BOOK OF ABSTRACTS

COST Action CA21144

SUPERQUMAP

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EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

SuperQUMAP

INTERNATIONAL CONFERENCE ON

Superconducting Nanodevices and Quantum Materials for Coherent Manipulation: Topological states in superconductors and magnetic materials

May 6 – 9, 2025
Liblice, Czech Republic

organized by the:

FZU - Institute of Physics of the Czech Academy of Sciences

FZU
Fyzikální ústav Akademie věd České republiky
Institute of Physics of the Czech Academy of Sciences

International conference on

Superconducting Nanodevices and Quantum Materials for Coherent Manipulation: Topological states in superconductors and magnetic materials

May 6 – 9, 2025

at the Conference Center of the Czech Academy of Sciences, Castle Liblice, Czech Republic

Local Organizer

FZU - Institute of Physics of the Czech Academy of Sciences

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(Institute of Physics, Czech Academy of Sciences)

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Contents

Preface

Advancing our understanding of topological superconductivity and the unique quantum behaviors of strongly entangled particles opens exciting possibilities for the development of next-generation quantum technologies. Initial concepts and platforms - particularly Majorana zero modes emerging at the edges of one-dimensional topological superconductors - have laid the groundwork for broader applications, including unconventional superconductors, spin liquids, and fractional quantum Hall states.

This international conference on **Superconducting Nanodevices and Quantum Materials for Coherent Manipulation: Topological states in superconductors and magnetic materials** in Liblice, Czech Republic, aims to bring together members of the Management Committee and other scientists to discuss ongoing research, review progress, and share key findings within the COST Action CA21144 "SUPERQUMAP". The conference will serve as a platform for exchanging ideas and showcasing recent developments. Current quantum technologies, despite relying on well-established fabrication processes, face substantial challenges in scaling environment-protected superconducting qubits. Addressing these obstacles requires a collaborative, research-driven approach that delves into the core principles of quantum devices and materials.

The discussions will shape the future direction of the Action, focusing on, but not limited to, the following three key areas:

- **Quantum Materials:** Investigating topological and triplet superconductivity, as well as exploring the relationship between electronic correlations, magnetism, and unconventional superconducting properties.
- **New Functionalities for Sensors and Devices:** Examining disorder in low-dimensional and low carrier density superconductors, understanding electronic behavior between the extremes of infinite and zero resistance, and analyzing transport in hybrid magnetic-superconducting systems, including pi- and phi-junction behaviors in heterostructures.
- **Building Quantum Systems:** Developing novel two-level systems in superconducting junctions and devices designed for quantum computation, along with advancing methods for coherent manipulation in quantum devices.

On behalf of the organizing committee,
Vladislav Pokorný & Jeroen Custers

Scientific Program

The conference starts on Tuesday the 6th of May and ends on Friday afternoon the 9th of May, 2025. The Monday is reserved for arrival.

There are only oral presentations at the conference:

- **Session talks:** 25 minutes of presentation and 5 minutes of discussion
- **Short talks:** 12 minutes of presentation and 3 minutes of discussion

Each day the scientific program starts with a presentation of a scientist affiliated to the Czech Republic.

The conference has 53 presentations in total:

- 44 session talks
- 9 short talks

Time	Tuesday 6th May
	chair: W. Lang
9h - 9:30h	**Katarzyna Roszak:** *Harnessing spin-qubit decoherence to probe strongly-interacting quantum systems*
	Session: Spintronics chair: W. Lang
9:30h - 10h:	**Jan Aarts:** *Generating dissipationless spin currents with a superconductor*
10h - 10:30h:	**Abdou Hassanien:** *Delocalized π-d Kondo effect in single component molecular unit*
10:30h - 11h:	**Coffee break**
	Session: Superconductivity 1 chair: H. Suderow
11h - 11:30h:	**Alexander Buzdin:** *Magnetoelectric effect in the helical state of a superconductor/ferromagnet bilayer*
11:30 - 12h:	**Nenad Lazarević:** *Lattice, spin, and charge excitations in Fe(Se:S)*
12h - 12:30h:	**Tomáš Samuely:** *Ising superconductivity in bulk transition metal dichalcogenides*
12:30h : 14h	**Lunch break**
	Session: Topology chair: V. Pokorný
14h - 14:30h	**Chuan Li:** *Higher-order topological edge states in 3D Dirac semimetals*
14:30 - 15h:	**Hugo Dil:** *Real and reciprocal space spin textures in altermagnetic MnTe*
15h - 15:30h:	**Changhee Lee:** *Odd-parity itinerant antiferromagnets by space group symmetry*
15:30h - 16h:	**José J. Baldoví:** *Modeling magnetism in 2D materials from first principles*
16h - 16:30h:	**Coffee break**
	Short presentations 1 chair: D. Kölle
16:30h - 16:45h:	**Stevan Đjurdjevic:** *Subgap states in hybrid junctions made of normal metal, altermagnets and Rashba superconductors*
16:45h - 17h:	**Malik Ayachi:** *Proximity effects in heterostructures combining high-T_C superconductors and 2D transition metal dichalcogenides*
17h - 17:15h:	**Lucas Baldo Mesa Casa:** *Defect-induced band restructuring and length scales in twisted bilayer graphene*
17:15h: - 17:30h:	**Pavol Neilinger:** *Optical Conductivity of Disordered Films for Superconducting Single-Photon Detectors.*
	Session: Qubits chair: D. Kölle
17:30h - 18h:	**Francesco Tafuri:** *Qubits Using Ferromagnetic Josephson Junctions: The Ferrotransmon*
18h - 18:30h	**Dijana Žilić:** *Coherent Manipulation of the Spin States in Copper and Vanadyl Molecular Qubits*
19h	**Dinner**
20:30h - 22h:	**MC Meeting**

Time	Wednesday 7th May
	chair: J. Villegas
9h - 9:30h	**Michal Vališka:** *Ultrasound Study of Field-Induced Superconducting Phases in* UTe_2
	Session: Superconductivity 2 chair: J. Villegas
9:30h - 10h:	**Hermann Suderow:** Scanning tunneling spectroscopy in heavy fermion superconductors
10h - 10:30h:	**Anna Böhmer:** *Single-crystal growth and superconducting properties of* $Sr_xBi_2Se_3$
10:30h - 11h:	Coffee break
	Session: Application 1 chair: F. Lombardi
11h - 11:30h:	**Joris Van de Vondel:** *DC-operated Josephson junction arrays as a cryogenic on-chip microwave measurement platform*
11:30 - 12h:	**Danica Krstovska:** *Organic bilayer films for sensing applications*
12h - 12:30h:	**Daria Szewczyk:** *INTiBS PAN vs SUPERQUMAP: opportunities and recent advancements*
12:30h : 14h	Lunch break
	Session: Vortex 1 chair: B. Leridon
14h - 14:30h	**Ioan Adrian Crisan:** *Anomalous Vortex Dynamics and Magnetic Memory Effect in* $BaFe_2(As_{0.68}P_{0.32})_2$ *due to the Rhombic-to-Square Transition of the Bragg Vortex Glass*
14:30 - 15h:	**Wolfgang Lang:** *Thin* $Bi_2Sr_2CaCu_2O_{8+x}$ *films: properties and nanoengineered vortex pinning*
15h - 15:30h:	**Glib Kakazei:** *Gyrotropic excitations in radial magnetic vortices*
15:30h - 16h:	**Oleksandr Dobrovolskiy:** *Vortex Jets in 2D and 3D Superconductor Nanomembranes*
16h - 16:30h:	Coffee break
	Short presentations 2 chair: J.J. Baldoví
16:30h - 16:45h:	**Hadi Hassan:** *Magnetization Dynamics in* $La_{1-x}Sr_xMnO_3/YBa_2Cu_3O_{7-\delta}$ *half-metal ferromagnet/d wave-Superconductor Bilayers*
16:45h - 17h:	**Jose David Bermudez Perez:** *Scanning Tunneling Spectroscopy of FeSe Under in-plane Magnetic Fields*
17h - 17:15h:	**Bartoz Rusin:** *Superconductivity in Co-doped iron-based superconductor GdFeAsO*
17:15h: - 17:30h:	**Óscar Bou Marqués:** *Scanning tunneling spectroscopy at high magnetic fields in* $CaKFe_4As_4$*: vortex lattice and normal phase properties*
17:30h -17:45h:	**Daniel Bobok:** *Scalable effective models for complex superconducting nanodevices*
	Session: Josephson Junction 1 chair: J.J. Baldoví
17:45h – 18:15h:	**Dieter Kölle:** $YbA_2Cu_3O_7$ *Josephson junctions and SQUIDS nanopatterned with focussd ion beams*
18:15h - 18:45h	**Vadim Geshkenbein:** *Abrikosov vortices switching current in magic-angle graphene*
19h 20:30h - 22h:	Conference Dinner

Time	**Thursday** 8th May
	chair: Š. Kos
9h - 9:30h	**Michal Šindler:** *Terahertz spectroscopy of thin superconducting films*
	Session: Superconductivity 3 chair: Š Kos
9:30h - 10h:	**Albert Varonov:** *Kondo s-d exchange in the CuO_2 plane as the long sought interaction determining T_c in cuprates*
10h - 10:30h:	**Todor Mishonov:** *On the theory of supermodulation of the superconducting order parameter created by structural supermodulation of apex distance in optimally doped $Bi_2Sr_2CaCu_2O_{8+x}$*
10:30h - 11h:	**Coffee break**
	Session: Vortex 2 chair: O. Dobrovolskiy
11h - 11:30h:	**Yonathan Anahory:** *Evidence of competing orders in few-layer $NbSe_2$*
11:30 - 12h:	**Dimitri Roditchev:** *Josephson Vortex Shaking Memory*
12h – 12:30h:	**Vladimir Fomin:** *Topological Transitions in Superconductor Nanoarchitectures*
12:30h : 14h	**Lunch break**
	Session: Application 2 chair: J. V.d. Vondel
14h - 14:30h	**Alejandro Silhanek:** *Magnetic Recording of Superconducting States.*
14:30 - 15h:	**Anna Palau:** *Nanoengineered High-Temperature Superconductors for Efficient Functional Devices*
15h - 15:30h:	**Floriana Lombardi:** *Nanostructured Surface Control of Quantum Phases in Ultrathin YBCO: Enhanced Superconductivity, Emergent Nematicity, and Unidirectional Charge Order.*
15:30h - 16h:	**Ali Gençer:** *Influence of Reaction Kinetics on MgB_2 Wires with Enhanced Properties: Optimization of Copper-Coated Magnesium Rod and Carbon-Coated Nano-Boron Powders in IMD Process*
16h - 16:30h:	**Coffee break**
	Session: Josephson Junction 2 chair: M. Milošević
16:30h – 17h:	**Zorica Popović:** *Josephson Diode Effect in Arbitrarily Oriented d-Wave Superconductor/Ferromagnet/d-Wave Superconductor Junction with Interfacial Rashba Spin-Orbit Coupling*
17h - 17:30h:	**Mads Peter Sørensen:** *Control of Chaotic Dynamics in Josephson Junctions*
17:30h - 18h:	**Martin Berke:** *Measuring the current-phase relation in Josephson junction using superconducting resonators*
18h - 18:30h	**Elisabetta Paladino:** *Current phase relation of short graphene Josephson junctions: dilute impurities and spin-orbit coupling effects*
19h	**Dinner**
20:30h - 22h:	**Open Discussion**

Time	**Friday** 9th May
	chair: T. Samuely
9h - 9:30h	**Šimon Kos:** *Critical behavior of the 1d superconductor in the FLEX approximation*
	Session: Superconductivity 4 chair: T. Samuely
9:30h - 10h:	**Manohar Kumar:** *Disorder effect on superconductor metal transition: quantum griffiths singularity.*
10h - 10:30h:	**Joseph A. Wilcox:** *Magnetically-controlled Vortex Dynamics in a Ferromagnetic Superconductor*
10:30h - 11h:	**Coffee break**
	Session: Superconductivity 5 chair: E. Paladino
11h - 11:30h:	**Javier Villegas:** *Electrical detection of giant spin-to-charge conversion in superconductors*
11:30 - 12h:	**Evangelia Moschopoulou:** *Intrinsic versus Extrinsic Strain Dependence of Superconductivity in the Quasi-2D Superconductor* $CeIrIn_5$.
12h - 12:30h:	**Milorad Milošević:** *<title>*
12:30h – 12;40h	**Closing words**
12:40h : 14h	***Lunch break***
14h - 14:30h	
14:30 - 15h:	**Departure to Prague**
15h - 15:30h:	
15:30h - 16h:	

Abstracts

Abstracts are listed as they appear in the program.

Harnessing spin-qubit decoherence to probe strongly-interacting quantum systems

M. Płodzień[1], S. Das[2], M. Lewenstein[1,3], C. Psaroudaki[4], and K. Roszak[2]*

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Extracting information from quantum many-body systems remains a key challenge in quantum technologies due to experimental limitations. In this work, we employ a single spin qubit to probe a strongly interacting system, creating an environment conducive to qubit decoherence. By focusing on the XXZ spin chain, we observe diverse dynamics in the qubit evolution, reflecting different parameters of the chain. This demonstrates that a spin qubit can probe both quantitative properties of the spin chain and qualitative characteristics, such as the bipartite entanglement entropy, phase transitions, and perturbation propagation velocity within the system. This approach reveals the power of small quantum systems to probe the properties of large, strongly correlated quantum systems.

Generating dissipationless spin currents with a superconductor

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Spin currents could be of clear use in cryo-electronics, since they might be able to control supercurrents through spin injection, or switch nanomagnets. In order to have dissipationless spin currents, there should be no accompanying resistive charge current. This can be achieved in different ways. One is to induce a triplet spin supercurrent in a ferromagnet. We find that we can induce such currents in halfmetallic ferromagnetic $La_{0.7}Sr_{0.3}MnO_3$ bars with superconducting (S) NbTi contacts. We currently reach a length of more than 1.5 μm, with a critical current of almost 1×10^9 A/m^2 at 2 K, as will be shown. Another way is to inject spins into a bar of normal (N) metal, and deflect the charge to one direction. In the other direction, there will be diffusive spin transport that can be measured with a non-local geometry. The issue then is that the spin current is dissipationless, but its generation through injection is not, and requires quite high current densities. We have recently set up an experiment in which a triplet supercurrent is generated in a ferromagnetic Co layer, which is in contact with a Cu layer. Triplet correlations can be induced in the same way as singlet correlations in SNS junctions. The first results of this study will be presented.

Delocalized *π-d* Kondo effect in single component molecular unit

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Interest in *π-d* charge transfer complexes stems from the fact that the electronic properties can be systematically manipulated by changing the type and/or the stoichiometry of donor and acceptor constituents. With this strategy, various crystalline organic conductors and superconductors have been realized. However, in order to achieve these properties at high temperature regime a strong coupling between frontier orbitals is required. With that in mind, another design of molecular systems based on transition metal dithiolate has emerged in which the generation of charge carriers is generated within a single molecular unit. Accordingly, various isostructural multiorbital correlated systems such as superconducting, magnetic and Dirac electrons have been fabricated. Here we study the atomic-scale electronic properties of single component molecular conductor $Au[tmdt]_2$; where the ligand tmdt is Trimethylenetetrathiafulvalenedithiolate. Scanning tunneling spectroscopy show that the neutral single molecule is magnetic and completely loses its magnetic moment when negatively charged by metal surface. The atomic-scale spatial variation of Kondo resonance shows evidence of intramolecular doping as the valence electrons traffic across *π* and *pdσ* orbitals. By taking advantage of both orbital and spin degrees of freedom, this spin 1/2 molecule possesses robust anisotropic magnetic moment which is an essential ingredient for molecular spintronics.

Magnetoelectric effect in the helical state of a superconductor/ferromagnet bilayer

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We investigate the nucleation of the helical superconducting state in a 2D superconductor/ferromagnet system with a spin-splitting field and weak Rashba spin-orbit coupling. By solving the Gorkov equations exactly, we describe the system's thermodynamic properties and derive the Ginzburg-Landau expansion. This enables analysis of magnetization control via transport supercurrent in dc and quasistatic ac regimes, linking these effects to the superconducting diode effect.

Lattice, spin, and charge excitations in Fe(Se:S)

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We use Raman scattering as a function of temperature and polarization to probe charge and spin dynamics in FeSe. In agreement with numerical simulations of a spin-1 Heisenberg model, several peaks in all Raman active symmetries can be assigned to spin excitations. The dominating feature is a peak in B_{1g} symmetry around 500 cm^{-1} which shows distinct temperature dependence. In the second step, all types of excitations including phonons, spins, and charges are analysed in detail for Fe(Se:S). Finally, the evolution of lattice excitations as a function of tensile uniaxial strain is analysed.

Tuesday, 12:00 – 12:30

Ising superconductivity in bulk transition metal dichalcogenides

T. Samuely[1]*, D. Volavka[1], T. Moško[1], M. Gmitra[1,2], Z. Pribulová[2], J. Kačmarčík[2], P. Samuely[2]
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Ising superconductivity allows in-plane upper critical magnetic fields to exceed the Pauli limit by aligning electron spins of Cooper pairs out-of-plane. Initially demonstrated in 2D monolayers of transition metal dichalcogenides, it has since been observed in layered bulk materials. Our previous study [1] explained the mechanism in bulk based on reduced electronic coupling between superconducting layers due to intercalation by insulating layers and restricted inversion symmetry. However, some transition metal dichalcogenide polytypes violate the Pauli limit even without intercalation. We used heat capacity measurements to show that pristine noncentrosymmetric bulk $4H_a$-$NbSe_2$ significantly violates the Pauli limit [2]. Ab initio calculations based on the crystal structure provide the microscopic mechanism of Ising protection due to broken inversion symmetry.

[1] P. Samuely, P. Szabó, J. Kačmarčík, A. Meerschaut, L. Cario, A. G. M. Jansen, T. Cren, M. Kuzmiak, O. Šofranko and T. Samuely, Phys. Rev. B **104,** (2021), 224507.

[2] D. Volavka, Z. Pribulová, J. Kačmarčík, T. Moško, B. Stropkai, J. Bednarčík, Y. Gao, O. Moulding, M.-A. Méasson, C. Marcenat, T. Klein, S. Sasaki, L. Cario, M. Gmitra, P. Samuely and T. Samuely, arXiv:2501.08867

Higher-order topological edge states in 3D Dirac semimetals

B. Bhattacharyya[1], Z. Wu[1], AQ.Wang[3],Y.Huang[2], M.Golden[2], Z. Liao[3], A.Brinkman[1] and C. Li[1]*

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Inducing superconductivity in topological materials stimulates the formation of novel quantum states of matter. Besides the original prediction in 3D topological insulators, the notion of topological phases has been generalized to different dimensions and extended to the higher-order states while more specific symmetries are taken into account.
In the last few years, our research has demonstrated the possibility of realizing the topological superconductivity in engineered 3D Dirac semimetals [1,2], and their 1D hinge states. Particularly, Cd_3As_2 is predicted to be a higher-order topological semimetal, possessing three-dimensional bulk Dirac fermions, two-dimensional Fermi arcs [3], and one-dimensional hinge states [4] or non-Hermitian states [5]. These topological states have different characteristic length scales in electronic transport. More recently, we investigated the thickness dependence of hinge modes in $Bi_{1-x}Sb_x$ family. A set of persistent hinge modes are found to be present in single crystal flakes [6]. We show that the superconducting proximity effect is not only an essential ingredient for Majorana bound states but can also be a sensitive probe for distinguishing these states.

[1] Li, C. *et al*. Nat. Mater**. 17,** 875 (2018).
[2] Wang, A. Q. *et al*. Phys. Rev. Lett. **121,** 237701 (2018).
[3] Li, C.-Z. *et al*. Nat. Communications. **11,** 1150 (2020).
[4] Li, C.-Z. *et al*. Phys. Rev. Lett. **124,** 156601 (2020).
[5] Chu, CG. *et al*. Nat Communications. **14,** 6162 (2023).
[6] B. Bhattacharyya, *et al*. in preparation (2025).

Real and reciprocal space spin textures in altermagnetic MnTe

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Altermagnetic spin order is rapidly gaining its place in the toolbox of condensed matter physicists [1]. This is largely driven by the promise of ferromagnetic-like functionality, but without stray fields and at antiferromagnetic-like frequencies. Whereas for some materials, with RuO_2 being the prime example, the presence of any magnetic order is still hotly debated, for the altermagnetic semiconductor MnTe the case is clear. Using angle-resolved photoemission spectroscopy (ARPES) in the soft X-ray range, we were able to directly image the non-relativistic spin splitting due to the altermagnetic order [2]. Furthermore, we could identify the additional spin degeneracy lifting that occurs in the nodal planes due to spin-orbit interaction. Our spin-resolved ARPES (SARPES) measurements were largely hindered by the problem of dealing with magnetic domains and hard to cleave single crystals, calling for a method to overcome this. By cooling the sample from above room temperature in a small magnetic field, it is possible to create an imbalance between the six possible domains, and by micro structuring we were able to even create single domains [3]. Besides discussing the basics of altermagnetic order and its manipulation, in this presentation I will show SARPES results relying on such approaches and also highlight the importance of distinguishing photoemission induced spin signals from those originating from the magnetic structure.

[1] C. Song *et al.* Nature Reviews Materials (2025)
[2] J. Krempasky *et al.* Nature 626, 517 (2024)
[3] O. Amin *et al.* Nature 636, 348 (2024)

Odd-parity itinerant antiferromagnets by space group symmetry

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Altermagnetism is celebrated as opening a new branch of magnetism and offering a promising new avenue to spintronics. At the core of its appeal lies the lifting of spin-degeneracy of the electronic bands even without spin-orbit coupling and net magnetization. Such non-relativistic spin degeneracy lifting is also possible in non-collinear antiferromagnets where p-wave–or more generally, odd-parity–spin texture of the bands is expected, and potential application of odd-parity antiferromagnets to spintronics is actively being investigated. Recent research proposes non-symmorphic systems as a promising platform for the odd-parity antiferromagnetism [1], where magnetic ions are positioned at Wyckoff position of multiplicity 2. However, how such magnetic states are established is still unclear. An itinerant mechanism is intriguing as the electrons causing the magnetic instability also exhibits the odd-parity spin-splitting.

This motivates us to explore the itinerant odd-parity antiferromagnetism [2]. We first identify the key symmetries that guarantees the odd-parity itinerant antiferromagnetism accessible through a second-order phase transition. The relevant Landau free energy is derived from a minimal microscopic Hamiltonian with on-site Hubbard model where magnetic ions are positioned at Wyckoff position of multiplicity 2. This exposes several conditions favorable to the emergence of odd-parity non-collinear antiferromagnetism: Inversion should not be a site symmetry of the Wyckoff position, and the nesting should involve different bands. Anisotropic structure and nesting of bands in high-symmetry planes are also helpful. The co-planar state is found to be stabilized near the peak of the spin susceptibility where the strongest magnetic instability is expected. Our results define the key principles for the appearance of the odd-parity antiferromagnetism and will be helpful for the identification of candidate materials.

[1] Y. Yu, M. B. Lyngby, T. Shishidou, M. Roig, A. Kreisel, M. Weinert, B. M. Andersen, and D. F. Agterberg, arXiv:2501.02057.
[2] C. Lee, and P. M. R. Brydon, arXiv:2502.16417.

Tuesday, 15:30 – 16:00

Modeling magnetism in 2D materials from first principles

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The recent isolation of two-dimensional (2D) magnets offers tantalizing opportunities for spintronics, magnonics and quantum technologies at the limit of miniaturization. [1] Among the key advantages of atomically-thin materials are their flexibility, which provides an exciting avenue to control their properties by strain engineering, and the more efficient tuning of their properties with respect to their bulk counterparts.

In this presentation, I will provide an overview of our recent results on this fascinating topic. First, we will take advantage of the outstanding deformation capacity of 2D materials to answer the question: Can we use strain engineering to control spin waves propagation? [2] For that, we will focus on the magnetic properties, magnon dispersion and spin dynamics of the air-stable 2D magnetic semiconductor CrSBr, investigating their evolution under mechanical strain and Coulomb screening using first-principles. Then, we will introduce the modulation of the magnetic properties, magnon dispersion and spin dynamics of this 2D magnet after the deposition of sublimable organic molecules in a journey towards molecular controlled magnonics. [3] On the other hand, we will look for topological magnons in chromium trihalides (CrX_3), [4] investigate magnetostriction effects in 2D van der Waals antiferromagnets such as $FePS_3$ and $CoPS_3$, [5] create new Janus 2D magnetic materials based in MPS_3 in order to answer: what are the effects of mirror broken symmetry on the magnetic properties? [6], and finally, we will delve into the origin of above-room-temperature magnetism in Fe_3GaTe_2 [7].

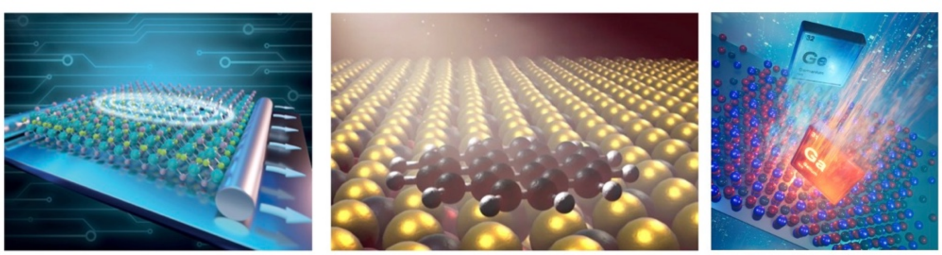

Fig. 1: *Artistic representation of (left) magnon straintronics device showing the chemical structure of CrSBr; (center) an irradiated coronene molecule on the surface of a 2D magnetic material; (right) formation of a Fe_3GaTe_2 single-layer representing the enhancement of T_C with respect to Fe_3GeTe_2.*

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Subgap states in hybrid junctions made of normal metal, altermagnets, and Rashba superconductors.

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We studied two dimensional junctions of normal metal, d-wave altermagnetic spin splitting material and Rashba superconductors with s-wave and d-wave symmetries of pairing. Based on Bogoliubov-de Gennes formalism we calculated incident angle resolved and total conductances of normal metal/d-wave altermagnet/Rashba superconductor (N/AM/RSC) junctions. In dependence of orientations of altermagnet and superconductor crystals, as well as parameters like strength of spin splitting energy of altermagnet, its thickness, and strength of the Rashba spin-orbit coupling, conductances can exhibit peaks on energies lower than superconducting gap energy. These peaks indicate the subgap states which are called Andreev bound states or de Gennes-Saint-James states. The zero bias conductance peak in tunnel transport is manifestation of zero energy surface Andreev bound states. These states can occur in the short junction limit because of the large difference between wave vectors of electronlike and holelike quasiparticles in unconventional magnetic ordering.

Proximity effects in heterostructures combining high-T_C superconductors and 2D transition metal dichalcogenides

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The development of high-Tc superconductors has been at the origin of several cutting-edge technological devices such as SQIFs sensors. The basic structure of such devices is the Josephson junction (JJ). This technological building block made of two superconductors linked through another material (metal, tunnel junction...) presents the property of current flowing at zero voltage. However, up to now it is still very difficult to create this basic structure with high-Tc superconductor in a way that would allow for easy tuning of its properties using external parameters such as electrostatic gating.

In this work, we explored the possibility of using 2D materials, especially transition metal dichalcogenides (TMDC), in contact with high-Tc superconductor YBCO. Such heterostructure would be extremely interesting to create new JJ that would be gate-tunable. Moreover, on a more fundamental perspective, this kind of heterostructures would be the perfect playground to study proximity effect in exotic materials and identify novel emerging physics. More specifically, we managed to develop heterostructures mixing the high-Tc superconductor YBCO with TMDCs such as MoS_2 and $PtSe_2$. This has been done by transferring through an etching-free process large-scale grown CVD or MBE 2D films on a patterned YBCO chip. The electrical measurements performed on these devices show strong hints of superconductive proximity effect, especially differential conductance measurements typical of SN and SNS junctions, and pave the way for further developments.

Defect-induced band restructuring and length scales in twisted bilayer graphene.

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Twisted bilayer graphene (TBG) hosts a set of moiré bands that become flat at the magic angle. In this work [1] we illustrate, using a fully atomistic tight binding model, how these bands enhance the effects of atomic scale defects, such as non-magnetic impurities and vacancies, leading them to affect a region dictated by the moiré length scale. We find that most defect locations lead to the removal of a moiré band from the low-energy spectrum, which causes states to be removed from the AA region even if the atomic defect is located away from it. We also report an intriguing band replacement process where this band removal continues into a band replacement as a valence band replaces the expelled moiré band. In this case, the depletion of the AA regions is not present and the dominant feature is instead the presence of a graphene-like defect state. As a consequence, we identify two universal length scales for defects, consisting of charge modulations on the atomic scale and on the moiré scale. We show that our conclusions hold beyond the magic angle and for fully isolated defects. In summary, our results demonstrate that the normal state of TBG and its moiré flat bands are extremely sensitive to both the location and strength of non-magnetic impurities and vacancies, what should have significant implications for any emergent ordered state.

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Optical conductivity of disordered films for superconducting single-photon detectors.

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Highly disordered NbN and NbTiN films find applications in various cryogenic devices, such as kinetic inductance detectors, traveling wave parametric amplifiers, and superconducting nanowire single-photon detectors. Given their broad range of applications, these films are the subject of extensive research. Despite this extensive study, inconsistencies in their fundamental electronic properties persist. For example, analysis of the optical conductivity of disordered ultra-thin NbN films using the standard Drude-Lorentz model provides parameters inconsistent with transport measurements. We argue that these discrepancies originate from the neglect of quantum corrections to the optical conductivity. Recently, these corrections were reported to be present up to the UV spectral range in the optical conductivity of strongly disordered MoC films[1]. We present a study of the optical and transport properties of a series of ultrathin NbN films with various thicknesses. To analyze the conductivities obtained by spectroscopic ellipsometry, we propose a modified Drude-Lorentz model with quantum corrections. Incorporating quantum corrections into the optical conductivity results in film parameters that are consistent not only with transport and superconducting measurements but also with ab initio calculations. The revised values describing conduction electrons, which differ significantly from commonly adopted ones, include an order of magnitude higher electron relaxation rate [2].

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Qubits using ferromagnetic Josephson junctions: The ferrotransmon.

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Josephson junctions (JJs) are key structures for a variety of applications including quantum technologies and are of undoubtful inspiration also for the development of novel notions in solid state physics. Progress in material science and nano fabrication gives opportunities to create unique hybrid JJs which can be smartly integrated in complex architectures, paving the way to novel effects and novel avenues for quantum control and detection. We will discuss the properties of a special class of tunnel ferromagnetic JJs, which are revealing new effects and can be also integrated into quantum architectures. They offer alternative layouts for the superconducting modules and are the basis for a new type of transom qubit - the ferrotransmon [1], main target of this contribution and of the Pathfinder European project FERROMON.

Different types of ferromagnetic JJs have been investigated changing barriers, layout and electrodes providing a phase diagram for spin nanoscale ordering at Superconductor/Ferromagnet (S/F) interfaces in terms of the magnetic moment induced in the S-layer and a feedback on their electrodynamical properties [1-4]. These findings have contributed to drive the design and the tailoring of S/F interfaces and of ferrotransmon itself. We will further discuss flux tuning of qubit frequencies, simulations, and preliminary experimental characterization of superconducting lines to provide in-plane magnetic fields and of the ferrotransmon. The diversity in Josephson junctions opens 'horizons'.

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Coherent manipulation of the spin states in copper and vanadyl molecular qubits.

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The coherent manipulation of the qubit spin states is one of the key steps for developing quantum technologies. Here we present the study of molecular spin qubits incorporated in the diamagnetic zirconium metal-organic frameworks (MOFs). The properties of copper- and vanadyl-porphyrins were investigated by pulse electron spin resonance (ESR) spectroscopy, measuring electron spin-lattice and phase-memory relaxation times, T_1 and T_m, respectively. Both copper and vanadyl qubits show a linear dependence of the frequency of Rabi oscillation ν_R on the intensity of the oscillating field B_1, proving the possibility of coherent manipulation in these systems. The copper *vs* vanadyl qubit properties will be discussed. [1]

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Ultrasound Study of Field-Induced Superconducting Phases in UTe_2

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Uranium ditelluride (UTe_2) is a prominent candidate for spin-triplet superconductivity, exhibiting a rich magnetic field–temperature phase diagram with multiple superconducting regions. Ultrasound velocity measurements were used to probe the elastic properties of UTe_2 under magnetic fields applied in the b-c crystallographic plane, up to 60 T. Clear anomalies in the sound velocity and elastic moduli were observed, corresponding to transitions between low-field and high-field superconducting states. In addition, a distinct feature near 15 T was identified, coinciding with anomalies previously reported in AC susceptibility measurements [1]. This additional phase boundary may indicate a change in the vortex structure or the emergence of a distinct superconducting state. The field and temperature dependence of the elastic response highlights the coupling between the lattice, magnetism, and superconductivity in UTe_2, providing further insight into the underlying mechanisms of its unconventional superconducting phases.

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Scanning tunneling spectroscopy in heavy fermion superconductors

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Heavy fermion superconductors have the potential to show unconventional and/or topological superconductivity. The surface is key in the debate of unconventional superconductivity, because topological phases invariably lead to edge states at surfaces through the bulk-boundary correspondence. Here I will review measurements made with millikelvin scanning tunneling microscopy (STM) revealing heavy fermion quantized states at the surface of URu_2Si_2 and discuss the relation to the superconducting properties. Furthermore, I will present new and relevant insight into the puzzling charge density wave (CDW) found in previous measurements at the surface of UTe_2, with new measurements performed at high magnetic fields.

Single-crystal growth and superconducting properties of $Sr_xBi_2Se_3$

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Bi_2Se_3 is a topological insulator for which Sr-intercalation has been reported to induce superconductivity with an unexpected two-fold anisotropy of the upper critical field, H_{c2}, in the basal plane. We examine how its properties relate to different single-crystal growth methods, including self-flux growth of free-standing plate-like single crystals from a Bi-rich melt. Notably, we identified $SrBi_2Se_4$ as a secondary phase with needle-like morphology in almost all of our growths. The Sr-content in the plate-like $Sr_xBi_2Se_3$ crystals was determined by proton-induced x-ray emission spectroscopy in our as-grown crystals with a resolution of up to 30 ppm. More standard energy-dispersive x-ray spectroscopy measurements failed to detect any Sr in our samples. Transport measurements in magnetic fields showed superconductivity with superconducting transition temperature T_c ~2-3 K at such surprisingly low Sr-contents. Intriguingly, the superconducting properties of our $Sr_xBi_2Se_3$ crystals were found to be very similar to the ones of $SrBi_2Se_4$ with a completely different crystal structure.

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DC-operated Josephson junction arrays as a cryogenic on-chip microwave measurement platform

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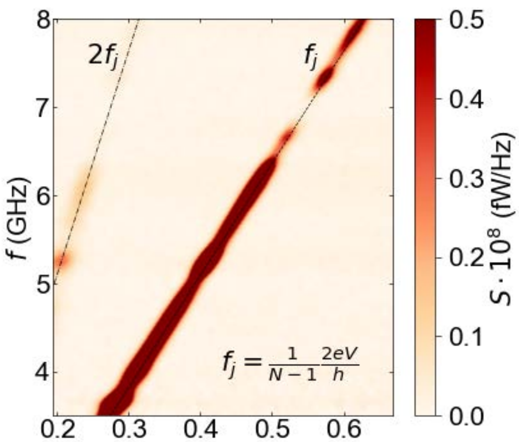

Figure 1: Emitted radiation (frequency and power) as a function of DC voltage over the junction array. Dashed lines show the Josephson relation (f_j), with N the number of junctions.

The control and readout of superconducting qubits conventionally relies on signals within the 4-8 GHz frequency range [1]. However, existing systems face challenges, as the high-frequency signal is typically generated at room temperature and transmitted through multiple attenuation stages to the cryogenic environment, inducing noise and lacking scalability [2]. Addressing these issues, it is more beneficial to situate the control circuits near the qubit devices. As a step towards this goal, we leverage arrays of weak link Josephson junctions as on-chip signal generators capable of converting DC voltage into AC current, emitting voltage-tunable radiation, according to the Josephson relations [3]. Our research group has successfully fabricated such arrays, utilizing superconducting MoGe and NbTiN islands with dimensions of 500 nm by 500 nm, that are placed on Au, as the weak link material [4]. Figure 1 shows the detected high-frequency signal emitted by the arrays when biased by a DC voltage, with high power regions, in red, following the Josephson relation. The figure proves that the fabricated devices work as an on-chip DC voltage-tunable RF source, providing signals in the ideal frequency range for quantum information. Furthermore, The emitted radiation can be further tuned using temperature, magnetic fields, applied currents and device design. Based on our results, we propose a fully DC-operated on-chip measurement platform as a viable alternative to the high-frequency circuitry currently required for several quantum applications.

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Organic bilayer films for sensing applications

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Flexible sensors made from organic bilayer films of molecular conductor on polymeric matrix have attracted many interest due to their simple fabrication with high potential for being scaled up, and for their high-performing multi-functionality at room temperatures. In particular, the piezoresistive property of the organic bilayer film is among one of the highest ever reported, allowing its utilization in various sensing applications. The study of the flexural piezoresistivity of an organic bilayer film based on β−(BEDT−TTF)$_2$I$_3$ on polycarbonate matrix from room temperatures down to cryogenics temperatures is presented. Due to the introduced disorder in the film, non-trivial temperature dependent profile of the gauge factor is revealed, including enhancement of the gauge factor from ∼18 at room temperatures to ∼48 at 4.3 K. The organic bilayer cantilever magnetometer is developed and demonstrated to measure magnetic properties of a single crystalline organic superconductor κ−(BEDT−TTF)$_2$Cu(N(CN)$_2$)Br at cryogenic temperatures down to ∼2.75 K and magnetic fields up to 5 T. The high-performing bilayer devices can be fabricated in a very simple manner, and they are robust and recyclable. It is also used for performing simultaneous torque-transport measurements of both the layered perovskite superconductor Sr_2RuO_4 and layered organic superconductor κ−(BEDT−TTF)$_2$Cu(NCS)$_2$. The measurements performed on the same sample enable observation and determination of the phase shift between magnetic quantum oscillations of the magnetization and magnetoresistance.

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INTiBS PAN vs SUPERQUMAP: opportunities and recent advancements

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The presentation will cover the presentation of the research profile of Institute of Low Temperature and Structure Research PAS in respect of the SUPERQUMAP Cost Action. Especially two Divisions are at the forefront of exploring superconducting materials, namely the Division of Low Temperature and Superconductivity and the Division of Magnetic Research. The research opportunities in these divisions encompass a broad spectrum of cutting-edge apparatus and topics. Some of the highlights of recent years will be presented as exemplary studies carried out.

The Division of Low Temperature and Superconductivity focuses on high-temperature superconductivity, thermal properties of solids, and cryogenic techniques. Key research areas include the formation and propagation of thermal excitations in crystals, mechanisms of heat transfer, and the coexistence of superconductivity and magnetism in doped compounds. Additionally, the division investigates the dynamics of magnetic vortices in high-temperature superconductors and the dissipation of electromagnetic energy in commercial superconducting composites.

The Division of Magnetic Research delves into the magnetic properties of materials, emphasizing the search for superconductivity in low carrier density materials and the study of magnetocaloric effects. Research includes the examination of magnetic properties in intermetallic compounds and rare-earth metals, as well as the exploration of magnetostrictive and magnetocaloric effects in Heusler alloys. These studies are crucial for developing advanced superconducting compounds and understanding quantum materials' behavior under various conditions.

Anomalous Vortex Dynamics and Magnetic Memory Effect in $BaFe_2(As_{0.68}P_{0.32})_2$ due to the Rhombic-to-Square Transition of the Bragg Vortex Glass

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We have investigated the vortex dynamics in a slightly-overdoped $BaFe_2(As_{1-x}P_x)_2$ single crystal using multiharmonic AC magnetic susceptibility measurements. Previous DC magnetic measurements identified a Second Magnetization Peak (SMP) in the isothermal field dependence of the critical current $J_c(H)$ and a Rhombic to Square structural Transition (RST) in the Bragg vortex glass [1]. However, the non-monotonous temperature dependence of the iso-field critical current density $J_c(T)$, known as the Peak Effect (PE), was not fully understood. By means of the combined analysis of the first and third harmonics of the AC susceptibility, the causes for the start and the end of the Peak Effect (PE) in temperature, i.e. the non-monotonous behavior of the temperature dependence of the critical current density $J_c(T)$ have been investigated. When $H_{DC} = 0$, the in-phase component of the third hsrmonic of susceptibility response χ_3'(T) showed the presence of a vortex dynamics associated with phenomena of Flux Creep and/or Flux Flow for temperature smaller than the temperature of the peak in the out-of-phase fundamental susceptibility, $T < T_p(\chi_1'')$ and the presence of the characteristic signal due to a critical state near T_c. Without DC field, there are no traces of the non-monotonous $J_c(T)$ behavior in the in-phase fundamental (χ_1') or third harmonic (χ_3') susceptibility, meaning a standard temperature behavior. When $H_{DC} \neq 0$, the χ_1'(T) and χ_3'(T) curves have shown a complex non-monotonous trend which evolves by increasing the DC field and AC frequencies. These behaviors were very different from the standard one reported without the DC field. In particular, it has been possible to divide the temperature range of the measurements in three regions: in the region (I) and (III), two different vortex states have been individuated with the region (II) representing the transition between them. In concomitance of the local maximum in the χ_1' corresponding to the onset of the PE and to the crossover between region (I) and (II), the χ_3' has shown an abrupt change in the vortex dynamics which terminates at the crossover between the region (II) and (III) where $\chi_3' \approx 0$ indicating a negligible vortex dynamics. The data points at the different DC fields and AC frequencies where the $\chi_3'(\mathrm{T})$ changes its behavior between regions (I) and (II) have been individuated and plotted on a vortex phase diagram already presenting the characteristic fields of the SMP and RST found in a previous work. It was observed that these data lie on the RST line so indicating that the onset of the PE was triggered by the RST of the vortex lattice. After that, $\chi_3' \approx 0$ has been associated to the end of the RST and the corresponding data have been plotted in the vortex phase diagram for all the DC fields and AC frequencies. These data do not show a frequency dependence, as expected in absence of detectable dynamic phenomena, and they overlap with the Second Peak line usually associated to a crossover between an elastic and a plastic pinning so showing that the stiffness of the vortex lattice corresponds to the completion of the RST due to the achievement of a more stable configuration. This analysis allows to individuate the regions in the H-T phase diagram corresponding to the pure rhombic and square state, with separate vortex dynamic response, and shows that the square configuration of the vortex lattice corresponds to the relative maximum in the shielding properties of the sample and in the $J_c(H)$ dependence. The importance of the RST was also proved by multi-harmonic AC susceptibility studies [2] performed in the three cooling/field protocols, ZFC, FC and FCW, which revealed the existence of three different regions in temperature regarding vortex dynamics: reversibility region (no difference between ZFC, FC and FCW) at high temperatures, irreversibility region with magnetic memory effect (difference between, ZFC, FC and FCW) at intermediate temperatures, and irreversibility region without magnetic memory effect at low temperatures (FC and FCW being the same, and different from ZFC).Since there is also a huge difference in the shapes of the third harmonics at low and high frequency, we can most likely attribute the magnetic memory effect to the interaction of the vortex dynamics with the RST, upon cooling down square-rhombic transition or warming-up rhombic-square transition.

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Thin $Bi_2Sr_2CaCu_2O_{8+x}$ films: Properties and nanoengineered vortex pinning

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Few-unit-cell $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) layers have drawn considerable interest for their extreme anisotropy and two-dimensional superconductivity, yet they are generally vulnerable to ambient conditions. We report on thin films (~13 unit cells thick) that remain stable in air, exhibit high anisotropy, and show remarkably high critical currents [1,2]. By examining the superconducting transition under out-of-plane and in-plane magnetic fields, we estimate key parameters, including pinning potentials, coherence lengths, London penetration depth, anisotropy, and the Ginzburg–Landau parameter. Notably, the Hall effect exhibits a large anomaly with a double sign change, challenging existing theoretical explanations for this phenomenon in copper-oxide superconductors.
Nanopatterning Bi-2212 films is more challenging than for $YBa_2Cu_3O_{7-\delta}$ (YBCO). Our previous work demonstrated that focused helium ion beam (He-FIB) irradiation effectively surpassed the resolution limits of etching techniques in YBCO, inducing vortex commensurability up to 6 T [3], vortex caging [4], and an ordered Bose glass of vortices formed by artificial and intrinsic pinning centers [5]. In YBCO, the 30 keV He^+ beam primarily displaces oxygen in the CuO chain sites, creating columns of point defects that locally suppress the critical temperature. Because Bi-2212 lacks such loosely bound oxygen, it was unclear whether He-FIB would be equally effective. We now show that He-FIB patterning can indeed be applied to Bi-2212 thin films, albeit requiring a higher ion dose than YBCO. These findings confirm the feasibility of engineering efficient vortex pinning landscapes in this highly anisotropic superconductor, underscoring its potential for advanced superconducting devices and sensors.

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Gyrotropic excitations in radial magnetic vortices.

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Magnetic vortices, renowned for their topologically nontrivial states, hold potential in applications such as spin-torque oscillators and magnetic memory. Most studies focus on Bloch magnetic vortices in sub-micron ferromagnetic disks with thicknesses above 10 nm. Recently we have demonstrated the possibility of creating a magnetic vortex state in a hybrid structure with a soft (SL) magnetic nanodisk within a hole in a hard magnetic layer (HL) with perpendicular magnetization [1]. The diameter of soft disk was slightly smaller than the diameter of hole, providing purely dipolar coupling between subsystems. Micromagnetic simulations and analytical calculations showed that the ground state of the soft nanodisk could be either a radial (Neel) vortex or a complex one - a mixture of Neel and Bloch vortices - depending on the strength of dipolar field from the HL.

Here we propose a simplified and more practical structure for creating a radial vortex: a three-layered circular nanodisk comprising SL/non-magnetic layer (NML)/HL). The NML goal is to prevents direct exchange coupling between SL and HL and dipolar coupling between SL and HL reduces the vortex's size in SL. Micromagnetic simulations using MuMax3 (with 0.5 nm cell discretization) revealed that radial vortex states can appear in significantly smaller disks compared to single layer soft ferromagnetic disks. With magnetizations of 1000 emu/cm^3 for HL and 810 emu/cm^3 for SL, radial vortices were observed in SL as small as 30 nm in diameter and 0.5 nm thick, significantly surpassing the limitations of Bloch vortices in isolated disks.

The magnetization dynamics was excited applying an in-plane microwave magnetic field with a sinc temporal profile on the SL, revealing a single intense peak corresponding to vortex core precession. The frequency increased with decreasing SL thickness and varied non-monotonically with diameter, reaching 9 GHz for an SL thickness of 1 nm and a diameter of 50 nm. These findings align well with analytical predictions and allow to consider three-layered hybrid circular nanodisks as next generation spin-torque nano-oscillators.

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Vortex Jets in 2D and 3D Superconductor Nanomembranes

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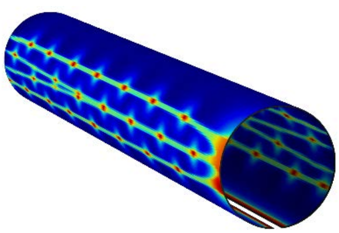
The dynamics of magnetic flux quanta (Abrikosov vortices) is known to determine the resistive response of superconductors. In pinning-free thin films, the penetration and motion of vortices is controlled by edge defects, leading to such arrangements as *vortex chains*, *vortex jets*, and phase-slip regimes. Previously, we showed both theoretically and experimentally [1] that at sufficiently large transport currents, a defect at the edge of a superconducting strip can act as a gate for the vortices entering into it. These vortices form a jet, which is narrow near the defect and expands due to the repulsion of vortices as they move to the opposite edge of the strip, giving rise to a transverse voltage. The one-by-one penetration of vortices leads to the appearance of *kinks* in the current-voltage curve, whose presence can thus be used for *fluxon counting and velocimetry* [2].



Recently, relying upon the time-dependent Ginzburg-Landau equation, we have predicted that vortex jets should appear in 3D superconductor open nanotubes even without edge defects, due to the inhomogeneity of the normal magnetic induction component B_n, caused by the 3D tube geometry [3]. In contrast to 2D thin films, the vortex jets in 3D open tubes are not diverging because of constraint to the tube areas where B_n is close to maximum. Furthermore, by tilting the direction of the applied magnetic field an angle α in the plane perpendicular to the axis of a nanotube carrying an azimuthal transport current, it is possible to steer vortex chains and vortex jets to a given point of the sample [4]. This approach surpasses the capabilities of vortex guiding in nanoengineered pinning landscapes in terms of reconfigurability. In all, these findings are essential for fluxonic devices which are operated in few- and multifluxon regimes.

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Magnetization Dynamics in $La_{1-x}Sr_xMnO_3/YBa_2Cu_3O_{7-\delta}$ half-metal ferromagnet/d-wave-Superconductor Bilayers

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We have used broadband ferromagnetic resonance (FMR) to study spin pumping from the half metallic ferromagnet $La_{1-x}Sr_xMnO_3$ (LSMO) into the *d*-wave superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO). The investigated heterostructures were grown epitaxially on $NdGaO_3$ (NGO) substrates via pulsed laser deposition, with YBCO growing along its *c*-axis, that is, the ab-plane of the YBCO is parallel to the interface. We have evaluated the spin conductance across the LSMO/YBCO interface by analyzing the magnetization dynamics in LSMO, particularly, by monitoring the FMR linewidth as a function of temperature. From this, we found that the Gilbert damping shows a striking upturn as the heterostructure is cooled across the normal-superconducting transition. This suggests a strong enhancement of the spin pumping into YBCO as it enters its superconducting phase. Such behavior is opposite to what we found for interfaces between similar c-axis YBCO films and metallic ferromagnets (Py), in which the opening of the superconducting gap drastically hinders spin pumping into YBCO and leads to a drop in the Gilbert damping [2]. We will discuss that the upturn observed in the damping for LSMO/YBCO reflects an increment in the spin injection efficiency which could be attributed to spin triplets. This hypothesis is supported by the observation of triplet supercurrents in c-axis oriented LSMO/YBCO interfaces [3]. We will also discuss the potential of these findings in the field of superconducting spintronics.

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Scanning Tunneling Spectroscopy of FeSe Under in-plane Magnetic Fields

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FeSe is one of the structurally simplest iron-based superconductors and has a critical temperature of about 9 K. The upper critical field is anisotropic, and the Fermi surface consists of several tubular like sheets with significant warping along the c-axis. The Fermi surface sheets occupy only a small part of the Brillouin zone, due to an extremely small electronic density. The electronic properties of the normal and superconducting phases have been studied via Scanning Tunneling Microscopy under magnetic fields applied along the c-axis. There are no measurements, however, for in-plane magnetic fields. Here we use a scanning tunneling microscope (STM) in a three-axis magnet [1]. We observe charge-ordered states and striped patterns in the density of states of FeSe crystals and we study their behavior for different directions of the in-plane magnetic field. Our results provide a platform to explore the relationship between electronic ordering in tilted magnetic fields of very low electronic density systems as FeSe.

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Superconductivity in Co-doped iron-based superconductor GdFeAsO

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Iron-based superconductors (IBSC) were discovered in 2008 by Hideo Hosono et al. [1]. Their discovery came as a big surprise, as there was a widespread belief that superconductivity and magnetism were two mutually exclusive phenomena. This discovery undermined the existing paradigm and revealed that iron-based superconductors could have a critical temperature (T_c) above 50 K and an upper critical field (H_{c2}) of the order of several dozen tesla. Such critical parameters make IBCSs candidates for the production of next-generation superconducting cables. Shortly after discovery of the first IBSC, the first gadolin-based system was synthesized [2]. Iron-based superconductors from the GdFeAsO family are of particular interest due to the interplay of magnetism and superconductivity. The effect of strongly correlated gadolinium f electrons on the superconducting state of the system is still not fully understood, so the study of these systems is important due to their potential use in, for example, spintronics and quantum computers.

In this work, we present the first results of the synthesis, structural and physical characterization of a cobalt-doped iron-based superconductor – Gd(Fe,Co)AsO. IBSC was obtained by the solid-state reaction method. The structure of IBSC was characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDXS). Superconductivity was investigated via electrical resistivity, AC susceptibility, DC magnetization, and specific heat measurements. Additionally, computational calculations within density-functional theory (DFT) were performed. The effect of cobalt on the microstructure and superconducting properties was examined. The upper critical field H_{c2} was estimated using the Werthamer–Helfand–Hohenberg (WHH) model. The obtained results showed that Gd(Fe,Co)AsO is a system in which the antifferomagnetic ordering of gadolinium competes with superconductvity.

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Scanning tunneling spectroscopy at high magnetic fields in CaKFe4As4: vortex lattice and normal phase properties

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We present a study of the electronic structure of the pnictide superconductor CaKFe4As4 (T_c = 35 K) at high magnetic fields using scanning tunneling microscopy and spectroscopy. We first focus on the properties of the vortex lattice and discuss the influence of temperature and magnetic field on the vortex dynamics. We construct the phase diagram for the vortex lattice, delineating the optimal pinning range and directly observing the transition to the vortex liquid phase. We will also discuss atomic scale measurements of the normal state properties at high magnetic fields.

Scalable effective models for complex superconducting nanodevices

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We have derived a Chain Expansion (ChE) method that maps superconducting leads onto finite chains for systems describable by the Superconducting Anderson Impurity Model (SCIAM). We show that ChE-based effective models closely match the Numerical Renormalization Group (NRG) solutions of the full SCIAM across a broad parameter range, already for short chains solvable via Exact Diagonalization (ED). In more challenging regimes, the agreement between NRG and ChE calculations systematically improves with increasing chain length. The one-dimensional nature of ChE enables the use of effective models with longer chains, inaccessible to ED, via the Density Matrix Renormalization Group. Interestingly, simpler systems, such as single quantum dot on a superconductor, require longer chains for converged ground-state expectation values in certain experimentally relevant regimes. Conversely, for more complex configurations, such as three coupled dots (trimers), shorter chains often suffice even there. Our findings demonstrate that ChE is a powerful tool for studying intricate superconducting systems, including those inaccessible to NRG.

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$YBa_2Cu_3O_7$ Josephson junctions and SQUIDs nanopatterned with focused ion beams.

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Strongly miniaturized superconducting quantum interference devices (SQUIDs) with Josephson junctions (JJs) intersecting the SQUID loop are promising devices for investigating magnetic properties of micro- or nanoscale objects, e.g., in scanning SQUID microscopy or detection of the magnetization reversal of individual magnetic nanoparticles [1]. NanoSQUIDs based on the high-transition-temperature (high-Tc) cuprate superconductor $YBa_2Cu_3O_7$ (YBCO) offer significant advantages with respect to their potential of operating them over a much wider range of temperature and magnetic field as compared to devices based on conventional metallic superconducting thin films, e.g. from Nb. However, the fabrication of YBCO nanodevices is quite demanding, in particular due to their susceptibility to defects down to the atomic scale because of the small coherence length of the high-Tc cuprates. This requires the use of epitaxially grown thin films on lattice-matched crystalline substrates of limited choice and makes the fabrication of high-quality JJs a difficult task. We present here some of our activities aimed at the realization of YBCO JJs and nanoSQUIDs by using nanopatterning and direct local modification by focused ion beam (FIB) techniques. This includes the fabrication of nanoSQUIDs based on bicrystalline grain boundary JJs that can be nanopatterned by Ga-FIB [2,3] or Ne-FIB and the use of He-FIB to locally suppress superconductivity on the nanometer scale. The latter approach can be used to locally “write” Josephson barriers to create barrier-induced JJs (bJJs) [4,5,6] or resistive areas for realizing constriction-type JJs (cJJs). We will discuss the effects of irradiation dose on the crystalline structure and electric transport properties of the fabricated JJs, and we will present properties of the nanoSQUIDs that are realized with JJs produced by FIB patterning.

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Abrikosov vortices switching current in magic-angle graphene

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Planar Josephson junctions made from atomically thin films exhibit poor transverse screening, causing the magnetic-field dependence of the Josephson current Ic(B) to deviate from the standard Fraunhofer pattern of conventional junctions. The relevant flux determining the oscillations in Ic(B) is not the usual flux $\Phi_\lambda = 2BW\lambda_L$ penetrating the junction but the larger flux $\Phi_W = 2BW^2$, including the lead areas near the junction, with W the junction width. The envelope of the Fraunhofer-like pattern also differs, with maxima decaying slowly $\propto 1/\sqrt{B}$ rather than the usual $\propto 1/B$.
Given the weak screening, the junction is highly sensitive to Pearl vortices in the leads. Vortices alter the phase pattern and affect the Josephson current. Thermal fluctuations can cause vortices to jump in and out of the leads, leading to shifts in the Fraunhofer-like pattern, as observed in the recent experiment [1]. Our model quantitatively explains these jumps, whose timescale depends on magnetic field, current, temperature, and superfluid stiffness. At elevated temperatures, fast vortex jumps may wash out the Fraunhofer pattern well below Tc. By analyzing the timescale of these jumps, we can determine the superfluid stiffness and the Berezinskii-Kosterlitz-Thouless transition temperature of magic-angle twisted four-layer graphene.
These values are in agreement with recent kinetic inductance measurements [2, 3].

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Terahertz spectroscopy of thin superconducting films

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Terahertz (THz) spectroscopy is a powerful tool for probing key properties of superconductors, including the superconducting gap, penetration depth, quasiparticle dynamics, vortex behavior, and non-equilibrium relaxation processes. In this work, we employ THz spectroscopy to investigate high-quality thin films of Nb, NbN, and $YBa_2Cu_3O_{7-}\delta$ (YBCO). For Nb and NbN films, we explore the influence of an external magnetic field on their THz response. For YBCO films, we compared the THz properties across three distinct hole-doping regimes: underdoped, optimally doped, and overdoped. Our analysis focused on the temperature evolution of the superfluid density, revealing a fraction of normal electrons persists and does not condense into Cooper pairs, even at low temperatures.

Kondo *s-d* exchange in the CuO_2 plane as the long sought interaction determining T_c in cuprates

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The well-known Pavarini et al. [1] correlation between the critical temperature $T_{c,max}$ and the shape of the Fermi contour of optimally hole-doped cuprates is explained within the framework of the BCS theory with Kondo exchange interaction incorporated as a pairing mechanism. The strong influence of the relative position of the Cu4*s* level with respect to the Cu3d_{x2-y2} level on the critical temperature T_c reveals why the *s*-*d* hybridization of the conduction band is so important. This hybridization is proportional to the *s*-*d* exchange scattering amplitude between the conduction electrons – the mechanism of *d*-wave pairing in the CuO_2 plane. In other words, the Kondo interaction considered as a pairing mechanism in the CuO_2 plane provides a natural explanation of the correlation between the critical temperature and the shape of the Fermi contour.

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On the theory of supermodulation of the superconducting order parameter created by structural supermodulation of apex distance in optimally doped $Bi_2Sr_2CaCu_2O_{8+x}$

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Recently using Scanning Josephson Tunneling Microscopy (SJTM) in the group of Séamus Davis super-modulation of the superconducting order parameter induced by super-modulation of the distance δ between planar Cu and apical O was observed [1]. Those authors conclude that "concurrence of prediction from strong correlation theory with these observations indicates that super-exchange is the electron pairing mechanism of $Bi_2Sr_2CaCu_2O_{8+x}$". Additionally, they study by STM the charge transfer energy E, probably between $O2p_z$ and $Cu3d_{x2-y2}$ levels. In our theoretical study we use the LCAO approximation, Hilbert space spanned on 5 atomic orbitals: Cu4s, Cu3d_{x2-y2}, $O2p_x$, $O2p_y$, $O2p_z$. For the only super-exchange amplitude J_{sd} we use Kondo double electron exchange between Cu4s and Cu3d_{x2-y2} orbitals; its antiferromagnetic sign is determined by adjacent to the copper ion in-plane oxygen orbitals. Within this approximations we calculate Measured dependence of the electron-pair density n_p on the displacement δ of the apical O atoms from the planar Cu atoms depicted in [1, Fig. 5 (C)] and obtained an acceptable accuracy. We conclude that logarithmic derivative $Q_{np} \equiv (\delta/n_p)\, \mathrm{d}n_p/\mathrm{d}\delta$ is the most convenient dimensionless parameter to solve the "concurrence of predictions from-strong-correlation theories for hole-doped cuprates". We also suggest that correlation between the shape of Fermi contour and the critical temperature of optimally hole-doped cuprates can be considered as and analogue of isotope effect of phonon superconductors. As a whole the analyzed SJTM experiment is one of the best confirmations of the Röhler [2] idea that the hybridization of the Cu4s with the conduction band leads to increasing of T_c. The lack of an alternative explanations for SJTM data n_p versus δ and shape-$T_{c,\max}$ correlations for the description of the critical temperature of optimally doped cuprates for several decades on the background of a simple view gives a hint that the long sought pairing mechanism has possibly been found and the Kondo exchange interaction as a property of strongly correlated quantum matter deserves further attention in the physics of layered cuprates.

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Evidence of competing orders in few-layer $NbSe_2$

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The coexistence of multiple types of orders is a common thread in condensed matter physics and unconventional superconductors. The nature of superconducting orders may be unveiled by analyzing local perturbations such as vortices. For thin films, the vortex magnetic profile is characterized by the Pearl-length $\boldsymbol{\Lambda}$, which is inversely proportional to the 2D superfluid density; hence, normally, also inversely proportional to the film thickness, $\boldsymbol{d}$. Here we employ the scanning SQUID-on-tip microscopy to measure $\boldsymbol{\Lambda}$ in $NbSe_2$ flakes with thicknesses ranging from $\boldsymbol{N = 3}$ to $\mathbf{53}$ layers. For $\boldsymbol{N > 10}$, we find the expected dependence $\boldsymbol{\Lambda \propto 1/d}$. However, six-layer films show a sharp increase of $\boldsymbol{\Lambda}$ deviating by a factor of three from the expected value[1]. This value remains fixed for $\boldsymbol{N = 3}$ to $\mathbf{6}$. This unexpected behavior suggests the competition between two orders; one residing only on the first and last layers of the film while the other prevails in all layers.

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Josephson vortex shaking memory.

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The ongoing progress of superconducting logic systems with Josephson junctions as base elements requires the development of compatible cryogenic memory. Long junctions subject to magnetic field can host quantum phase 2π-singularities—Josephson vortices. We will present the realization of the superconducting memory cell whose state is encoded by the number of present Josephson vortices. By integrating the Superconductor (Nb) - Normal metal (Cu) – Superconductor (Nb) junction into a coplanar resonator and by applying a microwave excitation well below the critical current, we shake Josephson vortices inside the junction and are able to control the state of the system. The memory effect arises due to the presence of the natural edge barrier for Josephson vortices. The performance of the device is evaluated, and the routes for creating scalable cryogenic memories directly compatible with superconducting microwave technologies are discussed.

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Topological Transitions in Superconductor Nanoarchitectures

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A topological transition between the vortex- and phase-slip-regime determines the magnetic-field–voltage and current–voltage characteristics in 3D superconductor nanoarchitectures revealing a nontrivial topology of SC screening currents [1]. An abrupt switch-on of the transport current triggers the transition from the vortex- to phase-slip-regime in superconductor open nanotubes [2]. Various dynamic topological transitions in superconductor open nanotubes take place under a combined dc+ac transport current [3]. Vortex chains, vortex jets, and phase-slip regimes occur in superconductor open nanotubes due to the inhomogeneity of the normal magnetic field component, leading to microwave generation [4]. Due to a stronger confinement of single vortex chains in tubes of small radii, jumps in the average voltage and frequency of microwave generation are unveiled, which occur when the number of fluxons moving in the half-tubes increases exactly by one [4]. In addition to prospects for tuning of GHz-frequency spectra and steering of vortices as information bits, the discussed findings lay the foundation for on-demand tuning of vortex arrangements in superconductor 3D nanoarchitectures in tilted magnetic fields. The onset of vortices changes the topology of the superconducting state in a superconductor quantum ring in such a way that the full magnetoresistance dynamics can be interpreted by the interference of the constituents of the order parameter induced by both the ring with its doubly connected topology and the vortex lattice in it [5]. A rigorous model for the topology of the Fermi surface [6] features hole pockets of electronic states forbidden by quantum confinement and reveals two topological transitions in the Fermi surface upon shrinking the quantum ring sizes, either paraxial or in-plane. Those transitions are manifested in a kink and a discontinuity, respectively, in the electronic density of states, which lead to the critical temperature of superconductor quantum rings with a strikingly different behavior as a function of the both confinement sizes.

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Magnetic recording of superconducting states

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The local polarization of magnetic materials has become a well-known and widely utilized method for storing binary information. Numerous everyday applications, such as credit cards, computer hard drives, and the popular magnetic drawing board toy, depend on this principle. In this presentation, we will review advances in magnetic recording of inhomogeneous magnetic landscapes created by superconducting films [1,2]. We summarize compelling experimental evidence indicating that magnetic recording can imprint the flux trajectory in a magnetic layer from a superconducting layer. This approach allows for ex-situ observation at room temperature of the imprinted magnetic flux landscape obtained below the critical temperature of the superconducting state. The undeniable appeal of the proposed technique lies in its simplicity and potential to enhance spatial resolution, possibly down to the scale of a few vortices.

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Nanoengineered high temperature superconductors for efficient functional device

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Today advances to store and analyze massive information offer huge opportunities and unprecedented benefits in business, healthcare, security, society, and industrial applications. Design and fabrication of novel materials and heterostructures with improved tailored properties are needed to achieve high performance in a sustainable way. Multifunctional materials based on complex oxides offer unique opportunities to tune their magnetic or electric properties with multiple external inputs, thus providing the basis for realizing energy-efficient electronic devices. Among numerous outstanding properties of strongly correlated multifunctional oxides, superconducting cuprates are of special interest due to their inherent energy efficiency.
This work is focused on the study of nanostructures, multilayers, and hybrid systems based on high-temperature superconducting cuprates with innovative functionalities that can contribute to the development of sustainable Information and Communication Technologies. The performance of the explored devices has been modified through material engineering: oxygen doping, crystallographic defects, epitaxy, strain, interfacial, or geometric effects.

Nanostructured surface control of quantum phases in ultrathin YBCO: enhanced superconductivity, emergent nematicity, and unidirectional charge order

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In cuprate high-temperature superconductors, the doping level is typically set during synthesis and remains largely fixed thereafter. As a result, unlike many other two-dimensional materials, the charge carrier density per CuO_2 plane in cuprates cannot be easily tuned using conventional gating techniques. This limitation has posed a significant challenge for exploring and optimizing their rich and complex electronic phase diagram.

In recent years,strain engineering has emerged as a versatile and powerful strategy to overcome this constraint. By changing lattice parameters, strain can effectively tune the delicate balance between competing orders—particularly charge and spin orders—and their intricate interplay with superconductivity. This approach has proven especially fruitful in thin-film systems, where the choice of substrate introduces additional degrees of freedom for controlling material behavior.

One particularly promising avenue involves exploiting substrate surface morphology to introduce local anisotropies and strain fields. In this context, nanofacets—naturally formed during high-temperature surface reconstruction of certain substrates—have garnered attention for their ability to impact thin-film growth and electronic structure. In our previous work, we demonstrated that such nanofaceted substrates profoundly influence the ground state of ultrathin $YBa_2Cu_3O_{7-x}$ (YBCO) films. Specifically, we observed the emergence of electronic nematicity and a unidirectional charge density wave (CDW) order, phenomena not typically seen in thicker films or bulk single crystals [1].

Building upon this foundation, we now show that nanofaceted substrates do more than just induce new electronic orders—they also lead to a significant enhancement of key superconducting properties. Most notably, we report a marked increase in both the superconducting onset temperature (T_{on}) and the upper critical magnetic field (H_{C_2}) in nanometer-thick YBCO films grown on these textured surfaces [2]. This enhancement signals a robust modification of the superconducting ground state, driven by the unique film–substrate interface.

From a theoretical standpoint, we attribute this enhancement to the interplay between electronic nematicity and unidirectional CDW, both of which can be described by an effective interfacial potential. This potential emerges from a superpotential imposed by the nanofaceted substrate, effectively acting as a tuning knob for the electronic landscape within the film [3].

Together, these findings establish a new paradigm in cuprate research: substrate engineering—particularly through morphological control—offers a powerful and scalable route to manipulate and enhance superconductivity. By harnessing nanoscale structural features at the interface, we open a new frontier in the design of next-generation high-performance superconducting materials with tailored properties.

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Influence of Reaction Kinetics on MgB_2 Wires with Enhanced Properties: Optimization of Copper-Coated Magnesium Rod and Carbon-Coated Nano-Boron Powders in IMD Process

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Magnesium diboride (MgB_2) wires fabricated by Internal Magnesium Diffusion (IMD) process are of renewed recent interest for potential superconducting applications due to their improved superconducting properties with flux pinning, high critical temperature ($T_c \approx 39$ K), cost-effectiveness, and potential for large-scale production. This talk focuses on the impacts of varying copper coatings on magnesium rods and the incorporation of different carbon-coated boron powders with experimental works on the microstructural and superconducting properties of MgB_2 wires. By systematically varying the copper coating content on Mg rods at various percentages and the carbon coated boron powder precursors, we aim to optimize the enhanced critical current density (J_c) especially in the applied magnetic fields. Characterization techniques such as optical microscopy, scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS), DTA analysis for reaction kinetics and electrical transport measurements were carried out to investigate the effects of porosity, grain connectivity, morphology, and superconducting physical properties of the MgB_2 wires.
The results show that both carbon and copper doping play an important role in enhancing flux pinning by introducing nanoscale defects and impurities that act as pinning centers for the vortices. However, excessive doping or improper copper coating thickness can lead to the formation of unwanted secondary phases and defects, which may a negative effect the superconducting properties and mechanical stability.
In conclusion, this study provides valuable insights into optimizing the IMD process for the fabrication of high performance MgB_2 wires. By balancing the thickness of the copper coating and the concentration of carbon doping, improved superconducting properties can be achieved, making the processed MgB_2 wires highly suitable for applications such as magnetic resonance imaging (MRI), particle accelerators, and high-field magnets. Experimental results with model dependent analysis will be presented to achieve higher critical current density at fields exceeding from 1 to 12 T.

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Josephson diode effect in arbitrary oriented *d*-wave superconductor/ferromagnet/*d*-wave superconductor junction with interfacial Rashba spin orbit coupling

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We have provided a theoretical study of the effect of interfacial Rashba spin-orbit coupling and insulating interfaces on the Josephson effect between two arbitrarily oriented d-wave superconducting electrodes connected through ferromagnet, based on the Bogoliubov-de Gennes equation and the extended McMillan's Green function formalism. Since in this kind of junction both time-reversal and space inversion symmetry are broken, Josephson junction can exhibit supercurrent diode effect characterized by nonreciprocal behavior in the critical supercurrent in two opposite directions, as well as anomalous Josephson current at zero phase bias. We evaluated the efficiency of diode effect and discuss the tunability of the Josephson supercurrent diode effect in terms of spin-orbit coupling, exchange field in ferromagnet, transparency of interfaces and crystal axes orientation of d-wave superconducting electrodes. We have shown that diode effect occurs in junction with nonsymmetrical oriented *d*-wave superconducting electrodes, and that large diode effect can be reached by tuning the crystal axes orientation of d-wave superconductors and the magnetization of ferromagnet. We predict that modulating the strength of the Rashba field or exchange field may induce phase transition which for a certain choice of parameters can be continuous between 0-like and π-like, because different individual transport channels have different phase shifts. The temperature induced phase shift and diode characteristic are investigated as well.

Control of Chaotic Dynamics in Josephson Junctions

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The Harmonically driven and damped point Josephson junctions exhibit chaotic dynamics for certain parameter values. A well-established mathematical model for point Josephson junctions is the resistively capacitance shunted junction (RCSJ) model. The current voltage characteristic of a Josephson junction is influenced by chaos leading to increased noise. Other nonlinear phenomena, such as bifurcations, global bifurcations and crisis phenomena, can lead to hysteresis and slip of phase locking in the current voltage characteristic [1-2].

In this paper we investigate control of chaos in the RCSJ model, by stabilizing the chaotic dynamics on unstable periodic-n orbits in the Poincaré map [3]. We extend the control to an arbitrarily chosen period-n unstable orbit, traversed in a predefined order and within a chaotic region. The method is based on a two-step procedure. In the first step we employ an optimal control problem formulation (Bolza problem) to introduce an arbitrarily chosen unstable period-n orbit by a discontinuous stepwise defined control. In the second step we apply a control mechanism based on the delay coordinate embedding developed by Ott, Grebogi and Yorke [4] to stabilize the system around the periodic-n orbit introduced through the optimal control.

We speculate that this control approach could be relevant in superconducting devices based on Josephson junctions within information processing or for sensors.

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Measuring the current-phase relation in Josephson junction using superconducting resonators

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Topological quantum computing architectures require the combination of superconductivity, spin-orbit interaction and electrostatic tunability, while scalability calls for two dimensional platforms. All these features are combined in semiconducting 2DEGs terminated by an epitaxial superconducting layer. Coupling and reading out the qubits necessitates the use of microwave resonators.
Here we demonstrate the current phase relation (CPR) measurement in InAs 2DEG using an inductive coupling to a coplanar waveguide resonator, where both the SQUID and the resonators are fabricated from the epitaxial aluminium layer on the 2DEG. Tuning the CPR by an external flux causes a change in the loading inductance of the resonator and hence a shift of the resonance frequency. Besides the CPR we could measure the Fraunhofer pattern of the junction using a larger magnetic field.

Current phase relation of short graphene Josephson junctions: dilute impurities and spin-orbit coupling effects

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Despite the structural simplicity of graphene, its mechanical and electronic remarkable properties make this material a versatile starting point for new technologies across a wide range of fields. The recent realizations of graphene-based hybrid systems, such as Josephson junctions, make graphene a promising a platform for new generations of devices for topological quantum computing and quantum sensing. To this aim, accurate control of the electronic properties of graphene Josephson junctions in the presence of disorder is essential.

In this work, we investigate the effects on the equilibrium supercurrent sustained by a ballistic graphene Josephson junction in the short junction limit due to a dilute homogeneous spatial distribution of non-magnetic impurities [1] and due to spin-orbit coupling (SOC) by proximity effect [2].

We find a modification of the current-phase relation with a reduction of the skewness induced by disorder, and a nonmonotonic temperature dependence of the critical current. In the presence of single magnetic impurity, the local density of states at subgap energies allows one to distinguish elastic and inelastic scattering processes and to identify the magnetic nature of the impurity [3]. Moreover we identify combinations of spin-orbit couplings that significantly suppress the supercurrent by opening a gap in the graphene band structure, and combinations which instead enhance it, effectively acting as an effective spin-valley resolved chemical potential. Moreover we find that a strong Rashba SOC produces a GJJ with extremely voltage tunable harmonic content.

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Critical behavior of the 1d superconductor in the FLEX approximation

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The dynamical quantum fluctuations below the lower critical dimension push the superconducting critical point to zero temperature. We study the quantum critical behavior of the 1d superconductor with one-particle self-consistency provided by the FLEX approximation within the canonical Baym-Kadanoff scheme. We use the noninteracting singlet electron-electron bubble in the two-particle vertex of the Schwinger-Dyson equation, allowing for a qualitatively correct and tractable treatment of the low-energy critical behavior compatible with the Mermin-Wagner theorem. We use a polar approximation to transform the convolutive Schwinger-Dyson equation into an algebraic one that can be solved semi-analytically. We confirm the position of the critical point and assess the low-temperature behavior of the Hubbard model with attractive interaction.

Disorder effect on superconductor metal transition: quantum griffiths singularity.

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In two-dimensional (2D) superconductors, the transition to the superconducting state is strongly influenced by quantum fluctuations and reduced dimensionality. These systems can undergo quantum phase transitions (QPTs), driven by external parameters such as magnetic field or temperature, leading to profound changes in the ground state. Such transitions offer deep insights into the physics of 2D superconductivity. One intriguing manifestation of these QPTs is the **Quantum Griffiths Singularity (QGS)** [1], which emerges from the interplay between quenched disorder and quantum fluctuations near a quantum critical point (QCP). QGS is characterized by rare superconducting regions embedded in a disordered matrix, giving rise to a vortex-glass-like phase near the QCP boundary. Here, we report the first observation of a magnetic-field-induced superconductor–metal transition (SMT) in a PdTex superconductor, formed via lateral diffusion of palladium (Pd) into tungsten ditelluride (WTe_2) within a WTe_2/Pd junction. Although Pd is a normal metal, its intercalation into WTe_2 produces the superconducting compound PdTex [2]. Through scaling analysis [1,3], we find that the dynamical critical exponent diverges near the characteristic magnetic field **B*_C = 7.8 T**, consistent with an infinite randomness critical point. Additionally, our resistance data **R(B, T)** reveals features of the anomalous metallic state aka 'failed superconductor' in the inhomogeneous PdTex superconductor, shedding light on disorder-driven phenomena in 2D superconducting systems.

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Magnetically-controlled Vortex Dynamics in a Ferromagnetic Superconductor

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The $EuFe_2(As_{1-x}P_x)_2$ system features a complex phase diagram characterized by various magnetically-ordered phases. Within the doping range of $0.15<x<0.3$, a region of superconductivity emerges, reaching a maximum T_c = 25 K at x~0.2, which overlaps with a ferromagnetic phase that arises below T_{FM}~19 K, originating from the Eu moments. The coexistence of the two orders is unusual due to the antagonistic effect of ferromagnetism on superconductivity, however, the weak exchange field in this material allows the two orders to coexist over a large temperature window of ΔT~19 K.

Magnetic force microscopy (MFM) measurements[1] have demonstrated the existence of two distinct stripe ferromagnetic domain structures when cooled below T_{FM}: initially with a narrow domain width and transitioning to a wider domain width upon further cooling. Here, the domain period is first renormalized by screening Meissner currents that eventually give way to the nucleation of spontaneous vortices (V) and antivortices (AV) at lower temperatures, demonstrating the subtle effect of superconductivity on the ferromagnetic domain structure. However, little is known of the reciprocal influence from the ferromagnetism on the superconducting vortex dynamics.

To address this, we have performed bulk magnetometry and magnetic relaxation measurements in conjunction with high-field MFM on samples with optimal phosphorous composition, x~0.21. Our findings indicate that magnetic irreversibility is enhanced, and magnetic relaxation is suppressed, in the region of the finely-spaced domain structure. Further, MFM images in applied field show evidence for the localized distortion of the domain structure due to the presence of vortices, as well as the presence of several anomalous vortex-type objects with substantially increased size and magnetic intensity. We interpret these results as evidence for the formation of *vortex polarons*: a local perturbation of the domain energies due to the interaction with the vortex magnetic field, leading to enhanced vortex pinning properties. Furthermore, the formation of the vortex polaron leads to a short-range attractive vortex-vortex potential, enabling pairs or even higher number chains of vortices to be stabilized.

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Electrical detection of giant spin-to-charge conversion in superconductors

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Non-dissipative spin-polarized transport in superconductors attracts increasing. One of the key facets of this problem is nonequilibrium spin injection and propagation in the superconducting state. Recent experiments of spin-pumping into a conventional s-wave superconductor have detected a strong open-circuit DC voltage developing in the superconductor, which is enhanced across the superconducting transition and has been interpreted in terms of spin-to-charge conversion via an analogous inverse Hall effect mediated by Bogoliubov quasiparticles [1]. In our work, we explore a similar phenomenology observed in $YBa_2Cu_3O_7$ (YBCO), a d-wave superconductor with an anisotropic superconducting gap, combined with ferromagnetic metals (F) like CoFeB or NiFe. The ferromagnetic layer is excited at resonance by shining microwaves with a coplanar waveguide, which ultimately produces spin-pumping into the superconductor. In this situation, a DC voltage is detected in YBCO in the direction parallel to the S/F interface. This DC signal is odd with respect to the sign of the applied magnetic field, and is fully reminiscent of the inverse spin Hall effect. These electrical measurements are accompanied by an analysis of the ferromagnetic resonance (FMR) linewidth, from which we can calculate the magnetic damping of the F as a function of the temperature.

The FMR results show a drop in the damping across the superconducting transition. This is well understood considering that the opening of the superconducting gap hinders the diffusion of non-equilibrium spin-polarized quasiparticles into the superconductor [2]. In contrast, the generated DC voltage exponentially increases and shows a sign reversal across the superconducting transition. These observations are difficult to reconcile with the presence of an inverse spin Hall effect in the superconducting phase, and suggest instead that the underlying physics for the spin-to-charge conversion is fundamentally different in the superconducting and the normal phases. I will discuss the existing models used to explain the observed phenomena in superconductors and, based on our experiments, I will propose an alternative theory that reconciles the damping drop and the DC voltage peak across the superconducting transition.

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Intrinsic versus extrinsic strain dependence of superconductivity in the quasi-2D superconductor $CeIrIn_5$

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The selective control of the structure and physical properties of correlated electron materials at local, nano- and micro- length scales forms the basis of quantum nanodevices. The most investigated control parameters and the associated phase transitions that they drive are temperature, pressure, magnetic field and doping. Strain is only recently being explored as an extrinsic tuning parameter of the properties of quantum materials, mainly in conjunction of reduced dimensionality via the growth of thin films. Yet, intrinsic strain (inherent to the structure of a quantum material), is equally important to the understanding and control of the physical properties of the material and to the establishment of coherence at the ground state.
We will present here the intrinsic strain dependence of the structure and superconductivity of the quasi 2D superconductor $CeIrIn_5$. The evolution of the strain and the associated structural parameters as a function of temperature down to 300 mK (i.e. below its bulk superconducting transition) is clearly associated with the zero-resistance superconducting state at 1.2 K and the bulk superconductivity at 400 mK. We will compare our results with those obtained for thin films where the structure and superconductivity of $CeIrIn_5$ are controlled by extrinsic strain.

Brain-inspired computing with superconducting neurons

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While modern experimental techniques are enabling increasingly multifold studies of superconductivity (from in-situ synthesis to transport and scanning-probe measurements), the community has witnessed an increasing gap between the ab initio calculations and those on mean-field levels, and even more to the desired device modelling. At present, the only tool able to address the needed multi-scale modelling of superconductors, nanopatterned into electronic circuitry, are the advanced Ginzburg-Landau simulations. Over the years we have developed a multiscale approach where information about fermiology, vibrational modes, and electron-phonon coupling are obtained from first principles for the materials of interest, to be subsequently translated into (anisotropic) superconducting properties, that can further serve to properly parameterize mean-field models in order to capture the behavior of that superconductor when nanoengineered into an electronic device [1-4].
In this talk, I will review our most recent breakthroughs in that respect, and show particular numerical design of superconducting circuitry (on advanced size and time scale), with focus on the realizations of superconducting artificial neurons [5] and field-effect transistors [6], as the key elements for scalable yet energy-efficient computational architectures of the future.

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