Monday, June 7th, 13:0-14:00 EEST (GMT+3)

Poster1: Aabir Mukhopadhyay,
Thermal signature of Majorana fermion in a Josephson junction

Poster2: Abdou Hassanien,
Antiferromagnetic ordering within a single layer oforganic superconductor

Poster3: Hugo Bartolomei,
Squeezing of edge magnetoplasmon states in quantum Hall edge channel

Poster4: Alessandro Braggio,
Nonlocal thermoelectricity in topological Josephson junctions

Poster5: Paramita Dutta,
Finding exotic superconducting pairing in topological semimetals

Poster6: Antonio L. R. Manesco,
Correlations and topology in buckled graphene superlattices

Poster7: Pretty Pandey,
A Ballistic Graphene Based Cooper Pair Splitter

Poster8: Arnob Kumar Ghosh,
Floquet generation of Second-order Topological Superconductor

Poster9: Cem Sevik,
Superconducting Properties of MXene Monolayers

Poster10: Dávid Pataki,
Triplet blockade in a Josephson junction with a double quantum dot

Poster11: Hermann Suderow,
Feedback driven Josephson effect in ultra-small tunnel junctions

Poster12: Vasily Vadimov,
Many-body Majorana-like zero modes without gauge symmetry breaking

Poster13: J. Wang,
Coexistence of superconductivity and spin-orbit splitting in $Sn_{1-x}In_xTe$ thin film

Tuesday, June 8th, 16:35-17:30 EEST (GMT+3)

Poster14: Kyungwha Park,
Zero-bias peak induced by a magnetic impurity in aconventional superconductor: first principles-based study

Poster15: Tania Paul,
Interplay of excitonic correlation with quantum spin hall effect and superconductivity in electron-hole bilayers

Poster16: Malcolm Jardine,
Integrating micromagnets and hybrid nanowires inheterostructure Majorana fermions experiments

Poster17: Maryam Khosravian,
Quasiperiodic criticality and spin-triplet superconductivity in superconductor-antiferromagnet moiré patterns

Poster18: Olivér Kürtössy,
Andreev molecule in parallel InAs nanowires

Poster19: Samuel D. Escribano,
Improved effective equation for the Rashba spin-orbit coupling in semiconductor nanowires

Poster20: Andrei Kudriashov**,**
Magnetic Gap of Fe-Doped $BiSbTe_2Se$

Poster21: Riku Tuovinen,
Electron correlation effects in superconducting nanowiresin and out of equilibrium

Poster22: Fredrik Brange,
Dynamic Cooper pair splitter

Poster23: R. Sánchez-Barquilla,
Magnetic field dependence of the tunnelingdensity of states in the type-II Weyl semimetal WTe_2

Wednesday, June 9th, 16:35-17:30 EEST (GMT+3)

Poster24: Archana Mishra,
A Yu-Shiba-Rusinov Qubit

Poster25: Samuel D. Escribano,
Majorana Bound States in Semiconductor/Ferromagnetic insulator/Superconductor nanowire heterostructures

Poster26: Panch Ram,
YSR-like band in the superconducting periodic Anderson model

Poster27: Lisa Rütten,
Coupling of Yu-Shiba-Rusinov states in the presence of a charge-density wave

Poster28: Uriel Allan Aceves Rodríguez,
Magnetic exchange interactions at proximity of a superconductor

Poster29: Patric Holmvall,
Phase crystals: a class of non-uniform superconducting ground states that break time-reversal symmetry

Poster30: Vivekananda Adak,
A theoretical proposal for detection of Majorana bound state in quantum spin Hall insulator using boost

Poster31: Anton Bespalov,
Large spectral gap and impurity-induced states in a two-dimensional Abrikosov vortex

Poster32: Tusaradri Mohapatra,
Probing helical vs chiral character of topological superconductors via non-local Hanbury-Brown and Twiss correlations

Poster33: Dmitry S. Golubev,
Transport in Josephson junctions with a graphene interlayer

Poster34: Muhammad T. Hague,
Thermoelectric current in graphene Cooper pair splitter

Thermal Signature of Majorana Fermion in a Josephson Junction

Aabir Mukhopadhyay, Sourin Das

Experimental attempts for detection of Majorana bound state (MBS) are primarily based on two theoretical predictions: (1) $2e^2/h$ resonant conductance peak at zero bias and (2) the 4 π Josephson effect. Both of these strategies rely heavily on the subgap physics of topological superconductors. In a complementary approach, we look for non-trivial signatures of MBS in heat transport across a Josephson Junction. The heat current is dominated by the above-the-gap transport of Bogoliubov quasiparticles. Specifically, we consider a thermally biased Josephson junction hosting a pair of MBS in a helical edge state of a 2D topological insulator. We show that the presence of Majorana end states in a three-terminal Josephson junction setup results in two sets of testable relations: (i) The ratios between the various multiterminal thermal conductances are independent of the Josephson phase bias. (ii) The ratios of 'ratios of the phase derivative of multiterminal thermal conductance and the corresponding Josephson current' are also independent of the Josephson phase bias. These results owe their existence to the fact that hybridization of an odd number of Majoranas always leaves a zero mode in the subgap spectrum of the junction. We establish that these results are unique to the presence of Majorana fermions and cannot be mimicked in a Josephson junction setup composed of a 1D topological superconductor hosting "Andreev type end states" (for example, the kind of end-state as observed by P. Marra and M. Nitta, Phys. Rev. B 100, 220502(R)). We also show that the thermal noise expected in our proposed setup will not overwhelm our proposed measurements within realistic values of the parameters obtained from existing experiments

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Antiferromagnetic ordering within a single layer of organic superconductor

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We present scanning tunneling microscopy and spectroscopy to study the interplay between superconductivity and magnetism in a single layer organic d-wave superconductors $(BETS)_2GaCl_4$ on Ag(111). Antiferromagnetic molecular chains of $GaCl_4$ are spontaneously formed within the superconducting single layer due to shortages of BETS dimers. Below transition temperature of 7K, the superconducting order masks the antiferromagnetic order and dominates the electronic properties showing a ubiquitous gap over the entire island with proximity effect across the island/Ag(111) interface. These features gradually decay with the rise in temperature giving way to a Kondo dip on $GaCl_4$ chains with additional inelastic vibronic features on $(BETS)_2GaCl_4$ stripes. The concurrent absence of these signals below T_c may be related to a renormalization process where both phonon and antiferromagnetic fluctuation exhibit a cooperative existence to mediate superconductivity in such d-wave superconductors.

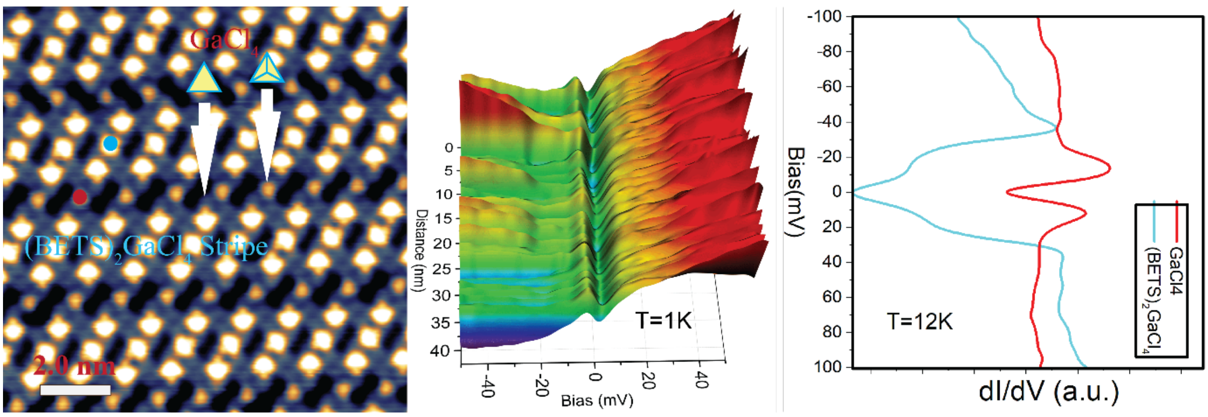

Figure 1. Atomically clean interfaces between superconducting stripes and antiferromagnetic chains are spontaneously formed within a single layer of charge transfer complex $(BETS)_2GaCl_4$. Low level excitations that dominate the higher temperature phase are absent below T_c which point to their possible renormalization to mediate superconductivity in such d-wave superconductors.

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EMP in Quantum Hall regime

Hugo Bartoloemi

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In quantum Hall conductors, charge excitations propagate ballistically along chiral one-dimensional waveguide at the edge of the sample. These edge channels have been used to propagate non-classical fermionic states of matter by manipulating electron wavefunctions in electronic interferometers for example. However, one dimensional charge propagation can also be described in terms of bosonic collective excitations called edge magneto-plasmon (EMP).

So far, most of the works have focused on the classical description of these waves. The tools of quantum electronics, such as the quantum point contact (QPC), allow for the generation of non-classical EMP states such as squeezed states. In that study, we show that the partitioning of a high frequency (few GHz) AC signal on top of a DC voltage can be used to generate squeezed EMP states, in analogy with a previous experiment performed on tunnel junctions [1].

This technique opens the possibility to generate non-classical bosonic states in a very high impedance transmission line, with a strong coupling to the mesoscopic systems.

References:

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Nonlocal thermoelectricity in topological Josephson junctions

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We consider a Josephson junction hosting a Kramers pair of helical edge states of a quantum spin Hall bar in contact with a normal-metal probe. In this hybrid system, the orbital phase induced by a small magnetic field threading the junction known as Doppler shift (DS), combines with the conventional Josephson phase difference and originates an effect akin to a Zeeman field in the spectrum. As a consequence, when a temperature bias is applied to the superconducting terminals, a thermoelectric current is established in the normal probe[1]. We argue that this purely non-local thermoelectric effect is a unique signature of the helical nature of the edge states coupled to superconducting leads and it can constitute a useful tool for probing the helical nature of the edge states. In this configuration, we investigate how the flux bias and the phase bias trigger the nonlocal thermoelectric effects under the application of a thermal difference between the superconducting terminals.[2] Possible experimental nonidealities such as asymmetric proximized superconducting gaps are considered showing how the nonlocal response is affected. The interplay between Doppler-shift, which tends to close gaps, and Andreev interferometry, which affects particle-hole resonant transport, are clearly identified for different operating regimes.[3] Finally, we discuss the power and the efficiency of the topological nonlocal thermoelectric engine which reaches maximum power at maximal efficiency for a good coupled normal probe. We finally prove quite high nonlocal Seebeck coefficient of the order of tenths of μV/K at a few kelvins, a signal that would be clearly detectable also against any spurious local effect even with moderate asymmetry of the gaps.

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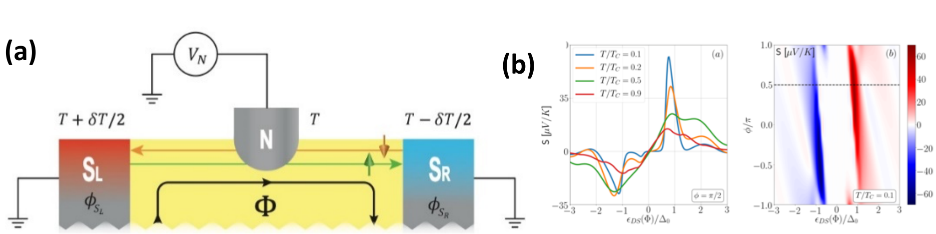

Figure 1. (a) Nonlocal thermoelectrical setup in a topological Josephson junction. (b) Nonlocal Seebeck effect of the topological Josephson junction as a function of flux bias(Doppler shift)[left figure] and phase bias [right figure]

Magnetic Gap of Fe-Doped $BiSbTe_2Se$

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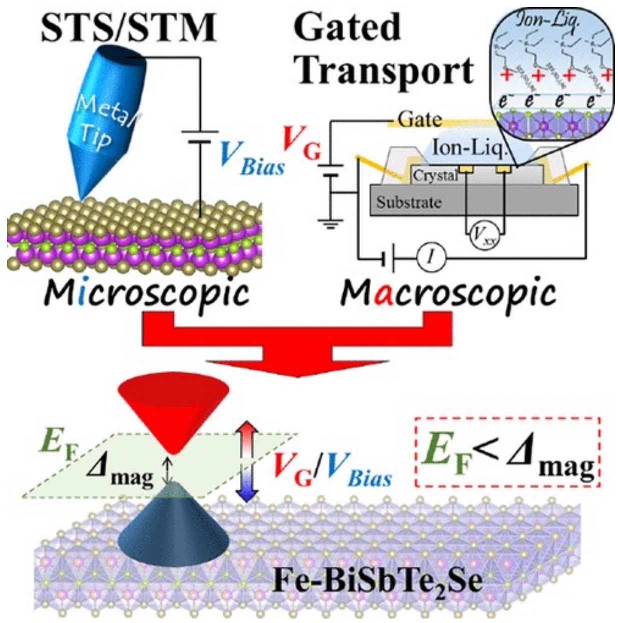
Topological insulators with broken time-reversal symmetry and the Fermi level within the magnetic gap at the Dirac cone provides exotic topological magnetoelectronic phenomena. Here, we introduce an improved magnetically doped topological insulator, Fe-doped $BiSbTe_2Se$ (Fe-BSTS) bulk single crystal. Scanning tunneling microscopy and spectroscopy (STM/STS) measurements revealed that the surface state possesses a Dirac cone with the Dirac point just below the Fermi level by 12 meV. The normalized dI/dV spectra suggest a gap opening with $\Delta_{mag} \sim 55$ meV, resulting in the Fermi level within the opened gap. Ionic-liquid gated transport measurements also support the Dirac point just below the Fermi level and the presence of the magnetic gap. The chemical potential of the surface state can be fully tuned by ionic-liquid gating, and thus the Fe-doped BSTS provides an ideal platform to investigate exotic quantum topological phenomena.



Large spectral gap and impurity-induced states in a two-dimensional Abrikosov vortex

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We study the subgap quasiparticle spectrum of a 2D Abrikosov vortex in an s-wave superconductor in the absence and presence of a magnetic or nonmagnetic point impurity [1]. Within the Eilenberger equations formalism, we calculate the energy spectrum of a vortex within two models: a "coreless" vortex with a constant modulus of the order parameter, and a more realistic vortex with the order parameter profile satisfying the Ginzburg-Landau equation. Both models yield qualitatively similar results. For a vortex without impurity, in addition to the known anomalous spectral branch, we find multiple upper branches corresponding to localized Andreev states. The number of these branches can be arbitrarily large provided that the magnetic field screening length is large enough. The large number of branches appears because of the Doppler effect connected with spontaneous currents in the vortex. These currents lower the effective gap edge, creating a potential well that is large enough to accommodate many Andreev states with the same angular momentum.

The quasiclassical local density of states in the vortex has a gap (more precisely, a double-gap symmetric with respect to the Fermi energy) with a width of the order of the bulk gap and a spatial extent of several coherence lengths. The existence of such a gap is the prerequisite for the appearance of discrete impurity-induced states. Indeed, within the Gor'kov equations formalism, we find that a single impurity induces up to four discrete quasiparticle states in the vortex. The energies and wave functions of the impurity states are calculated for different parameters. In a sense, our study extends the analysis of impurity-induced states by Larkin, Ovchinnikov and Koulakov [2] from the limit of low energies to the whole subgap energy range. Most of the spectral features that we have found can be observed in scanning tunnel microscopy/spectroscopy experiments.

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Correlations and topology in buckled graphene superlattices

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Electronic correlations stemming from nearly flat bands in van der Waals materials have demonstrated to be a powerful playground to engineer artificial quantum matter. Here we show that spontaneously buckled graphene can yield a correlated state, emerging from an elastic pseudo Landau level. Our results build on top of recent experimental findings reporting that, when placed on top of hBN or $NbSe_2$ substrates, wrinkled graphene sheets relax forming a periodic, longrange buckling pattern. The high density of states at the lowest pseudo Landau level leads to the formation of a periodically modulated ferrimagnetic groundstate, which can be controlled by the application of external electric fields [1]. We also demonstrate the emergence of valley topology driven by competing electronic correlations in buckled graphene superlattices [2]. We show, both by means of atomistic models and a low energy description, that the existence of longrange electronic correlations leads to a competition between magnetic and charge density wave instabilities. Interestingly, we find that the emergent charge density wave has a topologically nontrivial electronic structure, leading to a coexistent quantum valley Hall insulating state. In a similar fashion, the magnetic phase realizes a spinpolarized quantum valley Hall insulating state. Our results indicate that periodically strained graphene is a versatile platform to explore topological and correlated.

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A Yu-Shiba-Rusinov Qubit

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Institute of Physics, Polish Academy of Sciences

Magnetic impurities in s-wave superconductors lead to spin-polarized Yu-Shiba-Rusinov (YSR) in-gap states and a chain of magnetic impurities offers one of the most viable routes for the realization of Majorana bound states. They hold a promise for topological quantum computing, but this ambitious goal looks distant since no quantum coherent degrees of freedom have yet been identified in these systems. To fill this gap we propose an effective two-level system, a YSR qubit, stemming from two nearby impurities. Using a time-dependent wave-function approach, we derive an effective Hamiltonian describing the YSR qubit evolution as a function of distance between the impurity spins, their relative orientations, and their dynamics. We show that the YSR qubit can be controlled and read out using the state-of-the-art experimental techniques for manipulation of the spins. Finally, we address the effect of the spin noises on the coherence properties of the YSR qubit, and show a robust behavior for a wide range of experimentally relevant parameters. Looking forward, the YSR qubit could facilitate the implementation of a universal set of quantum gates in hybrid systems where they are coupled to topological Majorana qubits.

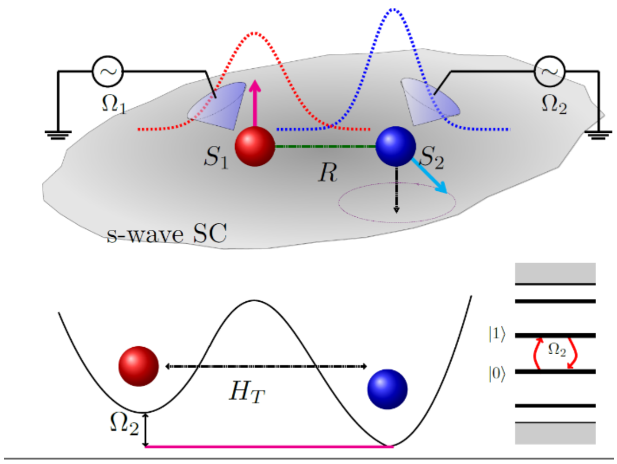

Fig: Two classical spins, target (red) and test (blue), respectively, are placed on top of a 2D s-wave superconductor at a distance R inducing a double-well potential that accommodates two in-gap states for a given parity: the odd parity states |0> and |1> define the YSR qubit states. The asymmetry of the potential stems from the slightly different coupling parameters at the two sites. Driving the test spin effectively tunes the potential bias, and when at resonance with the qubit splitting, it allows for coherent rotations of the qubit, while the target spin is interrogated off-resonantly for quantum non-demolition detection.

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Floquet generation of Second-order Topological Superconductor

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In our work, we theoretically investigate the Floquet generation of second-order topological superconducting (SOTSC) phase, hosting Majorana corner modes (MCMs), considering a two-dimensional (2D) quantum spin Hall insulator (QSHI) with proximity induced superconducting *s*-wave pairing in it. Our dynamical prescription consists of the periodic kick in time-reversal symmetry breaking in-plane magnetic field and four-fold rotational symmetry breaking mass term in the bulk while these Floquet MCMs are preserved by anti-unitary particlehole symmetry. The first driving protocol always leads to four zero energy MCMs (*i.e.,* one Majorana state per corner) as a sign of a *strong* SOTSC phase. Interestingly, the second protocol can result in a *weak* SOTSC phase, harbouring eight zero energy MCMs (two Majorana states per corner), in addition to the *strong* SOTSC phase. We characterize the topological nature of these phases by Floquet quadrupolar moment and Floquet Wannier spectrum. Furthermore, we extend our idea both in 2D and three dimension (3D) starting from a *d*-wave superconducting pairing gap *i.e.,* in the high-temperature platform.

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Superconducting Properties of MXene Monolayers

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Abstract: MXenes are a new class of van der Waals materials, consisting of a transition metal layer sandwiched in between two carbon or nitrogen layers. Various experimental studies demonstrated that these crystals have extensive and growing application areas such as Li-ion batteries [1] super-capacitors [2] fuel-cells [3] and hydrogen storage [4]. Since most of the MXene monolayers are metals, they could also host superconductivity, depending on their electronic and vibrational properties. Therefore, we have systematically investigated the superconducting properties of monolayer MXenes of stoichiometry M_2X (M being the transition metal and X either C or N), with a first-principles approach to Eliashberg theory. Due to the presence of the transition metal, we found that the type of chosen pseudopotential and inclusion of spin-orbit interactions to be crucial to describe the vibrational and superconducting properties of these monolayers. As a result, we have identified five new monolayer superconducting MXenes, out of which three carbides (Mo_2C, W_2C, and Sr_2C) and two nitrides (Mo_2N and Ta_2N). The highest predicted critical temperature (TC) of 17 K is found for Mo2N. Our first principle based systematic analysis clearly has opened up a whole new class of superconductors with sizeable TC in the monolayer limit.

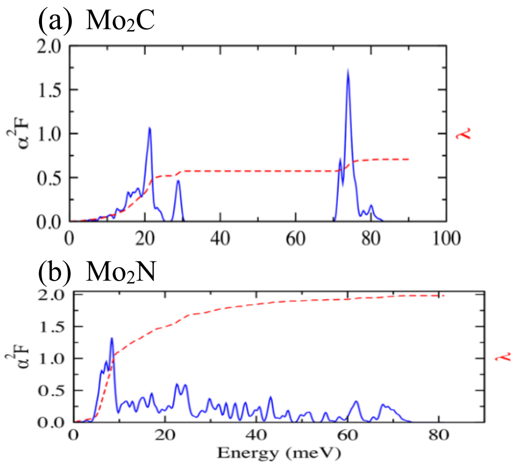

Figure 1: The isotropic Eliashberg function for Mo_2C and Mo_2N, $\alpha^2F(\omega)$ and resulting electron-phonon coupling λ.

Acknowledgement
This material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-19-1-7048 and also supported by Scientific and Technological Research Council of Turkey (TUBITAK- 118F187).

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Triplet blockade in a Josephson junction with a double quantum dot

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Topological superconductors are promising building blocks for future quantum computers, although their experimental realization remains a challenging task. Here we present theory results [1] on a Josephson junction with a double quantum dot, a minimal model system toward engineered topological superconductivity based on quantum dot chains [2]. In the (1,1) charge sector of the serially coupled double quantum dot, we illustrate a magnetically induced singlet-triplet ground-state transition via triplet blockade: the Josephson current carried by the triplet ground state at high magnetic field is much suppressed compared to the current carried by the singlet ground state at low magnetic field. The theory results we present are based on the zero-bandwidth approximation [3]. Simple arguments for a strong triplet blockade are provided in the large-gap [4], and the strong-Coulomb-repulsion limit, furthermore we also outline a process-counting argument that supports partial triplet blockade in the intermediate regime, using perturbation theory [5]. We also present experimental data showing the triplet blockade predicted by the theory [1]. The triplet blockade mechanism could provide a coupling mechanism between spin qubits, and (topological or non-topological) superconducting qubits.

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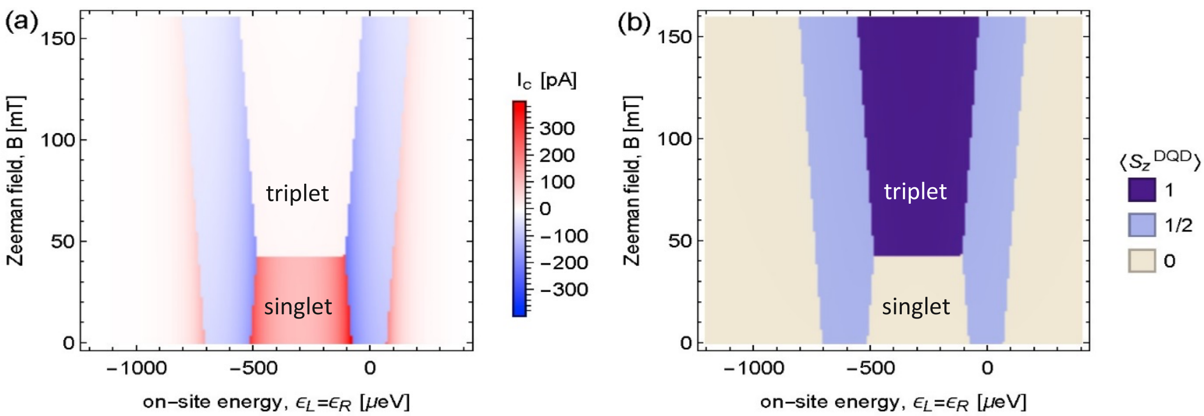

Figure 1. (a) Magnetic stability diagram of the double quantum dot Josephson junction; (b) Ground state expectation value of the z-component of the total double quantum dot spin reveals that the supercurrent is blockaded in the triplet configuration.

Feedback driven Josephson effect in ultrasmall tunnel junctions

Víctor Barrena[1], Samuel Díaz[2], Marta Fernández Lomana[1], David Perconte[1], Edwin Herrera[1], Beilun Wu[1], Isabel Guillamón[1], Alfredo Levy Yeyati[2] and **Hermann Suderow[1]**

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The Josephson effect is the consequence of coupling between two superconducting electrodes and consists of a Cooper pair current flowing between two superconductors at zero bias voltage V=0 and coherent emission of microwave photons at a finite bias voltage V≠0. Here we show that a Josephson junction coupled to a circuit element with feedback has a large bias range above the critical current where the junction periodically flows back to the V=0 state from the V≠0 branch. We discuss the parameter range for the new oscillatory behavior with a RCSJ model modified by a feedback. We measure the resulting low frequency AC oscillations in atomic size ultrasmall vacuum tunnel junctions of Pb-Pb, Al-Al and Pb-$NbSe_2$ obtained by using superconducting tips in a Scanning Tunneling Microscope.

Coexistence of superconductivity and spin-orbit splitting in $Sn_{1-x}In_xTe$ thin film

J.Wang, W. Powers, S. Bac, L. Riney, M. Zhukovskyi, T. Orlova, X.Liu, B. A. Assaf

University of Notre Dame

SnTe is identified to be a topological crystalline insulator, whose surface states are protected by crystal mirror symmetry. It has been recently found that by In doping, $Sn_{1-x}In_xTe$ (SIT) can be superconducting and also maintains its topological surface states. However, the non-trivial character of superconductivity in SIT remains debated. Most previous research of SIT was focused on single crystals. The growth and analysis of SIT thin films are necessary to search for boundary Majorana states. Here, we investigated the MBE growth of $Sn_{1-x}In_xTe$(x=0.05~0.3) thin films(~100nm) on BaF2 (111), and characterized them by XRD, TEM and magneto-transport measurement. A superconducting transition is consistently observed in films, and the critical temperature increases as we increase the concentration. Hall measurements show that In is more likely to act as an electron donor instead of an acceptor as reported in earlier works. The normal state is shown to host coexisting weak localization (WL) and weak antilocalization (WAL), analyzed using a 2D HLN model. The WL only occurs in superconducting samples, indicating that electrons from trivial spin-orbit split states may play a dominant role in the superconducting state. Further experiments are needed to find the origin of a possible spin-orbit splitting.

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Zero-bias peak induced by a magnetic impurity in a conventional superconductor: first principles-based study

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Topological superconductivity has emerged a promising platform for fault-tolerant quantum computing using braiding of Majorana modes. Considering that intrinsic topological superconductors are rare, various heterostructures including s-wave superconductors have been proposed to realize topological superconductivity. One of the viable heterostructures consists of ferromagnetic chains on conventional superconductors. Here we present our first-principles based study of a single magnetic impurity at the surface of an s-wave superconductor by solving the Bogoliubov-de Gennes equations for embedded impurity clusters within the screened Korringa-Kohn-Rostoker method in the framework of density-functional theory. We investigate the local density of states or bound Yu-Shiba-Rusinov states within the superconducting gap by varying the location of the magnetic impurity, the magnitude and direction of the magnetic moment, and spin-orbit coupling. Interestingly, we find a zero-energy peak near the single magnetic impurity with a judicious choice of environmental factors which may be observable in experiment.

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Coupling of Yu-Shiba-Rusinov states in the presence of a charge-density wave

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Chains of magnetic adatoms on superconductors are promising platforms to realize topological superconductivity and Majorana zero modes. Single magnetic impurities on superconductors introduce so called Yu-Shiba-Rusinov (YSR) states inside the superconducting gap of the substrate. In chains of magnetic adatoms the YSR states of the individual atoms are expected to couple and form bands in which the topological gap opens. Here, we take a step back and investigate the coupling of Fe dimers on $NbSe_2$ using scanning tunneling spectroscopy. $NbSe_2$ hosts a charge-density wave (CDW) imposing variations of the local density of states. Fe atoms sitting at the same atomic lattice site but different sites with respect to the CDW, exhibit different YSR states. Here, we deliberately position Fe atoms at various distances and CDW sites. We track the evolution of the YSR states and conclude implications for possible coupling in chains.

Integrating micromagnets and hybrid nanowires in heterostructure Majorana fermions experiments

Malcolm Jardine

Introduction and Purpose

Majorana zero modes are expected to arise in semiconductor-superconductor hybrid systems, with potential topological quantum computing applications. One limitation of this approach is the need for a relatively high external magnetic field that should also change direction at the nanoscale.

This work proposes devices that incorporate micromagnets to address this challenge. We performed numerical simulations of stray magnetic fields from different micromagnet configurations, which were then used to solve for Majorana wavefunctions. Several devices were proposed, starting with a basic four-magnet design to align magnetic field with the nanowire and scaling up to nanowire T-junctions. The experimental feasibility of the approach was assessed by performing magnetic imaging of prototype patterns.

Summary and Conclusions

We consider device concepts in which micromagnets generate stray field patterns suitable for the generation of Majorana zero modes. Our approach assumes micromagnets placed next to semiconductor nanowires that possess strong spin-orbit coupling, and are coated with superconducting shells. The requirements on the stray magnetic fields are that they are of sufficient strength to drive a topological transition, and should be oriented as much as possible along the nanowire. The building block of our magnetic design is a Dragonfly configuration in which four micromagnets are magnetized such that the magnetic field lines flow out of one pair of mircomagnets, along the nanowire, and into the other pair (Figs 1 and 2). By repeating the Dragonfly pattern along the nanowire, we can extend the length of the topological segment with addition of coupling magnets. The approach can also be applied to T-junctions required for Majorana braiding experiments, in which case magnetic field turns into the T-junction leg that is perpendicular to the junction top.

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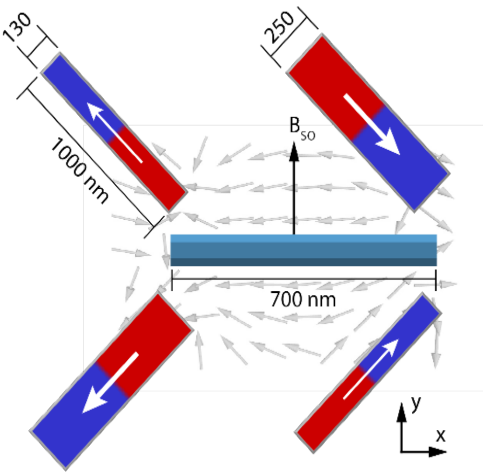

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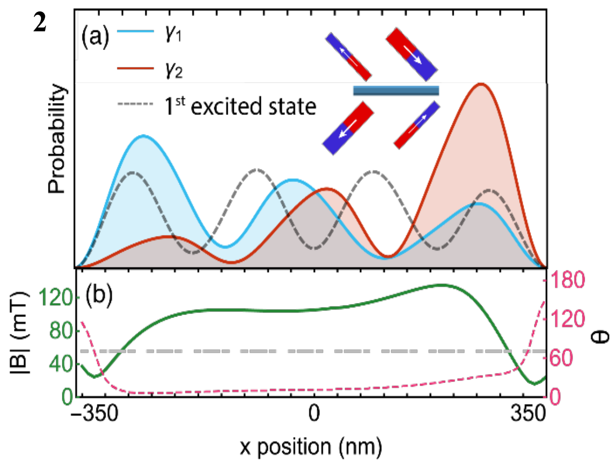

(1) The Dragonfly setup with four micromagnets (blue/red) and an overlay of the magnetic field calculated with MuMax3 (gray arrows). The nanowire runs horizontally with the spin-orbit axis vertical, indicated by B_{so}.

(2) (a) Probability distributions for two Majorana wavefunctions \gamma_1 and \gamma_2. The first excited state (dashed line) is a bulk nanowire state. (b) Magnetic field profile produced from Dragonfly magnet configuration.

Quasiperiodic criticality and spin-triplet superconductivity in superconductor-antiferromagnet moire patterns

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Quasiperiodicity has long been known to be a potential platform to explore exotic phenomena, realizing an intricate middle point between ordered solids and disordered matter. In particular, quasiperiodic structures are promising playgrounds to engineer critical wavefunctions, a powerful starting point to engineer exotic correlated states. Here [1] we show that systems hosting a quasiperiodic modulation of antiferromagnetism and spin-singlet superconductivity, as realized by atomic chains in twisted van der Waals materials, host a localization-delocalization transition as a function of the coupling strength. Associated with this transition, we demonstrate the emergence of a robust quasiperiodic critical point for arbitrary incommensurate potentials, that appears for generic relative weights of the spin-singlet superconductivity and antiferromagnetism. We show that inclusion of residual electronic interactions leads to an emergent spintriplet superconducting state, that gets dramatically enhanced at the vicinity of the quasiperiodic critical point. Our results put forward quasiperiodicity as a powerful knob to engineer robust superconducting states, providing an alternative pathway towards artificially designed unconventional superconductors.

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Andreev molecule in parallel InAs nanowires

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Coupling individual atoms via tunneling fundamentally changes the state of matter: electrons bound to atomic cores become delocalized resulting in a change from an insulating to a metallic state, as it is well known from the canonical example of solids. A chain of atoms could lead to more exotic states if the tunneling takes place via the superconducting vacuum and can induce topologically protected excitations like Majorana or parafermions [1]. Toward the realization of such artificial chains, coupling a single atom to the superconducting vacuum is well studied, but the hybridization of two sites via the superconductor was not yet reported. The peculiar vacuum of the BCS condensate opens the way to annihilate or generate two electrons from the bulk resulting in a so-called Andreev molecular state[3][4]. By employing parallel nanowires with an Al superconductor shell, two artificial atoms were created at a minimal distance with an epitaxial superconducting link between. Hybridization via the BCS vacuum was observed between the two artificial atoms for the first time, as a demonstration of an Andreev molecular state.

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YSR-like band in the superconducting periodic Anderson model

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A magnetic impurity placed on a surface of a conventional superconductor gives rise to discrete sub-gap states in the spectral function known as Yu-Shiba-Rusinov (YSR) states. When an array of magnetic impurities is placed on a superconductor, the individual localized YSR states hybridize and form a continuous band. A recent experimental study in a system of superconducting boron-doped diamond coated with a hydrogen monolayer shows indeed this case [1].

Motivated by the experimental findings, we use the superconducting periodic Anderson model (SCPAM) at half-filling to describe the in-gap YSR bands [2, 3]. The SCPAM consists of a superconducting BCS-type band that hybridizes with a correlated localized band (impurities). We use the dynamical mean-field theory method with quantum Monte Carlo and iterative perturbation theory as impurity solvers to study the model on a square lattice [4, 5]. We find the spectral function for the localized electrons shows in-gap YSR-like bands and a transition from a singlet to doublet ground state similar to the 0-pi transition known from the superconducting impurity Anderson model.

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Finding exotic superconducting pairing in topological semimetals

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We explore the possibility of exotic superconducting pairing in topological semimetals. The topology and the associated symmetries of the semimetals result in a unique electronic band structure, which affects the superconducting gap structure and pair amplitude. In addition to the conventional spin-singlet even-frequency pairing it is possible to find odd-frequency spin-triplet pairing and also pairing with higher intrinsic angular momentum. We also investigate possible experimental probes which can distinguish the signatures of the exotic pairing.

Phase crystals: a class of non-uniform superconducting ground states that break time-reversal symmetry

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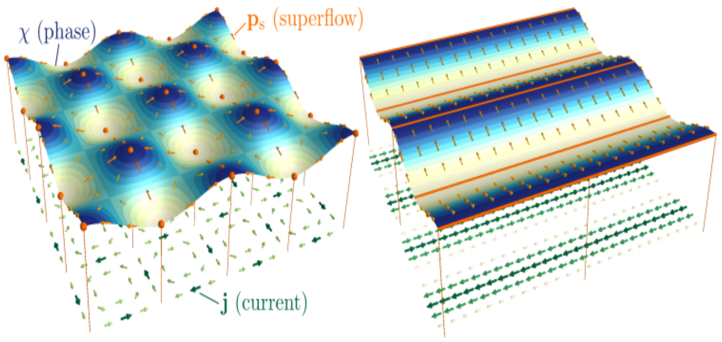

Superconductivity owes its properties to the phase of the electron pair condensate that breaks the U(1)-symmetry. In the most traditional ground state, the phase is uniform and rigid. In the presence of external fields, the normal state can be unstable towards special inhomogeneous superconducting states: the Abrikosov-vortex state and the Fulde-Ferrell-Larkin-Ovchinnikov state. Here we show that even in the absence of external fields, the phase-uniform superconducting state can go into a fundamentally different and more ordered non-uniform ground state, referred to as a "phase crystal" [1]-[6]. This state breaks translational invariance through the formation of a spatially periodic phase, manifested by unusual superflow patterns. The latter non-locally drives spontaneous currents and magnetic fields, breaking time-reversal symmetry.

This phase is analytically modelled using quasiclassics and Ginzburg-Landau theory [1], and crucially relies on the fact that the superfluid density is not generally a local or constant scalar, but rather a non-local and non-uniform tensor. Based on this non-local response theory, the general conditions for the instability to occur are presented, with different possible superflow patterns depending on the underlying system symmetries. As a concrete example of realization, we consider [110]-interfaces of unconventional d-wave superconductors and p-wave superfluids, and conventional S-I-F junctions, where we show that the conditions are naturally satisfied. In these environments, resonant Andreev reflection breaks superconductivity and and leads to zero-energy flat bands. Phase crystallization arises spontaneously to remove the flat bands, consequently healing the broken superconductivity.

The analytic results are compared with self-consistent numerics, using both quasiclassical theory [2]-[4] and Bogoliubov-de Gennes theory [5]-[6]. These methods show qualitative agreement, and effects of size quantization and Friedel oscillations are not detrimental. Furthermore, the state shows robustness against competing orders, external fields and surface disorder. The transition into the phase-crystal state is of second order and occurs at roughly 20% of Tc.

Phase crystals offer a possible explanation to the long-standing controversy of experimental detection of spontaneous currents in the cuprates, and more generally extends the paradigm of non-uniform superconducting ground states.

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Magnetic field dependence of the tunneling density of states in the type II Weyl semimetal WTe_2

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We present STM measurements at very high magnetic fields in the type II Weyl semimetal WTe_2. WTe_2 presents a huge nonsaturating magnetoresistance (6 orders of magnitude between 0 T and 14 T at 4.2 K [1,2]). To understand the origin of this effect, which has been put in relation to possible topological properties in the bandstructure, we have performed detailed atomic scale tunneling density of states measurements as a function of the magnetic field. We follow topography and tunneling density of states as a function of the magnetic field up to 14 T. We show that the overall bandstructure remains magnetic field independent, apart the formation of Landau Levels [3,4]. We notice a phase difference in these oscillations that follows the atomic periodicity. I will discuss the relationship of this observation to the topological properties of the band structure in this material.

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A Ballistic Graphene Based Cooper Pair Splitter

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We present an experimental study of a Cooper pair splitter where ballistic graphene acts as a weak link between two superconducting electrodes [1]. Our devices are fabricated by using h-BN encapsulated graphene which is connected to two superconducting electrodes on two parallel edges and to two normal metal electrodes on the other two edges. As a result, two transverse junctions are formed, namely the superconductor/graphene/superconductor (SGS) junction and normal metal/graphene/normal metal (NGN) junction. The electronic transport properties of a Josephson weak link can be modified by applying a normal current/voltage in the transverse direction to the Josephson junction [2]. In a recent theoretical report, multiterminal Josephson junctions are studied and expected to serve as a testbed for nonlocal transport processes [3]. Here, we study the low temperature electronic transport across the SGS junction as a function of control voltage applied across the NGN junction and vice versa. The tuning of charge transport in graphene from n-type to p-type by an applied gate voltage provides us an additional experimental knob to tune. We observe clear signatures of the Cooper pair splitting in our device that are most prominent close to the charge neutrality point of the graphene weak link. The observed signatures become less pronounced at higher charge carrier densities due to the presence of supercurrent in the device. The experimental data can be very well described by a three-terminal beam splitter model. Our results show the possibilities to design new experiments for the detection of entangled states.

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ELECTRON CORRELATION EFFECTS IN SUPERCONDUCTING NANOWIRES IN AND OUT OF EQUILIBRIUM

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One-dimensional nanowires with strong spin–orbit coupling and proximity-induced superconductivity are predicted to exhibit topological superconductivity with condensed-matter analogues to Majorana fermions [1, 2]. Here, the nonequilibrium Green's function (NEGF) approach with the generalized Kadanoff–Baym ansatz is employed to study the electron-correlation effects and their role in the topological superconducting phase in and out of equilibrium. In equilibrium, the NEGF approach was found to be in accordance with density matrix renormalization group data of Reference [3], where it was found that repulsive interactions enhance the effective Zeeman splitting while suppressing the pairing potential (see the energy-band structure obtained by the spectral functions in Figure 1). Moreover, electron correlation effects were found to affect the transient signatures regarding the zero-energy Majorana states, when the superconducting nanowire was subjected to external perturbations such as magnetic field quenching, laser-pulse excitation, and coupling to biased normal-metal leads [4].

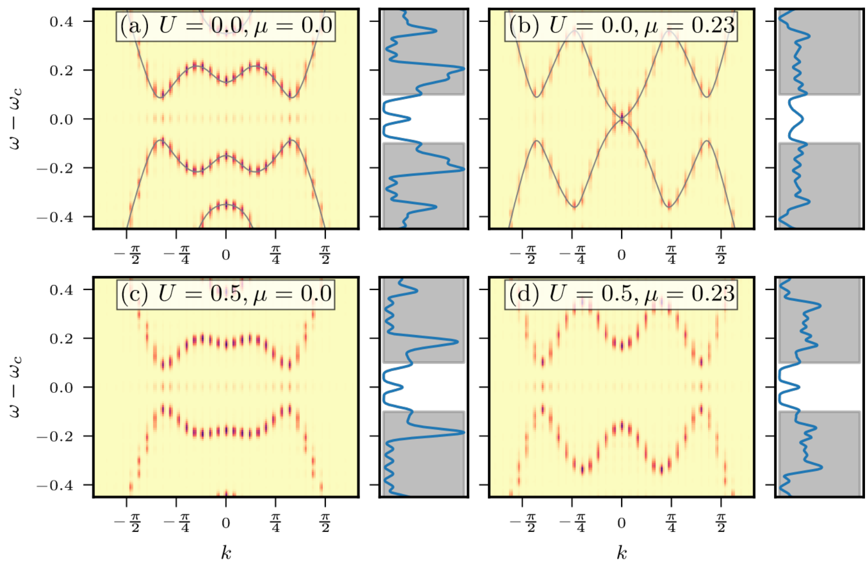

Figure 1: Momentum and energy-resolved spectral function (color map; arbitrary units, where darker is higher) for the (a-b) noninteracting, U=0.0, and (c-d) interacting, U=0.5, nanowire.

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Majorana Bound States in Semiconductor/Ferromagnetic insulator/Superconductor nanowire heterostructures

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Hybrid semiconducting nanowire devices combining epitaxial superconductor and ferromagnetic insulator layers have been recently explored experimentally as an alternative platform [1-3] for topological superconductivity at zero applied magnetic field. In this proof-of-principle work [4] we show that the topological regime can be reached in actual devices depending on some geometrical constraints. To this end, we perform numerical simulations of InAs wires in which we explicitly include the superconducting Al and magnetic EuS shells, as well as the interaction with the electrostatic environment at a self-consistent mean-field level. Our calculations indicate that the topological phase is robustly achieved in significant portions of the phase diagram only in configurations where the Al and EuS layers overlap on some wire facet due to their rather local induced proximity effects. Moreover, we find that the spin polarization induced directly in the semiconductor by the EuS is much stronger than the one induced indirectly through the superconductor. Finally, we comment on how the topological phase can be tuned and optimized using external gates.

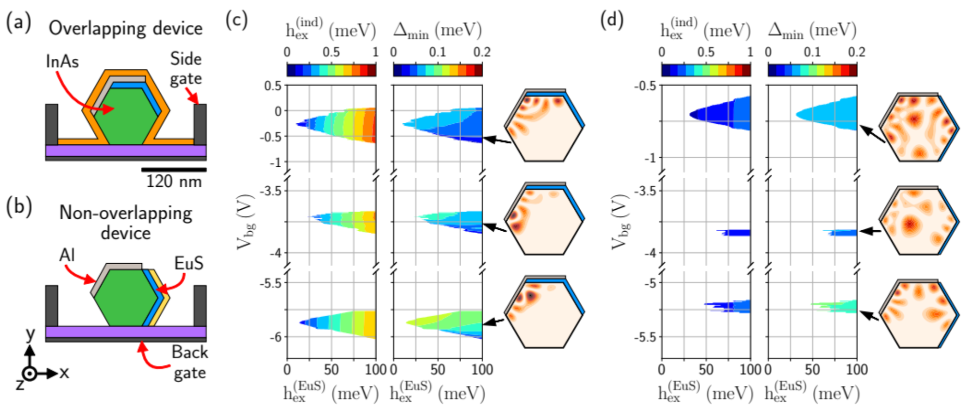

Figure 1: (a-b) Sketch of the devices studied in this work, in which an InAs wire is proximitized by two layers: one superconducting (Al) and another one ferromagnetic insulator (EuS). There are several gates used to tune the chemical potential inside the hybrid wire. Note that in (a) the EuS and the Al overlap in one facet, while in (b) they lie in different ones. (c-d) Topological phase diagrams of the devices (white means trivial, colours mean topologically non-trivial). It is also shown the induced exchange field, topological mini-gap, and wavefunction profile of the topological states, respectively.

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Improved effective equation for the Rashba spin-orbit coupling in semiconductor nanowires

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Semiconductor Rashba nanowires are quasi-one dimensional materials that have large spin-orbit (SO) coupling arising from a broken crystal potential symmetry due to an external electric field. There exist parametrized multiband models that can describe accurately this effect [1]. However, simplified single band models are highly desirable to study geometries of recent experimental interest, since they may allow to incorporate the effect of low dimensionality and the nanowire electrostatic environment [2] at a reduced computational cost. Commonly used conduction band approximations, valid for bulk materials, greatly underestimate the SO coupling in Zinc-blende crystal structures and overestimate it for Wurzite ones when applied to finite cross-section wires, where confinement effects turn out to play an important role. We demonstrate [3] that an effective equation for the linear Rashba SO coupling of the semiconductor conduction band (CB) can reproduce the behaviour of more sophisticated eight-band k·p model calculations. This is achieved by adjusting a single effective parameter that depends on the nanowire crystal structure and its chemical composition. We further compare our results with the Rashba coupling extracted from magnetoconductance measurements in several experiments on InAs and InSb nanowires (see Fig. 1 below), finding excellent agreement. This approach may be relevant in systems where Rashba coupling is known to play a major role, such as in spintronic devices or Majorana nanowires.

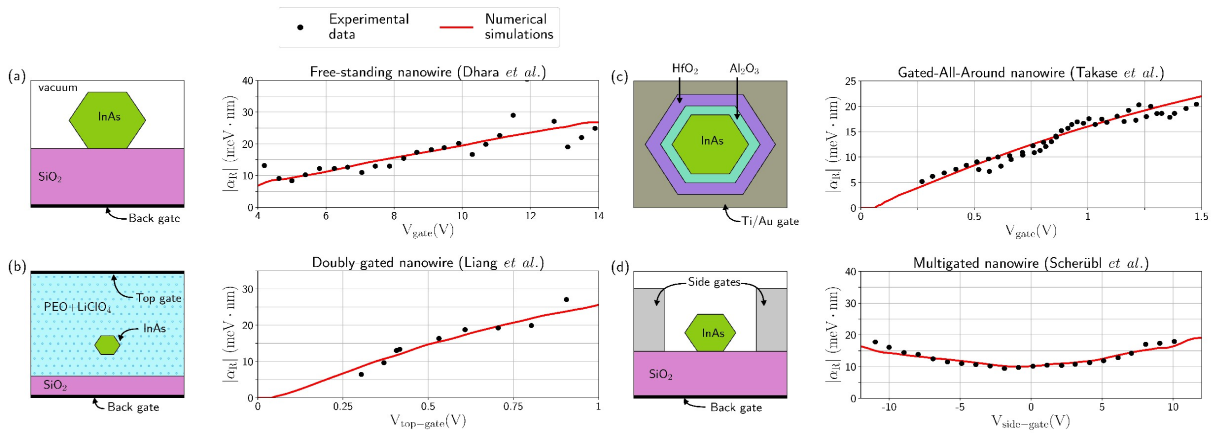

Figure 1. Electrostatic environment modelling of some experimental setups (left), and corresponding effective Rashba couplings (right) obtained with magnetoconductance measurements (dots) and with numerical simulations using the conduction band approximation (red lines).

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Interplay of excitonic correlation with quantum spin hall effect and superconductivity in electron-hole bilayers

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It has been proposed that in band-inverted electron-hole bilayers the excitonic correlations arising due to Coulomb interactions lead to phase transitions from a trivial insulator phase to an insulating phase with spontaneously broken Time-Reversal Symmetry (TRS) and finally to a nontrivial quantum spin Hall insulator phase as a function of increasing electron and hole densities[1]. Importantly, in contrast to the standard paradigm of topological phase transitions, the trivial insulator phase is connected to a quantum spin Hall insulator without an energy gap closing appearing in the fermionic spectrum. Here, we show that it is possible to realize Majorana Zero Modes (MZMs) in the time-reversal symmetry broken phase in the presence of proximity-induced superconductivity in the absence of magnetic field. We demonstrate that the Majorana zero modes can be detected in superconductor/time-reversal symmetry broken insulator/superconductor Josephson junctions through the measurement of a 4π Josephson current. For a better understanding of our numerical results, we develop an effective low-energy theory in the presence of time-reversal symmetry breaking order parameter and obtain analytically the Majorana zero modes and the Andreev bound states localized at the junction using a scattering-matrix formalism. We find a good agreement between the numerical and analytical results in the limit of weakly-broken time-reversal symmetry.

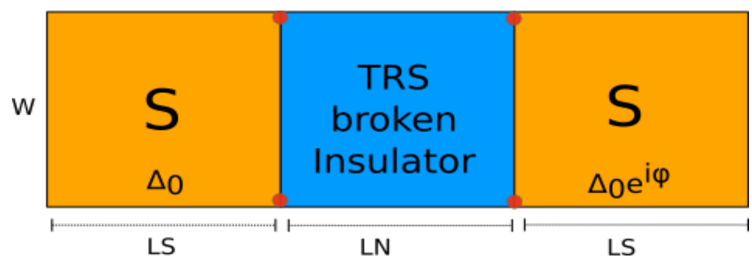

FIG.1. Device setup: superconductor/time-reversal symmetry broken insulator/superconductor with MZMs (in red circles) appearing at the interface.

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Probing helical vs chiral character of topological superconductors via non-local Hanbury-Brown and Twiss correlations

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Hanbury Brown and Twiss (HBT) correlations and the non-local differential conductance show the distinct character of helical and chiral superconductors as well as their difference from non-topological superconductors. Topological nature of unconventional superconductors can be clearly distinguished regardless of the setup whether symmetric, non-local or asymmetric by observing HBT correlations. Our chosen model is a generic model to study non-local shot noise cross correlations. Experimentally, it has been seen that this model, which is metal/superconductor/metal, is easy design and bias voltages can be easily tuned. Probing helical and chiral superconductor is significant because at metal-chiral superconductor junctions stable Majorana bound states (MBS), which persist even in presence of magnetic field have been predicted to occur that will help even in the search for stable MBS, which have potential importance in topological quantum computation. Further, motivation for our work arises from inconsistency in previous experiments which have probed the different topological and non-topological pairing symmetries via Knight shift or scanning SQUID microscopy.

Knight shift measurement do not resolve the helical versus chiral dichotomy. We propose HBT correlation-based tests that will give an easy way out for experimentalists to distinguish non-topological superconductors from both chiral-p, chiral-d as well as from helical-p topological superconductors. This additional approach to distinguish the different pairing symmetries in unconventional superconductors is via HBT correlations and non-local conductance with change in barrier strength as well as bias voltages, with simple expressions in the fully transparent as well as tunneling limit for shot noise in the small bias voltage regime too.

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Magnetic exchange interactions at proximity of a superconductor

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Magnetic impurities coupled to superconductors give rise to sub-gap states like Yu-ShibaRusinov states and Majorana modes. These states are key ingredients on the road towards the realization of a topological quantum computer. Spin-orbit coupling and (non-collinear) magnetism coact to enrich the complexity and topological properties of these in-gap states hosted in proximity-induced superconductors. However, little is known about the impact of superconductivity on the magnetic exchange interactions, especially on the bilinear isotropic exchange and the Dzyaloshinskii-Moriya interaction — and in turn the impact on magnetic textures. In this work, we extract the tensor of exchange interactions in the superconducting regime as described in the framework of the Bogoliubov-de Gennes method. We investigate monolayers of Mn deposited on the Nb(110) surface based on our multi-orbital tight-binding code TITAN.

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MANY-BODY MAJORANA-LIKE ZERO MODES WITHOUT GAUGE SYMMETRY BREAKING

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Topological superconductors represent one of the key hosts of Majorana-based topological quantum computing. Typical scenarios for one-dimensional (1D) topological superconductivity assume a broken gauge symmetry associated to a superconducting state. However, no interacting 1D many-body system is known to spontaneously break gauge symmetries. Here, we show that zero modes emerge in a many-body system without gauge symmetry breaking and in the absence of superconducting order [1]. In particular, we demonstrate that Majorana zero modes of the symmetry-broken superconducting state are continuously connected to these zero-mode excitations, demonstrating that zero-bias anomalies may emerge in the absence of gauge symmetry breaking. We demonstrate that these many-body zero modes share the robustness features of the Majorana zero modes of symmetry-broken topological superconductors. We further show that the interface between the interacting model and a 1D topological superconductor does not support Majorana modes. We introduce a bosonization formalism to analyze these excitations and show that a ground state analogous to a topological superconducting state can be analytically found in a certain limit. Our results demonstrate that robust Majorana-like zero modes may appear in a many-body systems without gauge symmetry breaking, thus introducing a family of protected excitations with no single-particle analogues.

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A theoretical proposal for detection of Majorana bound state in quantum spin Hall insulator using boost

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Since the first few experimental attempts made in 2012, an unambiguous detection of Majorana bound state (MBS) in a quantum transport measurement remains a challenge. Though the initial experimental attempts were based on the nanowire setup but since then the field has evolved and the two-dimensional platforms based on helical edge state (HES) of quantum spin Hall (QSH) state has emerged as a potential alternative. We propose a setup comprising superconductivity-proximitized quantum spin Hall insulator for detection of Majorana bound state, which could provide unprecedented immunity from disorder induced masking of its detection. An unexplored phase space involving exchange field induced boost of helical edge state is proposed for the detection of MBS. Analytic results from 1-D effective edge theory for the set-up, in the topological phase, are shown to present a remarkable resemblance to the results obtained from 2-D transport simulations in presence of disorder which demonstrates the experimental feasibility of our proposal.

Dynamic Copper pair splitter

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Cooper pair splitters are promising candidates for generating spin-entangled electrons. However, the splitting of Cooper pairs is a random and noisy process, which hinders further synchronized operationson the entangled electrons. To circumvent this problem, we propose and analyze a dynamic Cooper pairsplitter that produces a noiseless and regular flow of spin entangled electrons [1]. The Cooper pair splitter is based on a superconductor coupled to two quantum dots, whose energy levels are tuned in andout of resonance to control the splitting of Cooper pairs. We identify the optimal operating conditions, for which exactly one Cooper pair is split per period of the external drive and the flow of entangled electrons becomes noiseless. To characterize the regularity of the Cooper pair splitter in the time domain,we analyze the $g^{(2)}$-function of the output currents and the distribution of waiting times between split Cooper pairs. Based on recent experiments demonstrating real-time detection of Cooper pairs in static systems [2] as well as dynamic control over the emission time statistics of a single-electron transistor [3], our proposal seems feasible using current technology, and it paves the way for dynamic quantum information processing with spin-entangled electrons.

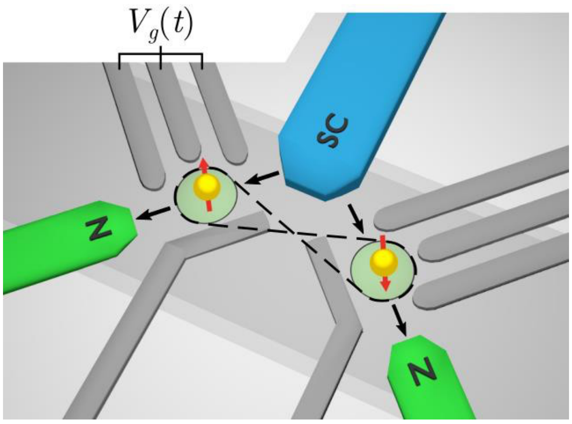

Figure 1: Schematic of the dynamic Cooper pair splitter, consisting of a superconductor (blue)coupled to two quantum dots (light green), themselves coupled to separate normal-metal leads(green). The splitting of Cooper pairs is dynamically controlled via a time-dependent gate voltage $V_g(t)$.

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Transport in Josephson junctions with a graphene interlayer

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We study, both theoretically and experimentally, the features on the current-voltage characteristics of a highly transparent Josephson junction caused by transition of the superconducting leads to the normal state. These features appear due to the suppression of the Andreev excess current. We show that by tracing the dependence of the voltages, at which the transition occurs, on the bath temperature one can obtain valuable information about the cooling mechanisms in the junction. We verify theory predictions by fabricating two highly transparent superconductor-graphene-superconductor (SGS) Josephson junctions with suspended and non-suspended graphene as an interlayer between Al leads. Applying the above mentioned technique we show that the cooling power of the suspended junction depends on the bath temperature as T^3 close to the superconducting critical temperature.

Thermoelectric current in a graphene Cooper pair splitter

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The phenomenon of generating electric voltage by applying a temperature gradient, known as Seebeck effect and its inverse has widespread application ranging from temperature sensing to thermoelectric power generation. The possibility of emerging thermoelectric current from non-local Cooper pair splitting and elastic co-tunneling processes has been theoretically predicted in recent years. In this work, we demonstrate such non-local Seebeck effect in a graphene Cooper pair splitter device with two quantum dots connected to an aluminum superconductor. Such observed effect provides a way for generating entangled electrons.

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