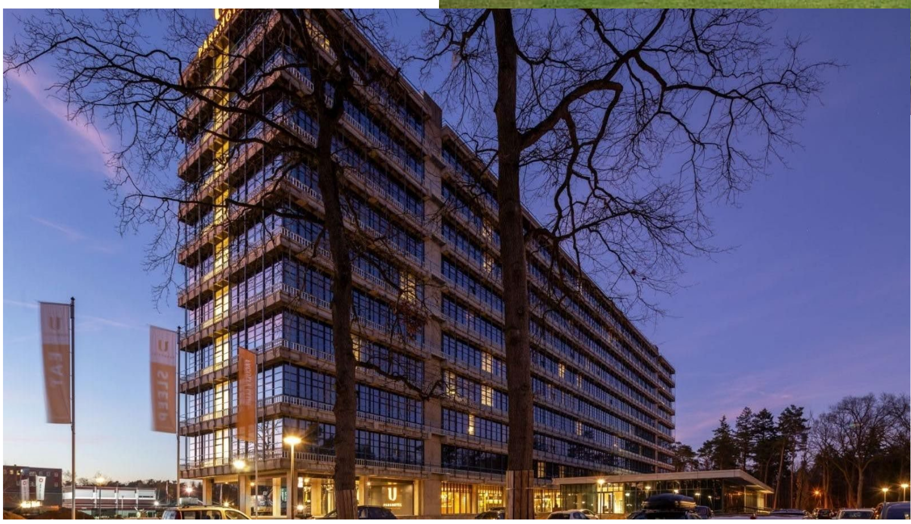
Abstract book of the International meeting on

‘Emergent phenomena in quantum materials and devices for unconventional superconducting systems’

8-10th June 2026
University of Twente, Enschede, The Netherlands



Contents

Aims and Scope

The International Workshop on 'Emergent phenomena in quantum materials and devices for unconventional superconducting systems' aims to present a comprehensive overview of recent advances in superconducting quantum materials and nanoscale superconducting systems, with particular emphasis on their fundamental properties and emergent phenomena.

The workshop seeks to bring together researchers from a range of closely connected and rapidly evolving fields. The closely connected topics (listed below) form a fertile ground for interaction between theory, numerical modeling, and experiment.

The scientific scope spans fundamental theoretical, numerical, and experimental investigations of superconducting and hybrid (nano-)structures, focusing on topology, vortex physics, and quantum coherence in tunable systems, and offering potential impact on future superconducting device concepts and quantum-information technologies.

Hosted in the Netherlands, with the University of Twente as an active hub in superconducting quantum materials and quantum technologies, strongly supported by the MESA+ Institute for Nanotechnology, the workshop offers an excellent opportunity for scientific exchange and collaboration within the European and international quantum-materials community.

Topics:

Topological and unconventional superconductivity

- Triplet pairing and spin-polarized superconductivity in Rashba systems, ferromagnetic hybrids, and oxide interfaces (e.g., $LaAlO_3/SrTiO_3$)
- Topological superconductivity in Dirac/Weyl semimetals (Cd_3As_2, WTe_2), topological insulators (Bi_2Se_3 family), and proximitized nanowires (InAs, InSb)

Magnetic and superconducting engineered devices

- Phase-engineered Josephson junctions (π, ϕ, ϕ_0 states) in superconductor–ferromagnet and spin–orbit coupled heterostructures (e.g., S/F/S, S/TI/S, S/semiconductor/S)
- Magnetic–superconducting hybrids with conventional superconductors

Low-dimensional and disordered superconductors

- Superconductivity in low-carrier-density and 2D materials ($SrTiO_3$, MoS_2, twisted bilayer graphene, $NbSe_2$ and other dichalcogenides, misfit systems)
- Flat-band systems
- Surface superconductivity (Fermi arcs and superconductivity in t-PtBi2)

Quantum devices and coherence

- Thin and ultra-thin film superconductors, SIT
- Superfluid stiffness and kinetic inductance in low-dimensional superconductors

The COST Action superqumap

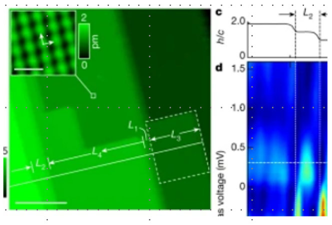
The COST Action SUPERQUMAP is organized by researchers from all European countries and includes collaborators all over the world. Superqumap started in October 2021 and will continue until October 2026. Superqumap will significantly shape research in superconductivity by a series of instruments provided by the well proven COST Action system. These includes two meetings a year, short term scientific missions and support to attend meetings organized by other entities in the same field. The management committee includes researchers from 29 countries, which share the common goal of advancing in the objectives of the Action. The approach is completely open to any researcher that can contribute to the objectives of the Action in any country.

The Action superqumap aims to harness the results obtained recently in superconductivity and build a collaborative effort to provide radically new approaches to superconducting based quantum devices. Research has three main objectives:

- To synthesize, characterize, model and understand superconducting materials and devices using a collaborative approach including techniques and capabilities available all over Europe.
- To improve our understanding of superconductors at interfaces and in combination with other systems such as magnets and insulators.
- To achieve a disruptive advance in superconducting devices for quantum technologies.

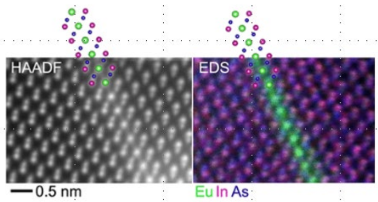
The work is organized in three work packages, which aid to shape the meetings and networking activities in which researchers mutually benefit from complementary knowledge to advance in the objectives of the Action.

Quantum well states at the surface of a heavy-fermion superconductor, Nature (2023), https://doi.org/10.1038/s41586-023-05830-1



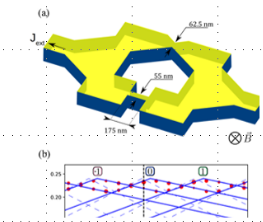
- Work package 1: Quantum materials
    - Obtain topological and triplet superconductivity by tuning correlations and the properties at interfaces.
    - Understand the relationship between electronic correlations, magnetism and unconventional superconducting properties.
- Work package 2: New functionalities for sensors and devices
    - Control the degree of disorder in low dimensional and low carrier density superconductors.
    - Achieve a better understanding of electronic behavior between the extreme limits of infinity and zero resistance.
    - Understand transport in hybrid magnetic-superconducting devices and explore the behavior of junctions made of hybrid heterostructures.

Intrinsic magnetic (EuIn)As nanowire shells with a unique crystal structure, Nano Lett (2022), 22, 8925



- Work package 3: Building Quantum Systems.
    - Create and characterize novel two-level systems in superconducting junctions and devices suitable for quantum computation.
    - Design and test methods for their coherent manipulation in quantum devices.

Metastable states and hidden phase slips in nanobridge SQUIDs, Phys Rev B (2022), 106, 134518



Everyone interested in contributing to the objectives of the Action is cordially invited to join us. Participation is very easy. First by joining a working group, which will allow us to keep you updated. Then, by attending one of our workshops, schools or conferences, by organizing a short term visit or by disseminating the results obtained in the field of the Action. Other, equally important, initiatives include dissemination activities, such as the promotion of books, both scientific and for the general public and the dissemination of our results.

The meeting in Budva, Montenegro, is our first in-person meeting. We purposely chose a location in an ITC country, with the aim to motivate activities within our field in these important European countries. The interest has been overwhelming and it was even difficult to make choices both in the program and in the available funds. The final result is an outstanding program, with about half of the participants from ITC countries, and where senior and young researchers openly meet around posters, talks and other collaborative activities.

Stay tuned to further activities of superqumap and we hope to see you very often.

Organizers

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Irene González Martín

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Invited Speakers

Name	Organisation
Ramon Aguado	Quantum Advanced Research Center (QuARC) and Instituto de Ciencia de Materiales de Madrid (ICMM), Consejo Superior de Investigaciones Científicas (CSIC)
Yonathan Anahory	The Hebrew University of Jerusalem
Mitali Banerjee	Ecole Polytechnique Federal de Lausanne (EPFL)
Julia Baumgarten	University of Liège
Janos Bekeart	University of Antwerp
Thomas Bernat	Uppsala University
Bernd Büchner	IFW Dresden
Eugenio Coronado	Univeristy of Valencia
Rosa Córdoba	Institute of Molecular Science, University of Valencia
Stevan Djurdjevic	University of Montenegro
Oleksandr Dobrovolskiy	CryoQuant, TU Braunschweig
Meydi Ferrier	University Paris-Saclay
Remko Fermin	University of Twente
Pol Forn	Institut de Física d'Altes Energies (IFAE)
Pertti Hakonen	Aalto University School of Science
Abdou Hassanien	Jožef Stefan Institute
Christian Hess	Bergische Universität Wuppertal
Alexei Kalaboukhov	Chalmers University of Technology
Matyas Kocsis	BME
Dieter Kölle	University of Tübingen, Germany
Filipp Kosuth	Institute of Experimental Physics, Slovak Academy of Sciences
Eduardo Lee	Universidad Autónoma de Madrid
Gualberto Miguel León Cuesta	Universidad Autónoma de Madrid
Jose Antonio Moreno	Universidad Autónoma de Madrid
Mikko Möttönen	Aalto University
Bhaskaran Muralidharan	Indian Institute of Technology Bombay
Laxman Nagi	Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay

Clara Palacios	Universidad Autónoma de Madrid
Sorin Paraoanu	Aalto University
Marta Perego	ETH Zurich
Vladislav Pokorny	FZU - Institute of Physics, Czech Academy of Sciences
Thijs Roskamp	University of Twente
Pablo San-José	Consejo Superior de Investigaciones Científicas (CSIC)
Gabriel Sant'Ana	Leiden University
Daniela Stornaiuolo	University of Naples "Federico II"
Hermann Suderow	Universidad Autónoma de Madrid
Francesco Tafuri	Università di Napoli Federico II
Senne Vervoort	KU Leuven
Yaojia Wang	KU Leuven
Alexander Weitzel	Universität Regensburg
Eli Zeldov	Weizmann Institute of Science

Program

Time	Monday 8 June	Tuesday 9 June	Wednesday 10 June
08:30	**Opening / welcome**	**Eli Zeldov** Reconfigurable chiral superconductivity	**Francesco Tafuri** Tunnel ferromagnetic Josephson junctions in transmon energy scale: the ferrotransmon
09:00	**Eugenio Coronado** Molecular spin-qubits integrated in quantum devices	**Meydi Ferrier** Probing the Protection of Topological Edge States: Interferences, High Frequency Susceptibility and Fluctuations of Supercurrent	**Jonas Bekeart** Monolayer materials as building blocks for superconducting quantum devices: An ab initio exploration
09:30	**Yonathan Anahory** Evidence of competing orders in few-layer $NbSe_2$	**Pablo San-José** Transport between quarter-metallic and chiral superconducting domains in rhombohedral graphene	**Abdou Hassanien** Kondo screening and coupling of spin states on graphene nanoribbon
10:00	**Marta Perego** Gate-tunable twisted graphene: from individual vortex dynamics to hybrid quantum devices	**Mitali Banerjee** Gate-tunable double-dome superconductivity in twisted trilayer graphene	**Daniela Stornaiuolo** From STO to KTO: Enhanced Spin–Orbit Coupling and Superconductivity in (111) Oxide Interfaces
10:30	**Coffee break**	**Coffee break**	**Coffee break**
11:00	**Pertti Hakonen** Voltage shot noise in superconducting nanowires	**Yaojia Wang** Superconductivity of a Kagome material and the global critical current phenomenon	**Thijs Roskamp** Towards nanoscale topographic and magnetic imaging with a wireframe SQUID on a self-sensing cantilever **Jose Antonio Moreno** Gapless Superconductivity From Extremely Dilute Magnetic Disorder in $2H\text{-}NbSe_{2-x}S_x$

11:30	**Senne Vervoort** DC-operated SNS Josephson junction arrays as a cryogenic on-chip microwave measurement platform	**Alexei Kalaboukhov** Unconventional Superconductivity in Complex Oxide Interfaces: the role of interface stoichiometry and localized vibrational modes	**Clara Palacios** Microwave characterization of induced superconductivity in Al/InAs heterostructures **Stevan Djurdjevic** Anomalous and diode Josephson effect in SFFS junctions with interfacial Rashba spin-orbit coupling
12:00	**Sorin Paraoanu** Three-level superconducting devices: high-fidelity control techniques and applications	**Filipp Kosuth** Ising Superconductivity in non-centrosymmetric bulk 4Ha-$NbSe_2$	**Dieter Kölle** SQUID-on-lever for magnetic imaging with spatial resolution below 100 nm
12:30	**Lunch**	**Lunch**	**Closing and Lunch**
14:00	**Gabriel Sant'Ana** Emergent Zeeman-Resilient Superconductivity Beyond the Spin-Paramagnetic Limit in Ultrathin NiBi3	**Ramon Aguado** From Majorana to Andreev and Back	
14:30	**Christian Hess** Unconventional Surface Superconductivity of t-PtBi2	**Bhaskaran Muralidharan** Probing true and false poor man's Majorana states via non-local shot noise	
15:00	**Hermann Suderow** Vortex lattice and superconductivity in two-dimensional surface superconductors: the case of PtBi2	**Mikko Möttönen** Superconducting qubits and millikelvin electronics aimed at scalable quantum processors	
15:30	**Bernd Büchner** Topological i-Wave Surface Superconductivity in $PtBi_2$	**Julia Baumgarten** Magnetic landscape of NbTiN superconducting resonators under radio-frequency excitation	
16:00	**Coffee break**	**Coffee break**	
16:30	**Rosa Córdoba** Focused Ion Beam Direct-Write Nanofabrication of Superconducting Nanostructures and Devices	**Oleksandr Dobrovolskiy** Fast moving fluxons generate short-wavelength magnons	

17:00	**Pol Forn** Nitridized aluminum for applications in superconducting quantum circuits	**Laxman Nagi** High-Tc d-wave Superconductor/2D Transition-Metal Dichalcogenide Heterostructures for studies of superconducting proximity effect	
17:30	**Eduardo Lee** Signatures of edge states in a van der Waals antiferromagnetic Josephson junction	**Thomas Bernat** Composite Quantum Geometry of Bogoliubov-de Gennes Hamiltonians	
18:00	**Remko Fermin** The possible trivial role of spin-orbit coupling in planar Josephson junctions	**Alexander Weitzel** Superfluid stiffness in strongly disordered NbN superconducting films	
18:30	**Matyas Kocsis** Strong Andreev bound state-to-photon coupling in a quantum dot based Josephson junction **Gualberto Miguel León Cuesta** Contact-Induced weak links in Superconducting Nanowires Via the Inverse Proximity Effect	**Vladislav Pokorny** Switchable superconducting molecular devices for information processing	
19:00	**Dinner**	**Dinner**	
	Poster	Poster	

Molecular spin-qubits integrated in quantum devices

Eugenio Coronado

Instituto de Ciencia Molecular (ICMol), University of Valencia, Spain

Scalability is a current challenge in quantum information technologies. The integration of molecular nanomagnets in quantum devices may provide a suitable approach to overcome this challenge [1]. Here we will exploit the versatility of coordination chemistry to design magnetic molecules with adjustable electronic structures that can act as robust spin qubits and be integrated in both superconducting cavities [2] and in a new type of quantum cavity based on 2D magnets. In this magnonic cavity we have reached a strong coupling between the molecular spins and the magnetic excitations (magnons) of the magnet [3]. This discovery inaugurates magnon quantum electrodynamics (QED) and experimentally demonstrates the ability to dynamically tune the spin-magnon coupling by adjusting magnon chirality. This last part has been developed in collaboration with the teams of M. J. Martínez-Pérez and D. Zueco (INMA, Zaragoza).

[1] A. Gaita-Ariño, F. Luis. S. Hill, E. Coronado. Nat. Chem. 11, 301-309 (2019)
[2] I. Gimeno et al. Phys. Rev. Appl. 20, 044070 (2023)
[3] D. García-Pons et al. Newton. 100515 (2026

Evidence of competing orders in few-layer $NbSe_2$

Yonathan Anahory

The Hebrew University of Jerusalem

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 Λ, which is inversely proportional to the 2D superfluid density; hence, normally, also inversely proportional to the film thickness, d. Here we employ the scanning SQUID-on-tip microscopy to measure Λ in $NbSe_2$ flakes with thicknesses ranging from N=3 to 53 layers. For N>10, we find the expected dependence ($\Lambda \propto 1/d$). However, six-layer films show a sharp increase of Λ deviating by a factor of three from the expected value1. This value remains fixed for N=3 to 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.

Gate-tunable twisted graphene: from individual vortex dynamics to hybrid quantum devices

Marta Perego

ETH Zurich

Experimentally, magic-angle twisted bilayer and multilayer graphene have been found to exhibit gate-tunable superconducting phases, enabling the realization of monolithic superconducting devices controlled purely by electrostatic gating. To probe the fundamental properties of these phases and explore their potential for quantum devices, we present our recent experiments on gate-tunable moiré devices. First, by using a Josephson junction as a sensitive vortex sensor in magic-angle four-layer graphene, we detect individual vortices in the superconducting leads, which manifest as abrupt shifts in the Fraunhofer interference pattern. Time-resolved measurements allow us to investigate the dynamics of individual vortices, providing access to the characteristic vortex energy scale and the London penetration depth. Our measurements reveal a high-temperature regime dominated by classical thermal activation over an energy barrier, which crosses over at low temperatures to a regime of macroscopic quantum tunnelling. We then extend this platform to twisted bilayer graphene, where we engineer two complementary types of hybrid quantum dot devices: superconducting islands and proximitized quantum dots. While the superconducting islands hold the 2e-periodic transport characteristic of a hard superconductor, the proximitized dots host a parity-dependent sub-gap structure with Kondo-like features. Together, these results demonstrate the versatility of twisted graphene for both fundamental studies of vortex physics and the development of complex hybrid quantum devices.

Voltage shot noise in superconducting nanowires

Pertti Hakonen

Aalto University

Coauthors: Tosson Elalaily, Stanislav Khaldeev, Yuvraj Chaudry, Tomas Novotny, Martin Zonda, Dmitry Golubev, Peter Makk, Szabolcs Csonka, Pertti Hakonen

We have investigated shot noise produced by phase slips in superconducting Al/InAs nanowires (NWs). Phase slips in superconducting nanowires result in voltage noise that can be regarded as the dual of electrical current shot noise where the electron charge is replaced by the flux quantum. Our shot noise experiments yield the Fano factor F of phase slip voltage noise and we observe $F \simeq 1$, which points to Poissonian statistics for the emission of phase slips. We have also studied the influence of gate voltage on the voltage shot noise and find evidence of appearance of hot spots in the nanowire caused by the gate leakage current.

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

Sene Vervoort

Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Belgium

Coauthors: S. Vervoort[1], L. Nulens[1], D. A. D. Chaves[1], H. Dausy[1], S. Reniers[1], M. Abouelela[1], I. P. C. Cools[2], A. V. Silhanek[3], M. J. Van Bael[1], B. Raes[4], J. Van de Vondel[1]
[1] Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Belgium.
[2] Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden.
[3] Experimental Physics of Nanostructured Materials, Q-MAT, Université de Liège, Belgium.
[4] IMEC, Kapeldreef 75, Leuven, Belgium.

The development of cryogenic microwave experimentation for radio frequencies (RF) in the GHz range is motivated by their strong potential for on-chip ferromagnetic resonance, electron spin resonance, as well as spin-based and superconducting qubits. 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, putting an upper limit on the available frequencies, inducing noise and lacking scalability. Addressing these issues, it is more beneficial to place the RF controls on-chip, thus removing the limitations of the cables. 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 [1]. 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 [2]. Figure 1a 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. The minimum linewidth is 106 MHz. Furthermore, the emitted radiation can be further tuned using temperature, magnetic fields, applied currents and device design.

Besides using it as source, they can also be used as detectors. Upon RF radiation, Shapiro steps appear in the IV characteristics of the arrays [3,4]. The height of the steps only depends on the frequency of the RF signal, while the width also depends on the power, see figure 1b. Thus, these arrays enable on-chip detection of RF signals, providing a route toward an integrated on-chip spectroscopy platform.

[1] B.D. Josephson, Phys. Lett., 1 (1963) 251-253.
[2] S. Vervoort, et al., Commun. Phys., 8 (2025) 292.
[3] S. Shapiro, Phys. Rev. Lett., 11 (1963) 80-82.
[4] R. Panghotra, Commun. Phys., 3 (2020) 1-8.

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Three-level superconducting devices: high-fidelity control techniques and applications

Gheorghe-Sorin Paraoanu

Aalto University

Superconducting devices studied in the context of quantum computing have in reality more than two energy levels. Here I will present a number of results pertaining to operating a transmon as a three-level system by using the technique of phase modulation. We have shown that this leads to better frequency robustness and we have observed a new type of Landau-Zener effect that involves two photons. In addition, by utilizing neural ordinary differential equations (Neural ODEs) we have obtained single-qubit gates with fidelity greater than 99.9%. I will show how these control methods improve the sensitivity of dark photon and axion detectors.

M.P. Silveri et al., Rep. Prog. Phys. 80, 056002 (2017); M. Kuzmanovic et al., Phys. Rev. Research 6, 013188 (2024); I. Björkman et al., Phys. Rev. Lett. 134, 060602 (2025); M. Kuzmanović et al., arXiv:2505.02054

Emergent Zeeman-Resilient Superconductivity Beyond the Spin-Paramagnetic Limit in Ultrathin $NiBi_3$

Gabriel Sant'Ana

Leiden University

The spin-paramagnetic limit sets a fundamental magnetic-field bound for conventional superconductors. Here we show that ultrathin NiBi3 films develop a highly field-resilient superconducting state, with in-plane critical fields surpassing the spin-paramagnetic limit even above 0.9Tc. This enhancement is activated by dimensional confinement and depends sensitively on film thickness and morphology. Standard mechanisms, including strong spin-orbit coupling and multiband superconductivity, fail to quantitatively explain the observed robustness. These findings uncover an unconventional pathway for Zeeman-resistant superconductivity in low-dimensional materials beyond known Ising and Rashba scenarios, and further support earlier theoretical predictions of triplet pairing in low-dimensional $NiBi_3$.

Unconventional Surface Superconductivity of t-$PtBi_2$

Christian Hemker-Hess

Bergische Universität Wuppertal

Coauthors: S. Schimmel[1,2], Julia Besproswanny[1,2], Y. Fasano1[3], G. Shipunov[2], S. Aswartham[2], D. Baumann[2], B. Büchner[2], C. Hess[1,2]
[1] Bergische Universität Wuppertal, 42119 Wuppertal, Germany
[2] Leibniz-Institute for Solid State and Materials Research (IFW-Dresden), Germany
[3] Instituto de Nanociencia y Nanotecnología and Instituto Balseiro, CNEA – CONICET and Universidad Nacional de Cuyo, 8400 Bariloche, Argentina

The Weyl semimetal t-$PtBi_2$ (trigonal) recently emerged as an interesting host of unconventional and potentially topological superconductivity. Sizable superconducting gaps up to about 20 meV have been observed in scanning tunneling spectroscopy (STM/STS) [1] and ARPES [2,3]. The data suggest surface superconductivity emerging from the Weyl Fermi arc states while the bulk states remain normal. The order parameter has been reported to possess nodes, suggestive of topological i-wave superconductivity [3]. Here we present STM/STS data of the quasiparticle interference (QPI) in both the superconducting and the normal state as well as temperature dependent measurements of the superconducting gap. Our data clearly reveal that i) the states which are gapped out by superconductivity indeed are located at the Fermi arcs, and ii) the large superconducting gaps correspond to a high critical temperature T_c up to about 50 K. Thus $PtBi_2$ indeed qualifies as a truly unconventional and topological superconductor.

[1] S. Schimmel et al., Nature Communications 15, 9895 (2024)
[2] A. Kuibarov et al., Nature 626, 294 (2024)
[3] S. Changdar et al., Nature 647, 613-618 (2025)

Vortex lattice and superconductivity in two-dimensional surface superconductors: the case of $PtBi_2$

Hermann Suderow

Universidad Autónoma de Madrid

The layered compound γ-$PtBi_2$ is a topological semimetal with Fermi arcs at the surface joining bulk Weyl points. Signatures of unconventional surface superconductivity confined to the surface have been unveiled in angular resolved photoemission and Scanning Tunneling Microscopy. Here I will present very low temperature Scanning Tunneling Microscopy (STM) showing that there is robust surface superconductivity in γ-$PtBi_2$ with T_c =2.9 K and H_{c2} ≈1.8 T. Quasiparticle interference at the superconducting gap edge shows Fermi arcs, suggesting that superconductivity arises on the topological surface states. I will discuss with detail the observation of quantized superconducting vortices and the vortex lattice as a function of the magnetic field and in different fields of view. I will also show the Josephson effect. Taken together, our results show robust two-dimensional superconductivity held by surface states.

Topological i-Wave Surface Superconductivity in $PtBi_2$

Bernd Büchner[1,2,3]

1 IFW Dresden, Germany

2 The Institute for Solid State Research (IFF), Germany

3 Experimental Condensed Matter Physics, TU Dresden, Germany

$PtBi_2$ is a promising platform for topological superconductivity, with the strongest evidence coming from angle-resolved photoemission spectroscopy (ARPES). I will show that in the non-centrosymmetric Weyl semimetal and van der Waals material $PtBi_2$, superconductivity is intrinsically confined to the surface: below about 20 K, ARPES detects a gap opening selectively on the topological Fermi-arc states, while the bulk-derived states remain completely ungapped in ARPES and the bulk remains normal in bulk-sensitive measurements. High-resolution ARPES further points to a nodal gap structure, consistent with unconventional pairing and a topological superconducting surface state. Because these surface states arise from the bulk Weyl topology, $PtBi_2$ provides an intrinsic interplay of bulk topology and surface superconductivity and may represent a rare case of superconductivity confined to the surface alone. A diamagnetic response appears in the same temperature range only in AC susceptibility, not in the DC Meissner signal, indicating strong superconducting fluctuations. These persist to low temperatures and are also observed by scanning SQUID microscopy. STM reveals the remarkable potential of this system, with some surfaces showing very large gap values, high apparent transition temperatures, and high critical fields. Superconductivity is also found in nanoscale exfoliated flakes, where it depends strongly on sample dimensions, consistent with a surface-dominated state. At the same time, STM and scanning SQUID reveal strong variations between different surfaces, indicating sensitivity to local surface conditions, possibly influenced by defects, strain, or morphology. Theory further suggests that the i-wave state intrinsically involves both non-equivalent surfaces, whose superconducting chiralities may differ. $PtBi_2$ thus emerges as a compelling but complex candidate for intrinsic topological surface superconductivity.

A. Kuibarov et al., Nature, (2024)
A. Kuibarov et al., Phys. Rev. B, (2025)
S. Changdar et al., Nature (2025)
S. Schimmel et al., Nat. Commun. (2024)
G. Shipunov et al., Phys. Rev. Mat. (2020)
A. Veyrat et al., Nanolett. (2023)
F. Caglieris et al., Phys. Rev. Materials, (2025)
A. Kuibarov et al., arXiv:2509.02178v1
X. Huang et al., arXiv:2507.13843v1
J. Besproswanny et al., arXiv:2507.10187v1
O. Kvitnitskaya et al., arXiv:2511.00920

Focused Ion Beam Direct-Write Nanofabrication of Superconducting Nanostructures and Devices

Rosa Córdoba

Institute of Molecular Science, University of Valencia

Superconducting nanostructures are attractive building blocks for next-generation quantum and nanoelectronic technologies because they combine dissipation-free transport, macroscopic quantum coherence, and a strong dependence of their properties on nanoscale geometry. Extending these systems from conventional planar layouts to three-dimensional (3D) architectures opens new possibilities for engineering superconducting, magnetic, and optical functionalities through structural design.

In this work, we demonstrate a direct-write additive nanofabrication strategy based on focused ion beam technology for the realization of superconducting nanoarchitectures with nanoscale accuracy. This method enables the controlled fabrication of free-form geometries, including 3D nanohelices, with tunable properties determined by their size and orientation. The fabricated structures exhibit superconducting behaviour with critical temperatures around 7 K and robust performance under high magnetic fields. In addition, dense arrays of engineered 3D curved superconducting nanostructures display enhanced vortex pinning, as revealed by resistance minima at specific magnetic fields arising from commensurability effects between the vortex lattice and the artificial geometry. We further show electric-field modulation of superconductivity in nanowires, underscoring the potential of these systems as tunable superconducting nanoelements.

These findings establish focused ion beam direct-write nanofabrication as a powerful and versatile approach for creating advanced nanosuperconductors in which superconductivity, 3D geometry, vortex manipulation, and field-effect tunability can be integrated within a single nanoscale platform.

Nitridized aluminum for applications in superconducting quantum circuits

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Materials that naturally display a high kinetic inductance per unit area are known as superinductors. These materials can lead to the improvement of coherence times of superconducting quantum circuits, such as the fluxonium qubit, by the combination of an enhanced impedance while introducing low loss. Typical examples of such materials include disordered superconductors and granular superconductors. An illustrative and widely used case is granular aluminum (grAl), which consists of an AlO_x matrix filled with pure Al grains. In this work, we present a new superconductor, nitridized aluminum (NitrAl, in short). NitrAl displays similar properties as grAl, the main difference being the presence of nitrides over oxides, possibly enhancing quality when used in applications for quantum devices. Within the scope of our research, superconducting NitrAl thin films have been fabricated and characterized both at room temperature and at low temperature, covering a wide range of resistivity, critical temperature and critical field. The obtained results reflect a strong sensitivity in the microscopic disorder either by either varying the film thickess or the nitrogen concentration during deposition. In comparison to both bare Al and grAl, NitrAl displays a clear enhancement of the superconducting critical temperature up to 3.5K. These results position NitrAl as a promising candidate to operate as a resilient superinductor in superconducting quantum hardware applications.

Signatures of edge states in a van der Waals antiferromagnetic Josephson junction

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The interplay between superconductivity and magnetic textures can give rise to unconventional superconducting phenomena [1-3]. Van der Waals (vdW) materials provide a versatile platform for investigating the competition between these orders. Here, we report on individual $NbSe_2/NiPS_3/NbSe_2$ Josephson junctions that exhibit behavior characteristic of superconducting quantum interference devices (SQUIDs) [4]. This response is attributed to the coupling between superconductivity in $NbSe_2$ and the spin texture of the vdW antiferromagnetic insulator $NiPS_3$. The SQUID-like behavior persists under in-plane magnetic fields of at least 6 T. Microscopic modeling of the antiferromagnetic insulator/superconductor (AFI/S) interface points to the emergence of localized states at the junction edges, which can form channels that dominate transport. These results highlight AFI/S heterostructures as a promising system for exploring engineered superconducting behavior and unconventional transport phenomena.

[1] J. Linder and J. W. A. Robinson, Nat. Phys. 11, 307 (2015).
[2] Sau et al., Phys. Rev. Lett. 104, 040502 (2010).
[3] Bergeret et al., Rev. Mod. Phys. 90, 041001 (2018).
[4] Gonzalez-Sanchez et al., Adv. Mater., https://doi.org/10.1002/adma.20252125

The possible trivial role of spin-orbit coupling in planar Josephson junctions

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The relativistic coupling between spin and orbital momentum (spin-orbit coupling) is one of the most profound effects of quantum mechanics, and plays a central role in functional properties of superconducting electronics. Prominent among these are the Josephson diode effect — a Josephson junction featuring a nonreciprocal critical current: $I^{+}_{c} \neq I^{-}_{c}$ — and the generation of a finite magnetization due to the spin Hall effect. Despite the undeniable potential of spin-orbit coupling in applications and its prowess of explaining unconventional properties of superconducting electronics, the right control experiments needed to distinguish the role of spin-orbit coupling from trivial effects are often overlooked.

In this talk, I will show that shifts in the magnetic interference pattern and Josephson diode effect — before attributed to the presence of a Rashba spin-orbit coupling in the weak link — can be reproduced in planar Josephson junctions formed between an s-wave superconductor and a non-relativistic copper weak link. Furthermore, these Cu-junctions reproduce a Josephson diode behaviour that mimics its high spin-orbit coupling counterpart; in particular, the in-plane field angle dependence. These results warrant caution when attributing unconventional features to spin-orbit coupling and need to be considered as additional factor when interpreting the characteristics of superconducting electronics.

Reconfigurable chiral superconductivity

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Rhombohedral multilayer graphene at high displacement fields hosts superconductivity emerging from a spin–valley-polarized quarter-metal, with transport signatures suggestive of time-reversal symmetry (TRS) breaking and chiral superconductivity (CSC). These observations have motivated proposals of topological superconductivity and non-Abelian quasiparticles, yet direct magnetic evidence and microscopic insight into the superconducting state remain lacking, limiting understanding of this unique state. Here we use nanoscale SQUID-on-tip magnetometry to image isospin-polarized domains in rhombohedral pentalayer graphene and establish CSC via spatially resolved thermodynamic detection of TRS breaking. We find that the density at which domain walls proliferate at elevated temperatures coincides with the onset of CSC, indicating an underlying transition in the parent state that both induces superconductivity and reduces domain-wall energy. We further show that the chiral domain structure in the superconducting phase is inherited from the isospin-polarized parent state. Strikingly, the CSC phase exhibits multiple transport regimes governed by configurations of chiral domains separated by highly resistive domain walls. We demonstrate deterministic, ultra-low-current control of these domains, enabling reversible switching between states of opposite chirality—a defining CSC property absent in other superconductors. These results establish rhombohedral graphene as a unique platform for reconfigurable CSC and ultra-low-power electronic functionality based on controllable isospin textures.

Probing the Protection of Topological Edge States: Interferences, High Frequency Susceptibility and Fluctuations of Supercurrent

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Second order topological insulators (SOTIs), are characterized by helical, non-spin-degenerate, one-dimensional states running along the crystal hinges. By coupling such material to superconducting electrodes, a non-dissipative current is carried by topological Andreev bound states (ABS), electron-hole pairs with spin-momentum locking theoretically preventing any backscattering. However, demonstrating the topological protection of Andreev states is an experimental challenge. I will present evidence of this protection through different experiments in multilayer WTe_2 [1] as well as in bismuth (Bi) nanowires connected to superconducting electrodes. Interference patterns observed in single wires as well as current-phase relation measured in squid geometries demonstrates that transport occurs selectively along ballistic hinges of the nanostructure. We have also demonstrated the topological character of hinge states by measuring the high-frequency susceptibility of a Bi-based Josephson junction whose dissipation peaks at π reveal protected Andreev level crossings. Finally, I will present supercurrent noise measurements of trivial ABS [2] showing that finite frequency dissipation corresponds to thermal fluctuations in the supercurrent at equilibrium as the fluctuation-dissipation theorem tells us. Thus, our measurement technique opens the possibility to probe the robustness of this crossing at equilibrium in topological material.

[1] Probing the topological protection of edge states in multilayer tungsten ditelluride with the superconducting proximity effect
X. Ballu et al, Phys. Rev. Res. 8, 023034 (2026)
[2] Supercurrent noise in a phase-biased superconductor-normal ring in thermal equilibrium
Z. Dou et al, Phys. Rev. Res. 6, L022023 (2024)

Transport between quarter-metallic and chiral superconducting domains in rhombohedral graphene

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Rhombohedral graphene multilayers have been shown to exhibit a range of symmetry-broken electronic phases, notably among them quarter-metals exhibiting anomalous quantum hall effect that, upon reducing temperature, transition into a (possibly chiral) spin-triplet superconducting phase. These phases can be controlled using electric and magnetic fields, and their symmetry (specifically valley, spin and chiral) can break in various directions, even yielding topologically disticts domains. We study the transport properties between normal and superconducting domains (NN, NS and SS junctions), and analyze how differential conductance, Andreev reflection and the Josephson effect can reveal information about the underlying electronic phases.

Gate-tunable double-dome superconductivity in twisted trilayer graphene

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Twisted trilayer graphene (TTG) has emerged as a particularly intriguing platform for studying moiré superconductivity. Its flat-band physics closely resembles that of twisted bilayer graphene, yet TTG offers an additional degree of tunability in its band structure, providing a valuable handle for uncovering the mechanisms of moiré superconductivity. In addition, the interference between the two moiré lattices in mirror-symmetry-broken TTG gives rise to a supermoiré lattice, introducing a new degree of freedom for exploring correlated electronic phenomena.

In the first part, we report the first transport observation of gate-tunable double-dome superconductivity in MATTG. We found that superconductivity is supressed near ν=-2.6 in a small displacement field region. Through temperature, magnetic field and current bias dependence, we reveal the distinct transport behavior of the right and left dome superconductivities, as well as their corresponding normal states. In the second part, we report the existence of the supermoiré lattice in the mirror-symmetry-broken TTG, elucidating its role in generating mini flat bands and mini Dirac bands. We also demonstrate interaction-induced symmetry-broken phases in the supermoiré mini flat bands alongside the cascade of multiple superconductor-insulator transitions enabled by the supermoiré lattice.

Our work provides new insights into moiré graphene superconductivity and highlights the importance of the supermoiré lattice as an additional degree of freedom for tuning the electronic properties of twisted multilayer systems.

Superconductivity of a Kagome material and the global critical current phenomenon

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Materials with a Kagome lattice, composed of corner-sharing triangles, have garnered significant interest due to their potential to host strong electronic correlations, exotic magnetism, and nontrivial topology. The AV_3Sb_5 family (A = K, Cs, Rb) has become a focal point of research because of its diverse physical properties, which include cascade charge orders, superconductivity, and topological states, as well as the complex interplay between these phenomena. This presentation will introduce the key physical properties of Kagome family AV_3Sb_5, with a focus on the superconducting properties. Our recent effort has focused on the intrinsic superconductivity in KV_3Sb_5. Supercurrent oscillations have been observed within KV_3Sb_5 itself, demonstrating inherent supercurrent interference. Specifically, we discovered the transfer of supercurrent interference patterns between the superconducting ring and the superconducting flake, which demonstrates the global critical current effect of the superconducting phase coherence. In addition to Kagome materials, the global critical current effect has been observed in various superconducting systems, where the superconductivity of a measured segment can be influenced by other segments along the applied current path. This highlights the broader importance of this effect in understanding superconducting behavior.

Unconventional Superconductivity in Complex Oxide Interfaces: the role of interface stoichiometry and localized vibrational modes

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$SrTiO_3$-based conducting interfaces, which exhibit coexistence of gate-tunable 2D superconductivity and strong Rashba spin-orbit coupling, are candidates to host topological superconductive phases. In our earlier experiments, we observed an anomalous behavior of critical current as a function of magnetic field which can be attributed to the presence of anomalous pairing components [1]. Yet, the superconductivity in oxide interfaces is usually in the dirty limit, which suppresses nonconventional pairing. In this work, we realized $LaAlO_3/SrTiO_3$ interfaces with remarkably large mobility and mean free paths comparable to the superconducting coherence length, approaching the clean limit for superconductivity [2]. By exploiting small variations of the La/Al chemical ratio we can fine-tune systematically the carrier density, mobility and the formation of the superconducting condensate. We find a region in the phase diagram where the critical temperature is not suppressed below the Lifshitz transition, at odds with predictions from Bardeen–Cooper–Schrieffer theory. We also established a link between superconductivity and strong electron-phonon coupling mediated by tunable localized phonons, providing new insights into the microscopic pairing mechanism [3]. These findings point out the relevance of achieving a clean-limit regime to enhance the observation of unconventional pairing mechanisms in these systems.

[1] G. Singh et al.,” Gate-tunable pairing channels in superconducting non-centrosymmetric oxides nanowires”, npj Quantum Materials 7, 2 (2022).
[2] G. Singh et al., “Stoichiometric control of electron mobility and 2D superconductivity at LaAlO3-SrTiO3 interfaces”, Communications Physics 7, Article number: 149 (2024).
[3] R. Guzman et al., “Electron-Phonon Coupling and Symmetry-Breaking in Superconducting Oxide Interfaces Near Ferroelectric Quantum Criticality”, Research Square https://doi.org/10.21203/rs.3.rs-6991826/v1

Ising Superconductivity in non-centrosymmetric bulk 4Ha-$NbSe_2$

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The interplay between reduced dimensionality, spin–orbit coupling, and superconductivity has emerged as a central topic in contemporary condensed matter physics. In transition metal dichalcogenides, strong spin–orbit interactions combined with broken inversion symmetry can give rise to Ising superconductivity, in which Cooper pairs acquire an out-of-plane spin polarization that protects the superconducting state against large in-plane magnetic fields. While this phenomenon has been extensively studied in monolayer systems, less is understood about its manifestation in bulk polytypes and structurally complex layered materials.

Here, we investigate the superconducting properties of non-centrosymmetric bulk 4Ha-$NbSe_2$ polytype. By the specific heat measurements, we show that the in-plane upper critical magnetic field exceeds the Pali paramagnetic limit three times. Ab initio band structure calculations based on experimentally determined crystal structure confirm the spin-valley locking. The theoretical model provides the microscopic mechanism of the Ising protection based solely on broken inversion symmetry [1]. In addition, low-temperature specific-heat measurements with magnetic fields oriented at various angles with respect to the basal plane, combined with scanning tunnelling microscopy and spectroscopy, were utilised to probe the superconducting order parameter.

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[1] D.Volavka et al. Phys. Rev. Lett. 136, 016002 (2026|

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From Majorana to Andreev and Back

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The promise of Majorana zero modes (MZMs) for fault-tolerant topological quantum computing stems from their unique non-Abelian statistics and inherent topological protection from local decoherence [1]. However, after fifteen years of research, distinguishing MZMs from near-zero-energy Andreev bound states (ABSs) in hybrid devices remains a key challenge. This "Majorana versus Andreev" challenge [2] has revealed that, rather than being a disadvantage, ABSs can serve as a foundation for novel qubit designs. One promising approach encodes a qubit in the spin of a quasiparticle residing in an ABS of a quantum dot [3]. Embedding such a superconducting spin qubit into a transmon circuit provides an intrinsic spin-supercurrent coupling, enabling an effective interface with circuit quantum electrodynamics for coherent control, readout, and strong qubit-qubit coupling [4]. Alternatively, a minimal Kitaev chain implemented in quantum dots coupled via superconductors [5] is a promising platform. Even a minimal chain of two dots can host a pair of Majorana modes and store quantum information in their joint parity. Recent quantum capacitance measurements on such platforms have enabled single-shot parity readout and demonstrated parity lifetimes exceeding 1 millisecond [6]. These results establish essential readout capabilities and resolve a long-standing experimental challenge, paving the way for time-domain control of Majorana-based qubits.

[1] Majorana qubits for topological quantum computing, Ramón Aguado, Leo P Kouwenhoven, Physics Today 73, 44 (2020).
[2] From Andreev to Majorana bound states in hybrid superconductor-semiconductor nanowires, Elsa Prada, Pablo San-Jose, Michiel WA de Moor, Attila Geresdi, Eduardo JH Lee, Jelena Klinovaja, Daniel Loss, Jesper Nygård, Ramón Aguado, Leo P Kouwenhoven, Nature Review Physics,2, 575–594 (2020).
[3] Spectroscopy of Spin-Split Andreev Levels in a Quantum Dot with Superconducting Leads, Arno Bargerbos, Marta Pita-Vidal, Rok Žitko, Lukas J Splitthoff, Lukas Grünhaupt, Jaap J Wesdorp, Yu Liu, Leo P Kouwenhoven, Ramón Aguado, Christian Kraglund Andersen, Angela Kou, Bernard Van Heck, Phys. Rev. Lett. 131, 097001 (2023)
[4] Direct manipulation of a superconducting spin qubit strongly coupled to a transmon qubit, Marta Pita-Vidal, Arno Bargerbos, Rok Žitko, Lukas J Splitthoff, Lukas Grünhaupt, Jaap J Wesdorp, Yu Liu, Leo P Kouwenhoven, Ramón Aguado, Bernard van Heck, Angela Kou, Christian Kraglund Andersen, Nature Physics, 19, 1110 (2023)
[5] Optimal Majoranas in Mesoscopic Kitaev Chains, M Alvarado, R Seoane Souto, María José Calderón, Ramón Aguado, arXiv preprint arXiv:2604.13945.
[6] Single-shot parity readout of a minimal Kitaev chain, Nick van Loo, Francesco Zatelli, Gorm O Steffensen, Bart Roovers, Guanzhong Wang, Thomas Van Caekenberghe, Alberto Bordin, David van Driel, Yining Zhang, Wietze D Huisman, Ghada Badawy, Erik PAM Bakkers, Grzegorz P Mazur, Ramón Aguado, Leo P Kouwenhoven, Nature 650, 334-339 (2026)

Probing true and false poor man's Majorana states via nonlocal shot noise

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There is a lot of current interest in assessing the nature of poor man's Majorana (PMM) states in minimal Kitaev chains [1]. A current contention is that for a realistic chain, one has a threshold region, which can yield "sweet spots" for the potential realisation of these states. Measures of Majorana purity [2] along with analysis of its evolution in the bulk limit can indeed distinguish the true PMM with a false PMM. In this talk, we wish to extend the analysis this distinction between true and false PMM to tangible transport signatures, specifically the nonlocal signals. We employ the Keldysh nonequilibrium Green's function [3] along with Buettiker scattering theory [4] to evaluate clearly the nonlocal shot noise signatures that can aid in making this distinction. Specifically, we show that in this Cooper pair splitter configuration, nonlocal shot noise can show the signatures of Majorana stability as a function of the dot detuning. Our analysis furthers the importance of noise signatures in making the possible distinction between true and false PMMs in minimal chains.

[1] A. Tsintzidis et. al., PRX Quantum, 5, 010323 (2024).
[2] M Leuthi, H. F. Legg, D. Loss and J. Klinovaja, Phys Rev B, 111, 115419, (2025).
[3] A.Arora, S. Midha, A Zyuzin, P. Hakonen and B. Muralidharan, npj Quant. Inf., 11, 40, (2025).
[4] M. Buettiker, Phys Rev B., 46, 485, (1992).

Superconducting qubits and millikelvin electronics aimed at scalable quantum processors

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Superconducting quantum circuits provide a versatile platform for exploring quantum thermodynamics, quantum-limited measurements, and energy-efficient control at millikelvin temperatures. In this talk, I will discuss recent work in our Quantum Computing and Devices group on quantum heat engines and refrigerators based on superconducting devices, highlighting how heat and work can be controlled at the level of individual microwave photons and quantum states. I will also present progress in superconducting qubits and millikelvin electronics aimed at scalable quantum processors, including the autonomous quantum processing unit (AQPU) concept, where key control and readout functions are integrated close to the quantum device. These developments open new opportunities for reducing wiring complexity, improving signal fidelity, and studying emergent phenomena in quantum materials and devices under well-controlled nonequilibrium conditions. Together, they point toward hybrid quantum systems in which thermodynamics, coherent control, and cryogenic electronics become integral parts of next-generation superconducting quantum technologies.

Magnetic landscape of NbTiN superconducting resonators under radio-frequency excitation

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Superconducting resonators are essential components in quantum circuits and highly sensitive sensors. However, their performance is often compromised by magnetic flux penetration, as the interaction of flux quanta and the induced radio-frequency (RF) currents in the superconducting thin film leads to significant energy dissipation. At low operating temperatures, this issue is aggravated as thermomagnetic instabilities can trigger the sudden propagation of magnetic flux avalanches [1]. An important open question is whether the RF excitation itself stimulates the nucleation and propagation of magnetic flux avalanches in the superconducting thin film. The literature remains inconclusive on this point, partly due to the lack of compelling evidence for this phenomenon. We address this issue by unprecedented direct visualization of magnetic flux penetration through Faraday rotation imaging under simultaneous RF excitation. We demonstrate that the avalanche activity exhibits a weak dependence on the RF intensity. However, magnetic flux bursts clearly influence the RF transmission properties of the device. Furthermore, we can unambiguously associate a particular avalanche event with a jump in resonance frequency. This enables us to identify the loci of most deleterious events and understand the distinct origins of upward and downward frequency shifts. These observations are supported by electromagnetic simulations in which local changes of the kinetic inductance mimic flux avalanches and confirm the invasive character of the MOI technique. The insights gained aim to contribute to the broader understanding of the magnetic resilience of superconducting resonators, with the goal of improving their efficiency and stability.

[1] L. Nulens, N. Lejeune, et al. Commun. Phys. 6, 267 (2023)

Fast moving fluxons generate short-wavelength magnons

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Magnons—the quasiparticles associated with spin-wave excitations—are viewed as contenders for future wave-based computing concepts and hybrid quantum devices. However, producing magnons with wavelengths below 50 nm by conventional microwave methods becomes increasingly difficult because shrinking antennas excite them less efficiently. In our work [1], we introduce a different mechanism: magnons are launched in a ferromagnetic Co-Fe strip by magnetic flux quanta (Abrikosov vortices) moving through a neighboring Nb-C superconductor at speeds exceeding 1 km/s. The moving vortex array influences the magnetic layer through both its static and time-varying stray fields [2]. We demonstrate excitation of magnons with wavelengths below 40 nm and the unidirectionality of excitation. In addition, the generation of magnons sustains the low-resistive state of the superconductor because it extracts energy from the superconducting system [1]. The demonstrated concept may also be transferable to other types of wave excitations, such as surface acoustic waves, for integration into advanced electronic and quantum-hybrid architectures.

[1] O. Dobrovolskiy, Q. Wang, D. Vodolazov, R. Sachser, M. Huth, S. Knauer, A. I. Buzdin, Moving Abrikosov vortex lattices generate sub-40 nm magnons, Nat. Nanotechnol., 20 (2025) 1764.
[2] O. Dobrovolskiy, R. Sachser, T. Brächer, T. Böttcher, V. Kruglyak, R. Vovk, V. Shklovskij, M. Huth, B. Hillebrands, A. Chumak,
Magnon-fluxon interaction in a ferromagnet/superconductor heterostructure, Nat. Phys., 15 (2019) 477.

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High-Tc d-wave Superconductor/2D Transition-Metal Dichalcogenide Heterostructures for studies of superconducting proximity effect

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The superconducting proximity effect arises when superconducting correlations are induced in a neighbouring non-superconducting material. These effects are particularly interesting in two-dimensional (2D) materials, where they can be controlled by electrostatic doping (gating). The use of high-critical-temperature(high-Tc) superconductors further expands the technological potential of such devices. In addition, their unconventional pairing symmetry enriches the interfacial proximity physics. Gate-tunable high-temperature proximity effects have already been demonstrated in $YBa_2Cu_3O_{7-\delta}$(YBCO)/Au/graphene devices through Klein-like tunneling of superconducting pairs, highlighting the potential of 2D materials for novel superconducting devices [1,2].

However, graphene has weak intrinsic spin-orbit coupling and no band gap, which limits the range of accessible functionalities. Monolayer transition-metal dichalcogenides (TMD) MX_2 (with M = Mo, W; X = S, Se), overcome these limitations. In the monolayer limit, many TMDs become direct band gap semiconductors, and the lack of inversion symmetry produces large spin splitting in the electronic bands through strong spin-orbit coupling. These properties make TMDs a promising platform for proximity devices based on electrically tunable Andreev transport and spin-valley physics. A persistent bottleneck, however, is interface transparency, since most superconducting/2D hybrids rely on polymer-assisted transfer, which introduces wrinkles, voids, and contamination that suppress Andreev reflection. To address this, Seurre et al. [3], introduced a method to grow MoS_2 epitaxially directly on Au-capped YBCO. They observed a Josephson coupling below 4 K in the few-layer limit, whereas thicker barriers behave purely tunnel. However, YBCO-specific processing limits compatibility, integration, and in-operando doping control.

Here, we address this challenge using direct gold-mediated exfoliation4 onto pre-patterned YBCO/Au stacks. This fabrication route avoids polymer handling at the active interface and is designed to preserve interfacial cleanliness. Using this approach, we successfully transferred MoS_2, WS_2 and $NbSe_2$ flakes onto patterned Au/YBCO devices. The quality of the transferred flakes was verified by Raman spectroscopy. This method provides a practical route toward high-transparency H-Tc/2D interfaces for superconducting proximity experiments and future hybrid superconducting devices.

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[1] Perconte, D. et al. Nat Phys 14, 25–29 (2018).
[2] Perconte, D. et al, PRL 125.8: 087002 (2020).
[3] Seurre, K. et al. Appl.Phys.Lett 125, 042602 (2024).
[4] L. Nagireddy et al. 2D Mat 12.4 045017 (2025).

Composite Quantum Geometry of Bogoliubov-de Gennes Hamiltonians

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Quantum geometry quantifies the change in amplitude (quantum metric) and phase (Berry curvature) of quantum states that evolve in parameter space. The consequences of the geometry of the normal Bloch state on superconductivity, including the possibility of superconductivity in flat bands, have been widely investigated [1]. In contrast, the geometry of emergent Bogoliubov quasiparticles has received less attention [2,3,4]. We thus explore the geometry of the eigenstates of the Bogoliubov-de Gennes Hamiltonian, and its interplay with the normal state geometry. Assuming specific conditions on both the normal and superconducting state, we show that the Quantum Geometric Tensor (QGT) separates into distinct normal and quasiparticle contributions. We further derive analytical expressions for the QGT for several order-parameter symmetry classes.

[1] P. Törmä, S. Peotta and B.A. Bernevig, Superconductivity, superfluidity and quantum geometry in twisted multilayer systems Nat. Rev. Phys. 4 528 (2022).
[2] D. Porlles W. Chen, Quantum geometry of singlet superconductors, Phys. Rev. B 08, 094508 (2023).
[3] A. Daido et al., Quantum Geometry Encoded to Pair Potentials, Phys. Rev. B 110, 094505 (2024).
[4] F. Simon, Normal-State Quantum Geometry, Nonlocality, and Superconductivity, Phys. Rev. B, 112, 104504 (2025).

Superfluid stiffness in strongly disordered NbN superconducting films

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In BCS-superconductors, the spectral gap, Eg, the pairing amplitude, Δ, and the mean-field critical temperature Tco are essentially identical. At strong disorder, close to the superconductor-insulator transition (SIT), this is no longer the case. Moreover, in BCS-theory the superfluid stiffness, Js, is determined by Δ and normal state resistance RN. Also this relation typically no longer holds close to SIT. Recently, we have experimentally determined Js(T) in ultra-thin NbN films by measuring kinetic inductance and found a sharp Berezinski-Kosterlitz-Thouless (BKT) transition. Our latest experimental data cover Js(T) over a wide range of disorder strength, up to normal state resistance ~ h/e2. We find a sharp BKT-transition right up to the SIT and independently measure the characteristic scales Eg, Js, Tco and TBKT over two orders of magnitude in RN. We present complementary numerical calculations of the superfluid stiffness, obtained from the Boguliubov-de Gennes (BdG) theory of disordered samples in a very broad range of disorder strengths. A detailed comparison of our measurements with the computational results will be presented

Switchable superconducting molecular devices for information processing

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Radical molecules on superconducting surfaces represent tunable frameworks to create electronic devices with desired functionalities at the current limit of miniaturization. We used a combination of scanning tunneling microscopy/spectroscopy with theoretical treatment using the Anderson impurity model solved using the numerical renormalization group to study the the properties of various assemblies of radical organic molecule tetrabromo-tetraazapyrene (TBTAP), from single molecules and dimers to short chains and triangular setups, deposited on superconducting Pb(111) surface. Such clusters can be constructed with atomic precision using lateral manipulation and they show a high level of tunability, including singlet-doublet quantum phase transitions and switching behavior which can be used to create stable molecular memory units for classical computing at molecular scale and quantum-dot cellular automata construction. The Yu-Shiba-Rusinov states, protected by the superconducting gap, dominate the density of states and can be utilized for easy readout of the information using scanning tunneling spectroscopy.

Tunnel ferromagnetic Josephson junctions in transmon energy scale: the ferrotransmon

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We have realized submicron tunnel ferromagnetic $Al/AlO_x/Al/Ni_{80}Fe_{20}/Al$ Josephson junctions (JJs) in Manhattan-style configuration for qubit applications and based on these junctions the very first samples of ferrotransmons. The current–voltage characteristics of the junctions are comparable with those of standard JJs implemented in state-of-the-art transmons, thus confirming the high quality of the devices and marking a significant step toward the realization of the ferrotransmon. Low-frequency characterization confirms that our junctions operate in the quantum phase diffusion limit, as tunnel JJs in conventional transmons with similar characteristic energies. The very first characterization of the ferrotransmon will be also presented.

Monolayer materials as building blocks for superconducting quantum devices: An ab initio exploration

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Real-space superconducting properties are increasingly important to characterize low-dimensional, layered, and nanostructured materials. We present a novel method to extract the real-space superconducting order parameter from the superconducting gap spectrum obtained via anisotropic Migdal-Eliashberg calculations, using the Bloch wave functions of the Fermi states [1]. We apply this approach to a selection of atomically thin material systems. Our analysis of gallenene, a monolayer of gallium atoms [2], shows that its planar and buckled phases exhibit distinct superconducting order parameter behaviors, shaped by their structural and electronic properties. Furthermore, we demonstrate that our real-space approach is exceptionally suited to identify and characterize Josephson junctions made from van der Waals materials. Our examination of a bilayer of $NbSe_2$ reveals that the van der Waals gap acts as an intrinsic weak link between the superconducting $NbSe_2$ layers [1]. Therefore, a bilayer of $NbSe_2$ represents one of the thinnest and most tunable Josephson junction architectures, with potential applications in quantum devices. Our findings underscore the utility of transformation into real space in understanding superconducting properties through atomistic simulations.

In the second part of the talk, we will focus on the computational discovery and optimization of new monolayer building blocks. Specifically, we will explore phonon-mediated superconductivity in two-dimensional (2D) materials based on boron (B). Possessing a rich research history, the element B continues to captivate the scientific community with its exceptional and distinctive chemical properties, as well as its light atomic mass. As far as superconductivity goes, B is well-established as the dominant element in several notable intermetallic compounds with elevated critical temperatures (T_c), such as MgB_2. In recent years, B is also attracting increasing attention in the form of elemental B layers, occurring in a plethora of different polymorphs, jointly called borophenes [3]. Using systematic ab initio and Migdal-Eliashberg calculations, we have explored the emergence of superconductivity in a wide variety of borophene systems [3]. We will discuss how key superconducting properties can be optimized by nanoengineering – through hydrogenation, applied strain and gating [3]. We have also explored the anisotropy of the superconducting gaps, based on fully anisotropic Migdal-Eliashberg calculations, and its influence on the T_c values. The obtained sizeable T_c's, as well as multigap superconducting behavior [3], recommend borophenes as promising candidates for future boron-based superconducting technologies.

[1] J. Bekaert, M. Petrov, and M. V. Milošević, Real-space superconducting properties in the atomically thin limit: Migdal-Eliashberg approach and its application to Josephson junctions, Physical Review B 112, L241407 (2025).

[2] M. Petrov, J. Bekaert, and M. V. Milošević, Superconductivity in gallenene, 2D Materials 8, 035056 (2021).

[3] B.N. Šoškić, J. Bekaert, C. Sevik, and M. V. Milošević, Enhanced superconductivity of hydrogenated β_{12} borophene, Nano Letters 24, 12650 (2024).

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Kondo screening and coupling of spin states on graphene nanoribbon

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Exploring the spatial dependence of mediated exchange interactions is very useful to understand the mechanism of magnetic ordering and entanglement of spin states. The confined structure and low spin-decoherence channel of 7-armchair graphene nanoribbon (7-AGNR) offer a suitable platform to partially isolate the effect of substrate and visualize the competition between exchange interactions and Kondo screening. Herein, we use scanning tunneling methods to map the spatial dependence of local density of states between two unpassivated sites across the terminus of 7-AGNR. A well-pronounced pair of delocalized Kondo resonances were observed which gradually decay away from the scattering centers but still visible at any point along the line profile. This ubiquitous presence of Kondo effect indicates mediated exchange interactions that may lead to magnetic ordering or exotic coupling between spin states. Although thermal decoherence weaken the signal intensity, temperature dependence shows that the interaction effects remain detectable at relatively high temperature of 14K. As the coupling strength of the two delocalized moments could be tuned by electric field, this system offers a great potential for applications in devices employing quantum information processing.

From STO to KTO: Enhanced Spin–Orbit Coupling and Superconductivity in (111) Oxide Interfaces

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Complex oxide heterostructures provide a unique platform to engineer electronic phases emerging from the interplay of symmetry breaking, orbital reconstruction, and spin–orbit coupling. In this contribution, we discuss recent advances in two-dimensional electron systems realized at (111)-oriented oxide interfaces, focusing on both published and preliminary results obtained on $SrTiO_3$ (STO)- and $KTaO_3$ (KTO)-based heterostructures.

First, we present our recent results on $LaAlO_3/EuTiO_3/SrTiO_3$ (111) interfaces, where the coexistence of ferromagnetism and strong spin–orbit coupling leads to anomalous magnetotransport signatures consistent with Dirac-like fermions and non-trivial Berry-phase effects [1]. The observed competition between weak localization and weak anti-localization highlights the role of time-reversal symmetry breaking in shaping the quantum transport properties of the interfacial two-dimensional electron system.

We then extend the discussion to ongoing investigations of $LaAlO_3/KTaO_3$ (111) heterostructures. Similar to STO, KTO is a quantum paraelectric material that can be driven metallic upon electron doping, exhibiting high-mobility transport. Recently, superconductivity has been observed at interfaces between (111)-oriented KTO substrates and insulating overlayers, with a critical temperature T_c~2K, nearly one order of magnitude higher than in STO-based two-dimensional electron systems [2,3]. Furthermore, the presence of heavier Ta ions is expected to enhance the Rashba spin–orbit coupling by a factor of 5–10 compared to STO [4]. We will show how magnetotransport measurements can be used to probe superconducting fluctuations and their interplay with spin–orbit coupling in these systems.

Overall, these results emphasize the (111) orientation as a versatile design principle for realizing correlated and spin-polarized electronic states in oxide interfaces.

[1] Chen, Yu, et al. "Dirac-Like Fermions Anomalous Magneto-Transport in a Spin-Polarized Oxide 2D Electron System." Advanced Materials 37.1 (2025): 2410354.
[2] Liu, Changjiang, et al. "Two-dimensional superconductivity and anisotropic transport at KTaO3 (111) interfaces." Science 371.6530 (2021): 716-721.
[3] Chen, Zheng, et al. "Electric field control of superconductivity at the $LaAlO_3/KTaO_3$ (111) interface." Science 372.6543 (2021): 721-724.
[4] Vicente-Arche, Luis M., et al. "Spin–charge interconversion in $KTaO_3$ 2D electron gases." Advanced Materials 33.43 (2021): 2102102.

SQUID-on-lever for magnetic imaging with spatial resolution below 100 nm

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SQUID-on-lever (SOL) scanning probes combine high-spatial-resolution magnetic and thermal imaging with tip-sample distance control and topographic contrast of non-contact AFM [1]. Here, we discuss the performance of Nb SOLs with inner-loop sizes down to 10 nm at the apex of individual planar Si cantilevers, that are fabricated via a combination of wafer-scale optical lithography with high-resolution nano-scale focused ion beam (FIB) milling with Ne and He ions [2]. These SQUID-on-lever probes overcome many of the limitations of existing devices, achieving spatial resolution better than 100 nm, magnetic flux sensitivity of 0.3 $\mu\Phi_0/\sqrt{Hz}$, operation in magnetic fields up to about 0.5 T. The FIB nanopatterning process also allows for the incorporation of a modulation line for coupling magnetic flux into the SQUID or a third Josephson junction for shifting its phase. Its advanced functionality, high spatial resolution, and the ease of use of a cantilever-based scanning probe, extends the applicability of scanning SQUID microscopy to a wide range of magnetic, superconducting, and quantum Hall systems [3]. We demonstrate the power of the SOL approach by magnetic imaging of skyrmions at the surface of bulk Cu_2OSeO_3. Moreover, we model the spatial response of the SOL probes. For given SQUID geometry, we extract the point spread function (PSF) and introduce the PSF width as a measure of spatial resolution of scanning SQUID microscopy probes. We benchmark these results against real measurements of individual magnetic skyrmions.

[1] M. Wyss et al., Phys. Rev. Applied, 17 (2022) 034002.
[2] T. Weber et al., Phys. Rev. Applied, 24 (2025) 054041.
[3] A. Vervelaki et al., arXiv:2603.18906 [cond-mat.mrl-sci].

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Abstracts – Short talks

Strong Andreev bound state-to-photon coupling in a quantum dot based Josephson junction

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BME

Hybrid superconducting-semiconductor circuits provide versatile platforms for developing novel quantum bits, and exploring Andreev physics in more detail. In this work, we investigate one such system, a quantum dot based Josephson junction coupled to a high-impedance differential lumped-element NbTiN resonator, close to the ultra-strong regime. This strong coupling allows us to map the quantum dot parameters using only single- and two-tone spectroscopy, and to reveal singlet-doublet transitions. By measuring spectra as a function of the superconducting phase as well as the gate voltage, we find an Andreev bound state to photon coupling as strong as $g_c/2\pi$ = 475 MHz. This large coupling causes significant deviations from the conventional Jaynes-Cummings model. We show that a generalized theoretical framework, incorporating second-order coupling terms and phase-dependent interaction strength is required to accurately describe the system.

Contact-Induced weak links in Superconducting Nanowires Via the Inverse Proximity Effect

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We investigate contact-induced inverse proximity effects (IPE) in epitaxial InAs-Al full-shell nanowires. We demonstrate that normal metallic contacts locally suppress superconductivity in the aluminum shell, creating weak spots that significantly reduce the critical current of the superconducting nanowire. Transport measurements performed under microwave radiation reveal Shapiro steps, pointing towards the formation of weak links at these contact regions. We perform numerical simulations to support the experimental results. Specifically, we model the system as two Josephson junctions in series under various configurations. Our findings highlight the importance of contact engineering for the development and interpretation of hybrid superconducting quantum devices.

Towards nanoscale topographic and magnetic imaging with a wireframe SQUID on a self-sensing cantilever

Thijs Roskamp

University of Twente

Superconducting quantum interference devices (SQUIDs) are the most sensitive magnetic flux sensors and are used in scanning SQUID microscopy (SSM) to spatially resolve and map magnetism. Conventional SSM probes make use of planar silicon substrates which limit their spatial resolution to several micrometers due to an increased sample-pickup area spacing. To increase both the probes spatial resolution and magnetic sensitivity the SQUID pickup area must be brought in closer proximity to the surface. By taking inspiration from other scanning probe techniques like atomic force microscopy moving the SQUID to the apex of tip on a scanning probe can significantly reduce the scanning height and thus increase the spatial resolution.

We have combined corner lithography with wafer scale molding to create self-aligned superconducting cantilever probes with a shadow-effect deposition of Nb. Using a focused-ion beam we can create SQUIDs at the apex of these wireframes with sizes from sub-100 nm to several micrometers large. I will show our efforts in further progressing our bottom-up wafer scale fabrication approach. Where we integrate metallic strain gauges on the cantilever to provide an on-chip fully electronic readout of the cantilever deflection, allowing for topographic readout. Furthermore, I'll show our work for integrating our SQUID on cantilever approach in a conduction-cooled scanning SQUID microscope.

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Gapless Superconductivity From Extremely Dilute Magnetic Disorder in 2H-$NbSe_{2-x}S_x$

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Most superconducting materials exhibit a vanishing density of states at the Fermi level and Anderson's theorem posits that the superconducting gap is robust against nonmagnetic disorder. Although dilute magnetic impurities lead to localized in-gap states, these states typically have no bearing on the material's bulk superconducting properties. However, numerous experiments reveal a finite density of states at the Fermi level in systems with an apparently negligible number of magnetic impurities. Here, using scanning tunneling microscopy and self-consistent Bogoliubov-de Gennes calculations, we find that gapless superconductivity emerges in 2H-$NbSe_{2-x}S_x$ at remarkably low magnetic impurity concentrations. Furthermore, our density functional theory calculations and in-gap quasiparticle interference measurements demonstrate that the Se-S substitution significantly modifies the band structure. This modification favours nesting and dictates the in-gap scattering for $x > 0$, in stark contrast to the dominant charge density wave interactions in pure 2H-$NbSe_2$. Our findings reveal an unusual superconducting response to disorder and highlight the importance of incorporating material-specific band structures in the understanding of a superconductor's response to even very low concentrations of magnetic impurities.

Microwave characterization of induced superconductivity in Al/InAs heterostructures

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Hybrid superconductor–semiconductor heterostructures are promising platforms for quantum circuits, combining superconducting coherence with the electrostatic tunability of low-dimensional semiconductors. In particular, InAs-based heterostructures have attracted significant interest due to their strong spin–orbit coupling, low effective mass, and large Landé g-factor, as well as the possibility of growing high-quality epitaxial aluminum with highly transparent interfaces, yielding a hard induced superconducting gap. For quantum circuits applications, it is essential to characterize these heterostructures in the microwave regime. It is necessary to evaluate both losses in this regime and the kinetic inductance. For this purpose, in this work we designed, simulated, fabricated, and characterized at cryogenic temperatures, microwave resonators based on Al/InAs heterostructures grown by MBE, with the goal of studying their performance in terms of quality factor, nonlinearity, and temperature dependence. These results represent a crucial step toward the development of more complex quantum circuits in the future.

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Anomalous and diode Josephson effect in sffs junctions with interfacial Rashba spin-orbit coupling

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We study the emergence of the anomalous Josephson effect (AJE) and the Josephson diode effect (JDE) in planar two-dimensional Josephson junctions comprising two ferromagnetic layers with arbitrarily oriented magnetizations and with Rashba spin–orbit coupling (SOC) at the superconductor–ferromagnet interfaces. The superconducting electrodes are considered with either s-wave or d-wave pairing symmetry with arbitrary orientations of the order parameter. Within the Bogoliubov–de Gennes framework, we perform a symmetry analysis of the junction Hamiltonian to determine the conditions necessary for the occurrence of AJE and JDE. Based on these symmetry considerations, we classify the junctions into three distinct groups. The first group includes junctions with either s-wave or antisymmetricaly oriented d-wave superconductors, where AJE and JDE require noncoplanar spin-splitting fields (SOC and two ferromagnets) and asymmetric out-of-plane exchange components. The second group consists of junctions with identically oriented d-wave electrodes, in which both effects are prohibited under specific symmetry constraints, where AJE and JDE are forbidden when the polar orientations are equal and the azimuthal orientations of the magnetizations in the ferromagnets are equal or opposite. The third group comprises all remaining configurations of d-wave superconductors, where AJE and JDE can arise when at least one ferromagnetic layer has a magnetization component perpendicular to the junction plane. As a specific example, we consider a junction between $d_{(x^2-y^2)}$ and d_{xy} superconductors, which belongs to the third class. We find that for coplanar orientations of the spin-splitting fields the Josephson diode effect is absent due to additional symmetries of the junction. In this case, the current–phase relation can be expanded in a Fourier series containing $\sin(2n\phi)$ and $\cos((2n-1)\phi)$ harmonics, resulting in degenerate ground-state phase differences and coexistence of 0-like and π-like states around $\phi = \pm\pi/2$. The anomalous Josephson effect vanishes at the transition between these states, and a sign change of the anomalous Josephson current can be used as an indicator of the junction phase transition.

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Abstracts – Posters

Multigap anisotropic superconductivity in V_2Ga_5

Levente Faber

Ústav experimentálnej fyziky, Slovenská akadémia vied

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We investigate the superconducting properties of V_2Ga_5 using high-resolution ac calorimetry and spatially resolved scanning tunneling microscopy and spectroscopy (STM/STS). Calorimetric measurements on single crystals reveal a sharp second-order transition at $T_c \approx 3.5$ K with a reduced specific heat jump, while the pronounced anisotropy of the upper critical field indicates a complex superconducting state.

Key insights are obtained from STM/STS performed down to 0.4 K on surfaces with different crystallographic orientations. Topographic imaging shows a pronounced terrace-like morphology with characteristic widths of 20–40 nm and clear signatures of twinning in the ab plane. Local tunneling spectra exhibit well-defined coherence peaks and a V-shaped density of states within the superconducting gap. A strong directional dependence is observed: the gap magnitude inferred from peak positions is about 0.7 mV for tunneling parallel to the c axis and about 1 mV for tunneling perpendicular to it. The temperature evolution of the spectra shows a continuous suppression of superconducting features, with the gap closing at $T_c \approx 3.45$ K, independent of direction. Magnetic-field-dependent measurements reveal anisotropic upper critical fields, in agreement with our specific-heat data.

These experimental observations—particularly the directional variation of the gap magnitude, the V-shaped spectral features, and the presence of multiple energy scales—are consistently captured within a multiband anisotropic superconducting model developed in this work. Using a single set of parameters, the model simultaneously reproduces the temperature dependence of the electronic heat capacity, the directional STM tunneling spectra, and the anisotropic upper critical field $H_{c2}(T)$. This quantitative agreement across independent probes demonstrates that the essential features of superconductivity in V_2Ga_5 arise from the interplay of gap anisotropy and multiband coupling, providing a coherent and unified description of both its thermodynamic and spectroscopic behavior.

Gate-controlled superconducting nanocircuits: nanosecond switching dynamics and logic gate applications

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Integrated circuits with superconducting building blocks would have several benefits, such as high speed and low power consumption. In recent years, surprisingly, control of the supercurrent with voltage applied to a nearby electrode in all-metallic materials has been observed. This phenomenon can be used to fabricate gate-controlled transistors from superconducting materials, analogous to field-effect transistors. The suppression of the supercurrent was investigated in several materials, however, there is no scientific consensus on the microscopic explanation [1-3].

We studied gate-tunable supercurrents in Al superconducting shells epitaxially grown on top of InAs nanowires [4-6]. The investigated device can be switched from superconducting state to normal state by applying fast voltage pulses on the gate, which is important for standard electronic applications. We examined the switching dynamics of the investigated nanowire and analyzed the achievable switching speed. We identified two distinct switching mechanisms and achieved switching speeds on the nanosecond timescale. Our studies are promising toward realizing fast superconducting gate-tunable switches. We studied gate-tunable supercurrents in NbTiN stripes. By forming complex geometries from these stripes, we realized superconducting logic gates based on the gating effect. We demonstrated the operation of such logic gates, enabling arbitrary Boolean logic. The output voltage of our logic gates is in the volt range, enabling direct compatibility with CMOS technology without additional signal amplification or interfacing.

[1] De Simoni, Giorgio, et al. "Nature nanotechnology 13.9 (2018): 802-805.
[2] Ritter, M. F., et al. Nat Commun 12.1 (2021): 1-6.
[3] Alegria, Loren D., et al. Nature Nanotechnology 16.4 (2021): 404-408.
[4] T. Elalaily, M Berke., et al. Nano Letters 2021, 21, (22), 9684-9690
[5] T. Elalaily, M Berke., et al. Nat Commun 15, 9157 (2024)
[6] Z. Scherübl, M. Kocsis, et al. ACS Nano 2025 19 (32), 29207-29215

STM measurements on atomically resolved As-terminated surfaces of $CaKFe_4As_4$

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$CaKFe_4As_4$ is a stoichiometric iron-based superconductor with a relatively high critical temperature of approximately 35 K. Its superconductivity is commonly described as multiband, nodeless s± pairing. This combination is believed to play a key role in achieving such a high critical temperature. However, the microscopic origin of superconductivity in iron pnictides remains an open question. Scanning Tunneling Microscopy (STM) studies at millikelvin temperatures in $CaKFe_4As_4$ provide strong support to the established view of a multiband, nodeless s± pairing system, from measurements of the superconducting gap and the vortex lattice. In vortex cores, Majorana modes have been proposed to emerge [1]. However, experiments are mostly done on Ca- and K-terminated surfaces, which often do not display atomic resolution [2]. In this work we perform STM measurements at 100 mK on atomically resolved surfaces of $CaKFe_4As_4$ to investigate the atomic scale spatial modulations of the electronic structure. We identify different surface terminations and carry out quasiparticle interference (QPI) measurements on As-terminated surfaces to probe the electronic properties near the superconducting gap. These atomically resolved surfaces exhibit vacancies which strongly modify the local density of states and influence the density of states in vortex cores. Our results highlight the importance of atomic-scale defects in shaping the local density of states observed by STM.

Josephson effect in junctions through the altermagnetic material with interfacial rashba spin-orbit coupling

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We theoretically investigate a two-dimensional Josephson junction with an altermagnetic barrier (S/AM/S), incorporating Rashba-type spin–orbit coupling (SOC) at both S/AM interfaces. Using the Furusaki–Tsukada formalism, we calculate the current–phase relations (CPRs). For s-wave superconductors, the junction can host ground states with minima of the Josephson free energy at phase differences different from 0 and π (so-called 0-like and π-like states), arising from the influence of SOC on different transverse transport channels. In the case of d-wave superconducting order parameter symmetry, in addition to ϕ-states, conditions for the anomalous Josephson effect (AJE) and the Josephson diode effect (JDE) emerge due to the simultaneous breaking of time-reversal and spatial inversion symmetries. These effects appear when the orientations of the superconducting electrodes are neither symmetric nor antisymmetric, the spin-splitting field has a nonzero component perpendicular to the junction plane, and the altermagnetic ordering deviates from the d_{xy} configuration. Under these conditions, AJE and JDE can be tuned by varying the orientation of the superconducting electrodes, the altermagnetic lattice, as well as the direction and magnitude of the spin-splitting field. In particular, for a $d_{(x^2-y^2)}$/AM/d_{xy} junction, additional constraints must be satisfied for the emergence of AJE and JDE. When the altermagnet is oriented along d_{xy}, both effects are absent; the Fourier spectrum of the CPR contains only $\sin(2n\phi)$ harmonics, exhibiting π-periodicity, with possible ground states at $\phi = \pi/2$ or coexistence of 0 and π states. For $d_{(x^2-y^2)}$ orientation of the altermagnet, AJE appears while JDE remains absent; in this case, the CPR contains $\sin(2n\phi)$ and $\cos((2n-1)\phi)$ harmonics and satisfies the relation $I(\phi) = I(-\phi + \pi)$. For other altermagnetic orientations, both AJE and JDE arise, accompanied by the presence of all harmonics in the CPR.

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Towards investigating Andreev molecule in InAs nanowire

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Topologically protected qubits based on one-dimensional Kitaev chains offer a promising route to overcome decoherence in quantum computation. A key building block of such chains is the Andreev molecule, in which two closely spaced quantum dots hybridize their Andreev bound states via a superconducting link.

In this work, we realize and characterize an Andreev molecule on an InAs nanowire platform using both DC transport and high-frequency reflectometry. Two quantum dots are defined along the wire using side gates, with one dot embedded in a superconducting loop to form an RF-SQUID geometry.

Our primary goal is to demonstrate hybridization by tuning the phase difference across the embedded dot while measuring the resulting Andreev spectrum in the adjacent dot. We aim to observe a periodic modulation of the junction's switching current as flux is varied—an unmistakable signature of Andreev molecule formation. Finally, we investigate how gating the embedded dot alters the Andreev spectrum, offering insights into nonlocal quantum processes in superconductor–semiconductor heterostructures.

Higher-order topology in $Bi_{0.97}Sb_{0.03}$ with coexisting topological hinge and Rashba states

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Edge transport in quantum materials, when arising from symmetry-protected topological channels, provides robust and dissipationless conduction that directly reflects the nontrivial topology of the bulk. Building on this concept, higher-order topological edge states in 3D materials, protected by crystalline symmetries, form hinge-localized 1D channels, where induced superconductivity can enable potential applications in topological quantum computing. We have performed comprehensive study of Josephson supercurrent in Nb-BiSb(3%)-Nb junctions fabricated on flakes of varying thicknesses, widths and junction lengths. The critical supercurrent modulates with magnetic field in a SQUID-like pattern, which upon radio-frequency excitation shows missing odd Shapiro steps. Interestingly, we found a strong correlation between fractional Shapiro steps, indicative of a 4π-periodic supercurrent, and the presence of long-ballistic hinge-localized modes. Tight-binding calculations further support our experimental observations by revealing the coexistence of higher-order topological and 1D Rashba states, while also indicating multiple hinge channels arising from structural irregularities that contribute to the total edge supercurrent. Additionally, an anomalous current-phase relation in asymmetric SQUID devices provides an independent probe of this coexistence.

Unconventional Josephson Effect in Superconductor-Quantum Spin Liquid Junctions

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Superconductor-magnet heterostructures represent a cornerstone of quantum technologies, providing platforms for superconducting diodes and topological qubits. In particular, the anomalous current-phase relations in Josephson junctions can be induced by the interplay of spin-orbit coupling and time-reversal symmetry breaking, and have been shown to be tunable via variable external parameters through both theoretical and experimental studies. Such effects have been widely studied, particularly in superconductor/ferromagnet/superconductor (S/F/S) and superconductor/topological insulator/superconductor (S/TI/S) systems. However, hybrid structures combining superconductivity with quantum magnetism remain a substantially unexplored territory. Here we demonstrate the emergence of unconventional Josephson effect in superconductor/quantum spin liquid tunnel junctions. The system consists of two conventional s-wave superconductors coupled through narrow quantum spin liquid insulator. In this geometry, interface-induced solitonic in-gap modes emerge at each superconductor-spin-liquid boundary[1], mediating the supercurrent contribution. We show that a 4π-periodic Josephson effect can emerge even in the absence of explicit symmetry breaking. This anomalous phase response is enabled by the quantum magnetic ground state of the tunnel barrier, originating from many-body excitations associated with spin fractionalization in the quantum spin liquid. Importantly, this effect does not rely on topological superconductivity or on time-reversal symmetry breaking, thereby clearly distinguish it from previously proposed mechanisms.

Our result establish quantum spin liquids as active mediators of unconventional Josephson physics and demonstrate that many-body modes can induce fractional Josephson effects in otherwise topologically trivial superconducting heterostructures. Our work puts forward a new strategy to engineer anomalous Josephson responses in low-dimensional systems using many-body quantum spin systems, without relying on conventional topological band-structure requirements. It further demonstrates the potential of quantum spin liquids as functional building blocks for future superconducting spintronic devices and quantum-information technologies.

[1] J. L. Lado and M. Sigrist, Phys. Rev. Research, 2 (2020) 023347.