological approaches [4], but in some cases an essential difference occurs. For example, vertical line nodes were obtained for triplet chiral SOP (superconducting order parameter) of Sr2RuO4 [5]. The Shubnikov group symmetry m□m□m of recently discovered ferromagnetic superconductorUTe2 [6] and the nodal structure of SOP corresponding to all experimental data were obtained [7]. Since recently triplet superconductivity of Sr2RuO4 was reconsidered [8], the relations between multiplicity, parity and angular momentum of a pair are verified making use the space-group approach. The points in a Blloulin zone of Sr2RuO4 where even triplet pairs are possible are identified. It is also shown, that the usually accepted assertion that angular momentum of an even pair is even and that of an odd pair is odd, is connected with the basis choice, but not with group theoretical requirements.

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Electronic properties of emergent topological defects in chiral p-wave superconductors and topological phase transitions in small disks

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Chiral p-wave superconductors in applied magnetic field can exhibit more complex topological defects than just conventional superconducting vortices, due to the two- component order parameter (OP) and the broken time-reversal symmetry. By solving the Bogoliubov–de Gennes equations self-consistently, we first present the electronic structure of those exotic states [1], some of which contain skyrmionic character in the relative OP space. We reveal the link between the local density of states (LDOS) of the novel topological states and the behavior of the chiral domain wall between the OP components, enabling direct identification of those states in scanning tunneling microscopy. For example, a skyrmion always contains a closed chiral domain wall, which is found to be mapped exactly by zero-bias peaks in LDOS. Moreover, the LDOS exhibits electron-hole asymmetry, which is different from the LDOS of conventional vortex states with same vorticity. The skyrmion can be surprisingly large in size depending on magnetic field and temperature.

Next, we present the equilibrium phase diagram for small mesoscopic chiral p-wave superconducting disks in the presence of magnetic field [2]. In the ultrasmall limit, the cylindrically symmetric giant-vortex states form the ground state of the system. However, with increasing sample size, the cylindrical symmetry is broken as the two components of the order parameter segregate into domains, and the number of fragmented domain walls between them characterizes the resulting states. Such domain walls are topological defects unique for the p-wave order, and constitute a dominant phase in the mesoscopic regime. Moreover, there are two possible types of domain walls, identified by their chirality-dependent interaction with the edge states.

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List of Contributions - Talks

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Asano	Yasuhiro	Josephson Effect of two-band/orbital superconductors
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Cybart	Shane	Helium Ion Beam Modification of High Transition Temperature Superconductors
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Herrera	Edwin	One-dimensional moiré charge density wave in the hidden order state of URu2Si2 induced by fracture
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Klinovaja	Jelena	Second Order Topological Superconductivity: Majorana and parafermion corner states
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Naaman	Ron	Chiral Molecules as Topological Devices- The Chiral Induced Spin Selectivity Effect
Santamaria	Jacobo	Long range unconventional Josephson effect across a half metallic ferromagnet
Schonenberger	Christian	One-dimensional states residing on edges and steps in few-layer WTe2
Shibauchi	Takasada	Possible transition to a topological ultranodal pair state in FeSe1-xSx superconductors
Sigrist	Manfred	Domain walls and critical currents in chiral superconductors
Stern	Adiel	The Josephson effect as a tool for creating topological superconductivity
Tanaka	Yukio	Odd-frequency pairing in topological superconductors
Villegas	Javier	Propagation and interference of d-wave superconducting pairs in graphene
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Ghosh	Shreenanda	Manipulation of time reversal symmetry breaking superconductivity in Sr2RuO4 by uniaxial stress
Gracia	Ruben	Robust Weak-Antilocalization effect in Bi2Se3 thin films
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Kawaguchi	Mayo	Discovery of superconductivity in the line-nodal material CaSb2
Kim	Jinkwon	Superconducting Sr2RuO4 thin film growth achieved by interface engineering
Kimbell	Graham	Two-channel anomalous Hall effect in SrRuO3
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Ko	Eun Kyo	Oxygen Vacancy Engineering for Highly Tunable Ferromagnetic Properties: A Case of SrRuO3 Ultrathin Film with a SrTiO3 Capping Layer
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Mishra	Archana	Dynamical torques from Shiba states in s-wave superconductors
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Ono	Seishiro	Z2-enriched symmetry indicators for topological superconductors in the 1651 magnetic space groups
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Zhang	Lingfeng	Electronic properties of emergent topological defects in chiral p-wave superconductors and topological phase transitions in small disks

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