SuperQUMAP

21-25th April 2024

#SuperQumap

European School on Superconductivity and Magnetism in Quantum Materials.

www. superqumap.eu

#ESSM24

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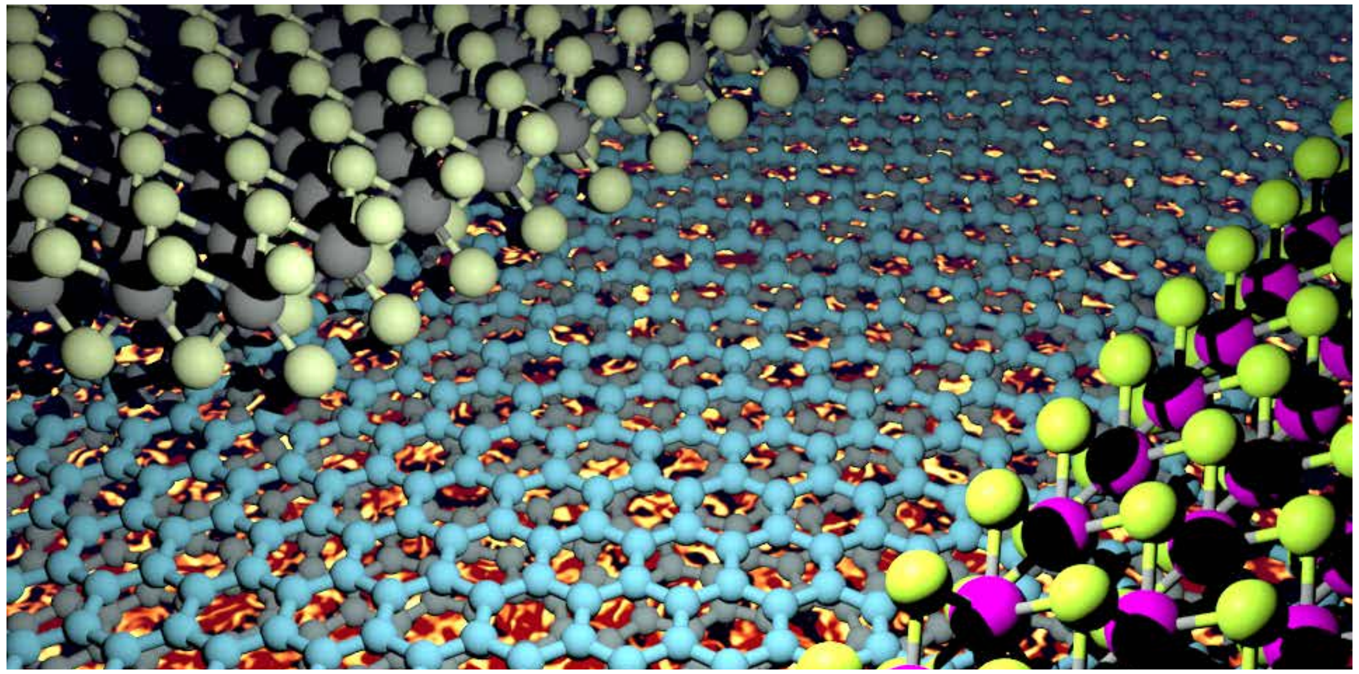
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union



The School

Superconducting and magnetic quantum materials are emerging as crucial building blocks for quantum devices covering nowadays a broad range of applications. The 1st European School on Superconductivity and Magnetism in Quantum Materials aims at providing a suitable framework based on comprehensive series of foundational lectures while also delving into the latest developments of the fields of superconductivity and magnetism. The School will illustrate and discuss the cutting-edge advancements within these interdisciplinary fields, as well as the synergies offered by the combination of both of them in novel structures and devices.

The program is intended to engage an audience of young scientists, mainly PhD students and post-docs, both experimentalists and theoreticians. This four-day event will feature lectures and hands-on sessions conducted by leading scientists in these areas and will provide a forum for communication between young researchers and trainers. The meeting will take place entirely in person, in a confined and relaxed atmosphere, that optimizes discussions and networking opportunities among all attendees. Additionally, this meeting serves an important purpose to promote and disseminate the activities of the COST Action SUPERQUMAP.

This School is based upon work from COST Action SuperQumap, supported by COST (European Cooperation in Science and Technology).

COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. Our Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

Topics include

- Fundamentals of superconductivity and magnetism
- Advanced modelling: theory and computation
- Materials design and crystal growth.
- Spintronics and magnonics.
- Emergent physics in superconductors.
- Unconventional and topological superconductivity.
- Light-matter control of quantum materials.
- Scanning tunnelling microscopy (STM) and atomic force microscopy (AFM).
- Interplay between magnetism and superconductivity in quantum materials.

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University of València (Spain)

José Lado (co-chair)
University of Aalto (Finland)

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Venue

Hotel RH Bayren & Spa ****

Paseo de Neptuno, nº 62 46730 Playa de Gandía, Valencia

46730 Playa de Gandia, Valencia (Spain)

HOW TO ARRIVE Hotel RH BAYREN ****

The Hotel in Gandía RH Bayren & Spa is located in front of the beach in Gandía. The hotel has beautiful views as it is right on the beachfront of Gandía. It is also surrounded by many points of interest such as the Gandia Yacht Club, and the shopping and leisure area of the beach.

SuperQUMAP

Program

	Sunday 21st	Monday 22nd	Tuesday 23rd	Wednesday 24th	Thursday 25th
8:45-9:00		*Opening*			
9:00-9:30		J. Sinova	M. Milosevic	E. Coronado	A. Levy Yeyati
9:30-10:00				Y. Maximenko	
10:00-10:30				Oral Communications	
10:30-11:00					
11:00-11:30		*Coffee break*	*Coffee break*	*Coffee break*	*Coffee break*
11:30-12:00		M. Guimarães	D. Koelle	P. Liljeroth	Oral Communications
12:00-12:30					
12:30-13:00					
13:00-13:30					
13:30-14:00		*LUNCH*	*LUNCH*	*LUNCH*	*LUNCH*
14:00-14:30					
14:30-15:00					
15:00-15:30		I. Timrov	E. Hassinger	Discussions & Networking	Departure
15:30-16:00	*Arrival and Registration*				
16:00-16:30					
16:30-17:00					
17:00-17:30		*Coffee break*	*Coffee break*		
17:30-18:00		A. Black-Schaffer	A./ Ramires		
18:00-18:30					
18:30-19:00					
19:00-19:30					
19:30-20:00					
20:00-20-30	*DINNER*	*DINNER*	*DINNER*		
20:30-21:00					
21:00-21:30				*DINNER*	
21:30-22:00		*Poster Session I*	*Poster Session II*		
22:00-22:30					
22:30-23:00					

	SUNDAY 21st	
15h00	Arrival and Registration	
20h00	*Dinner*	

	MONDAY 22nd	
08h45	**José J. BALDOVÍ- ICMol, University of Valencia Hermann SUDEROW- University Autónoma de Madrid**	***Opening of the 1st European School on Superconductivity and Magnetism in Quantum Materials***
09h00	**Jairo SINOVA- Johannes Gutenberg Uni. Mainz (DE)**	***Introduction to altermagnetism and spin symmetries***
11h00	*Coffee break*	
11h30	**Marcos H.D. GUIMARÃES- University of Groningen (NL)**	***Introduction to 2D magnetic materials and manipulation of their magnetization***
13h30	*Lunch*	
15h00	**Iurii TIMROV- Paul Scherrer Institut (CH)**	***Modeling magnetic materials using advanced DFT functionals: Hubbard, hybrids, and meta-GGA***
17h00	*Coffee break*	
17h30	**Annica BLACK-SCHAFFER- Uppsala University (SE)**	***Fundamentals of topological superconductivity***
20h00	*Dinner*	
21h30	**Poster Session I**	

	TUESDAY 23rd	
09h00	**Milorad MILOSEVIC- University of Antwerpen (BE)**	***Ginzburg-Landau theory of superconductivity: from basics to applications***
11h00	*Coffee break*	
11h30	**Dieter KOELLE- University of Tübingen (DE)**	***Josephson junctions and superconducting quantum interference devices (SQUIDs)***
13h30	*Lunch*	
15h00	**Elena HASSINGER- TU Dresden Technical University (DE)**	***Thermodynamic and transport experiments on the ground state of strongly correlated electron systems***
17h00	*Coffee break*	
17h30	**Aline RAMIRES- Paul Scherrer Institut (CH)**	***Standard classification of superconducting order parameters from the point group perspective***
20h00	*Dinner*	
21h30	**Poster Session II**	

	WEDNESDAY 24th	
09h00	**Eugenio CORONADO- ICMol, University of Valencia (ES)**	***2D Magnetic heterostructures: from twisted magnets to smart molecular/2D heterostructures***
09h30	**Yulia MAXIMENKO- Colorado State University (US)**	***Quantifying unconventional magnetism in devices using scanning tunneling microscopy***
10h00 (12'+3')	Núria ALCALDE-HERRAIZ- Chalmers University of Technology (SE)	***Engineering underdoped CuO_2 nanoribbons in nn-thick a-axis $YBa_2Cu_3O_{7-\delta}$ films***
	Jazmín ARAGÓN SÁNCHEZ- Università degli Studi di Roma Tor Vergata (IT)	***Structural and electronic characterization of atomic defects in $FeSe_{1-x}S_x$ superconductor: STM and DFT study***
	Javier CORRAL-SERTAL- CiQUS, University of Santiago de Compostela (ES)	***Temperature and Thickness Dependence of the Thermal Conductivity in 2D Ferromagnet Fe_3GeTe_2***
	Yelko DEL CASTILLO- Int. Iberian Laboratory (PT)	***Probing spin fractionalization with absolute magnetometry ESR-STM***
11h00	*Coffee break*	
11h30	**Peter LILJEROTH- Aalto University (FI)**	***Visualizing designer quantum states in van der Waals heterostructures***
13h30	*Lunch*	
15h00	**Discussions and networking**	
21h00	*Dinner*	

	THURSDAY 25th	
09h00	**Alfredo LEVY YEYATI- University Autónoma de Madrid (ES)**	***Mesoscopic superconductivity: From Andreev transport to Andreev qubits***
11h00	*Coffee break*	
11h30 (12'+3')	Alessia GARIBALDI- Chalmers University of Technology (SE)	***Ex-situ techniques for grain boundary-based Josephson junction optimization***
	Konrad NOROWSKI- Polish Academy of Sciences (PL)	***Quantum thermodynamics with a single superconducting vortex***
	Meike PFEIFFER- Dresden University of Technology (DE)	***Resistivity and heat capacity studies under hydrostatic pressure in the locally non-centrosymmetric superconductor $CeRh_2As_2$***
	Varun RAJEEV PAVIZHAKUMARI- Technical University of Denmark (DK)	***Evaluating the critical temperatures for ferromagnetic order in solids: beyond the random phase approximation***
	Johanne Bratland TJERNSHAUGEN- Norwegian University of Science and Technology (NO)	***Superconducting phase diagram and spin diode effect via spin accumulation***
	Beatriz VINA-BAUSA- University Autónoma of Madrid (ES)	***Controlling magnetic interactions between S=1/2 spins at unusually large distances***
	Diego LÓPEZ-ALCALÁ- ICMol, University of Valencia (ES)	***Exploring magnetic insulator proximity effect in 2D biphenylene network from first-principles calculations***
13h30	*Lunch*	
15h00	Departure	

Lecturers of the School

Marcos Guimaraes
University of Groningen, Netherlands

Jairo Sinova
Johannes Gutenberg Universität Mainz, Germany

Milorad Milosevic
University of Antwerpen, Belgium

Annica Black-Schaffer
Uppsala University, Sweden

Aline Ramires
Paul Scherrer Institut, Switzerland

Dieter Koelle
University of Tübingen, Germany

Elena Hassinger
TU Dresden Technical University, Germany

Alfredo Levy-Yeyati
Universidad Autónoma de Madrid, Spain

Iurii Timrov
Paul Scherrer Institut, Switzerland

Peter Liljeroth
Aalto University, Finland

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.

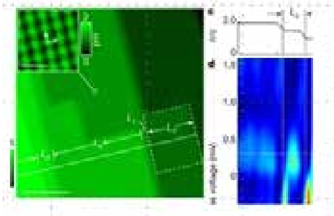
The work is organized in three work packages, which aid to shape the meetings and networking activities in which researchers mutually benefit from complementary knowledge to advance in the objectives of the Action.

• Work package 1: Quantum materials

o Obtain topological and triplet superconductivity by tuning correlations and the properties at interfaces.

o Understand the relationship between electronic correlations, magnetism and unconventional superconducting properties.

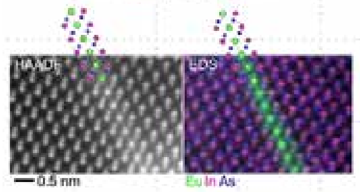
of a heavy-fermion superconductor, Nature (2023), https://doi.org/10.1038/s41586-023-05830-1



• Work package 2: New functionalities for sensors and devices
o Control the degree of disorder in low dimensional and low carrier density superconductors.

o Achieve a better understanding of electronic behavior between the extreme limits of infinity and zero resistance.
o 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

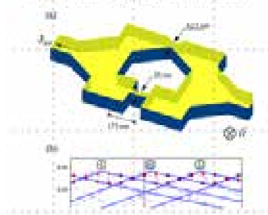


• Work package 3: Building Quantum Systems.

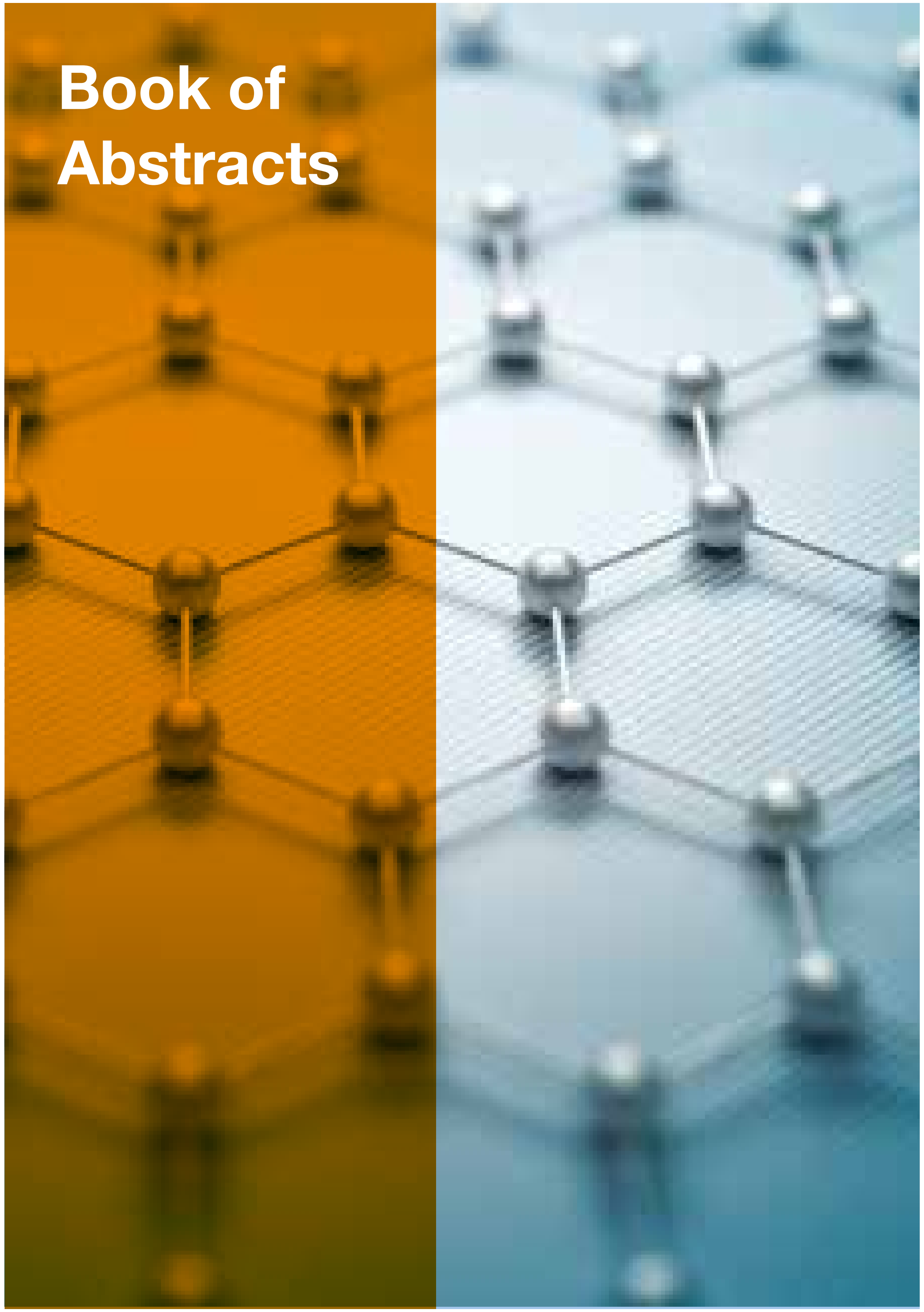
o Create and characterize novel two-level systems in superconducting junctions and devices suitable for quantum computation.

o 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.



LECTURE 1

Sinova is an Alexander von Humboldt Professor of Physics at Johannes Gutenberg Universität Mainz and director of the Spin Phenomenal Interdisciplinary Center (SPICE). He has received the Alexander von Humboldt Professorship Award, the Johannes Gutenberg Research Fellowship, the ERC Advance Synergy Grant, National Science Foundation's Career Award, the Cottrell Scholar Award, and is a Fellow of the American Physical Society.

INTRODUCTION TO ALTERMAGNETISM AND SPIN SYMMETRIES

Abstract:
Prior to the discovery of altermagentism, we believed that our understanding of conventional ferromagnets and antiferromagnets, at least in their collinear forms, was fairly complete from both a microscopic and symmetry perspective. It forces us to rewrite the introductory chapters of magnetism textbooks and has instantly ignited a new field of unconventional magnetism beyond the s-wave paradigm of ferromagnets and the dipolar description of the conventional order. Inspired by anomalous spin transport in a peculiar compensated collinear magnet with d-wave symmetry of its spin-polarized band structure, we have developed the full delimitation and classification of collinear magnetic systems. From this, altermagnetism has emerged as a distinct and symmetry delimited new magnetic phase. Altermagnets exhibit an unconventional spin-polarized d/g/i-wave band structure in reciprocal space, originating from the local sublattice anisotropies in direct space. This gives properties unique to altermagnets (e.g., the spin-splitter effect), while also having ferromagnetic (e.g., polarized currents) and antiferromagnetic (e.g., THz spin dynamics and zero net magnetization) characteristics useful for spintronics device functionalities. I will cover the basic introductory view to altermagnetism and spin-symmetries, and its consequences to spintronics as well as its consequences in the possibility of p-wave magnetism.

LECTURE 2

Dr. Timrov is a tenure-track scientist at the Laboratory for Materials Simulations at PSI. He received his PhD in 2013 in France at the Ecole Polytechnique working on first-principles DFT developments and simulations. Then he went for a postdoc in Italy at SISSA to work on computational spectroscopies and then a second postdoc in Switzerland at EPFL to work on DFT+U. He is one of the core developers of the Quantum ESPRESSO package.

MODELING MAGNETIC MATERIALS USING ADVANCED DFT FUNCTIONALS: HUBBARD, HYBRIDS, AND META-GGA

Abstract:
This lecture explores the application of density-functional theory (DFT) in modeling magnetic materials. Transition-metal and rare-earth elements, prevalent in many magnetic materials, present challenges for standard DFT functionals like local-density approximation (LDA) and generalized-gradient approximation (GGA) due to large self-interaction errors in partially filled and localized d and f electrons. To address these challenges, advanced functionals have been developed. We will discuss three popular approaches: DFT+Hubbard (DFT+U and DFT+U+V, employing on-site U and inter-site V Hubbard parameters), hybrid functionals (e.g., HSE), and meta-GGA (e.g., SCAN). While focusing primarily on DFT+Hubbard, we will also explore hybrids and meta-GGA, widely adopted in the field. The lecture covers theoretical concepts, including the computation of Hubbard parameters, and extensively examines practical applications across various magnetic materials. Topics include electronic structure, phonons, electron-phonon coupling, magnetic spectroscopies (magnons), applications to Li-ion batteries, and much more. The lecture aims to provide students with an introductory understanding of these methods, igniting curiosity for further exploration.

LECTURE 3

Marcos H. D. Guimarães is an Associate Professor at the Zernike Institute for Advanced Materials of the University of Groningen. He received his PhD from the University of Groningen in 2015 and several awards during his career, such as an ERC Starting Grant (2022), NWO Rubicon (2014) and Veni (2017), and a Kavli Postdoctoral Fellowship (2014).

INTRODUCTION TO 2D MAGNETIC MATERIALS AND MANIPULATION OF THEIR MAGNETIZATION

Abstract:
Magnetism and magnetic materials are present in many modern devices we use everyday, from your laptop and mobile phone, to your car and your fridge. With the ever increasing need of smaller, faster, and more energy-efficient devices, there is a strong drive in finding new materials and device architectures to miniaturize magnetic devices. In this lecture I will introduce the field of van der Waals magnetic materials, and show why these materials provide the ideal platform to study and manipulate magnetization in the atomically-thin limit. I will give a brief introduction to the field of two-dimensional magnetic materials and discuss different methods to manipulate their magnetization which are promising for nanodevice applications. Finally, I will also show how the tiny magnetic moments of these materials can be measured by electrical, optical and magnetometry techniques.

LECTURE 4

Annica Black-Schaffer is a professor and head of quantum matter theory at Uppsala University. She received her Ph.D. from Stanford University in 2009. She is the recipient of two consecutive ERC grants (StG 2017 and CoG 2022), Wallenberg Academy Fellow (2014), Wallenberg Scholar (2024), the Göran Gustafsson prize for young researchers, the L'Oréal-UNESCO For Women In Science Prize Sweden, and the Rudbeck Medal.

FUNDAMENTALS OF TOPOLOGICAL SUPERCONDUCTIVITY

Abstract:
Topological states of matter have emerged as one of the most vibrant areas of condensed matter physics, with their defining property being a global non-trivial topology of their electronic structure. This is fundamentally different from the Landau paradigm traditionally used to classify matter, where local order parameters appearing due to spontaneous symmetry breaking instead play the key role. Topological superconductors are particularly interesting as they automatically join these two fundamentally different views of matter, having both a global topological order and a local superconducting order parameter. Combining this with the distinctive particle-hole mixing in superconductors gives rise to emergent Majorana fermion states, which can be viewed as half electron quasiparticles offering unique possibilities to realize robust quantum computation. The lecture will cover the basic theory of topological superconductivity. Starting from an elementary understanding of conventional BCS superconductivity and topology, I will discuss several different topological superconducting phases, as well as focus on where and why Majorana fermions appear as topological protected edge states.

POSTER SESSION I

by alphabetical order

ID	SURNAME, Name
22_P01	ÁLVAREZ, Covadonga
22_P02	ANDRINO-GÓMEZ, Alberto
22_P03	ANTÃO, Tiago V.C.
22_P04	BABA, Yuriko
22_P05	BAÙ, Nicolas
22_P06	BESPROSWANNY, Julia
22_P07	BOU MARQUÉS, Óscar
22_P08	CARRASCO, Roberto
22_P09	COLANGELO, Francesco
22_P10	COURTOIS, Théo
22_P11	ESCORZA, Jonathan
22_P12	FERRI-CORTÉS, Mar
22_P13	FRIDMAN, Nofar
22_P14	GÖKSAL, Cemal Ilkin
22_P15	JETTER, Daniel
22_P16	KAYATZ, Florian
22_P17	TANWAR, Khaghesh

INTERCALATION OF VAN DER WAALS MATERIALS WITH PHOTOCHROMIC MOLECULES

C. Álvarez[1*], D. Tezze[1], J.M. Pereira[1], M. Gobbi[2,3] and L. E. Hueso[1,2]

[1] CIC nanoGUNE BRTA; 20018 San Sebastián, Spain.
[2] IKERBASKE, Basque Foundation for Science, 48013 Bilbao, Spain.
[3] Materials Physics Center CSIC-UPV/EHU, 20018 Donostia-San Sebastián, Spain.

**Presenting author: Covadonga Álvarez: c.alvarez@nanogune.eu*

Intercalation of guest species in vdW materials is an effective processing technique for customizing their properties. [1-2] Compared to metal ions, often used as guest species [3], organic molecules provide an impressive versatility with multiple options to vary their size, charge, dipolar moment, magnetic spin and optical properties [4]. Moreover, functional molecules can be intercalated to provide unique capabilities to layered materials. For instance, photochromic molecules can be switched between two metastable isomers with different sizes through light irradiation. They can be used to modify the interlayer distance through light irradiation, causing consequent light-controllable modifications in the materials properties.

In this work, we explore the intercalation of a photochromic spiropyran derivative in magnetic FeOCl and superconducting TaS2. Spiropyrans are characterized by a reversible change between a colorless closed form and a colored open form called merocyanine [5]. Preliminary data indicates that different interlayer distances can be obtained by intercalating one isomer or the other, as obtained by irradiating with UV or visible light during the intercalation process. These data indicate the potential of the intercalation of photochromic molecules to tune the physical properties of layered compounds through light irradiation.

[1] J. Zhou, et al. Adv. Mat. 33 (2021) 2004557
[2] M. Rajapakse, et al. npj 2D Mat. Appl. 5 (2021) 30
[3] Y. Koike, et al. Solid State Commun. 27 (1978) 623-627
[4] J.M. Pereira, D. Tezze, et al. Adv. Phys. Res. 2 (2023) 2200084
[5] S. Bèrnard, et al. Chem. Matter. 13 (2001) 3709-3716

PREPARATION AND STUDY OF POTENTIAL AMORPHOUS TOPOLOGICAL SUPERCONDUCTORS OF Bi-Sb

A. Andrino-Gómez[1,2,3*], M. Moratalla[2,3]. A. Redondo-Cubero[1,3], N. Gordillo[1,3] and M. A. Ramos[2,3]

[1]Laboratorio de Microelectrónica, Dpto. Física Aplicada, Facultad de Ciencias, Universidad Autónoma de Madrid, Campus de Cantoblanco, E-28049 Madrid, Spain
[2]Laboratorio de Bajas Temperaturas, Dpto. Física de la Materia Condensada, Facultad de Ciencias, Universidad Autónoma de Madrid, Campus de Cantoblanco, E-28049 Madrid, Spain
[3]Centro de Micro-Análisis de Materiales (CMAM) and Instituto Nicolás Cabrera (INC), Universidad Autónoma de Madrid, Campus de Cantoblanco, E-28049 Madrid, Spain

**Presenting author: alberto.andrinog@uam.es*

Exotic properties of topological superconductivity are expected to pave the way towards quantum computing [1,2]. However, a stable topological superconductor has not yet been found experimentally. Good candidates have been proposed to be bismuth and its alloys (particularly, bismuth-antimony, Bi-Sb), which are among the most studied topological insulators [3,4] and which, in amorphous state, become superconductors below a critical temperature close to 6 K [5].

The aim of this work is to grow $Bi_{100-x}Sb_x$ alloys and induce, by ion beam irradiation, enough damage to their internal structure as to amorphize the material. Although amorphous Bi-Sb tends to recrystallize unless at low temperatures [5,6], our idea to overcome such difficulty is trying to amorphize only a region of the material a few μm deep from the surface. To do so, we use ions in the MeV range, exploiting the capabilities of CMAM's 5 MV ion-beam accelerator [7]. By characterizing the morphological, structural and electrical properties of the resulting material, we analyze its potential as an amorphous topological superconductor [8].

[1] C. Beenakker and L. Kouwenhoven, Nat. Phys., 12 (2016) 618-621.
[2] R. Aguado and L. Kouwenhoven, Phys. Today, 73 (2020) 44-50.
[3] D. Hsieh et al., Nature, 452 (2008) 970–974.
[4] A. Nishide et al., Phys. Rev. B, 81 (2010) 041309(R).
[5] J. S. Shier and D. M. Ginsberg, Phys. Rev., 147 (1966) 384.
[6] J. Barzola-Quiquia et al., Supercond. Sci. Tech., 30 (2017) 015013.
[7] A. Redondo-Cubero et al., Eur. Phys. J. Plus, 136 (2021) 175.
[8] A. Andrino-Gómez et al., Low Temp. Phys., accepted (2024).

DESIGNING FRUSTRATED MOIRÉ ORDER WITH TWISTED VAN DER WAALS MULTIFERROICS

Tiago V.C. Antão[1*], Adolfo O. Fumega[1], Jose L. Lado[1]

[1]*Department of Applied Physics, Aalto University, 02150 Espoo, Finland*

**Presenting author: tiago.antao@aalto.fi*

The design of artificial materials with van der Waals heterostructures has dramatically influenced the landscape of quantum materials. One possibility that has opened new avenues is the control of the relative twist of stacked monolayer materials. This has led to the field of moiré physics. A paradigmatic example of moiré phenomena is that of twisted bilayer graphene, where a specific twist angle has been shown to result in superconductivity and a variety of correlated states. Engineering twisted structures is not restricted to graphene, as for many materials, the possibility of controlling the twist angle in moiré structures is a valuable degree of freedom, useful for tuning different types of correlated quantum phenomena. For instance, twisted magnetic structures have been shown to host artificial multiferroic order [1]. Another recently isolated novel class of monolayer materials, exemplified by NiI2 [2], showcases this same kind of multiferroic order, characterized by coexisting electric and magnetic order. The emergence of magnetic frustration, as well as non-collinear textures in the spin ground state of this class of materials, enables the possibility of the coexistence and coupling of the two different orders.

Here we show how the frustrated magnetism inherent in non-collinear spin-spiral ground states via twisting enables the emergence of a moiré multiferroic texture. Specifically, we consider a twisted van der Waals multiferroic bilayer and use a combination of ab-initio methods and spin Hamiltonian models to determine how the ground state spin configuration is affected by the twist angle, as well as the strength of the coupling between the two layers. These mechanisms, together with the inherent strong magnetoelectric coupling of multiferroic van der Waals materials provides a strategy to control frustrated magnetic order at the moiré length scale [3]. Ultimately, our strategy establishes a material where moiré multiferroic order can be controlled by electric fields which can couple to the material's electric polarization and spin degrees of freedom.

[1] A. O. Fumega, J. L. Lado 2023, 2D Mater., 10 (2023) 025026.
[2] Q. Song, C.A. Occhialini, E. Ergeçen et al., Nature 602 (2022) 601-605
[3] T. V. C. Antão, A. O. Fumega, J. L. Lado to appear in 2024

TRIPLET PAIRING ON CHIRAL ANDREEV EDGE STATES ON THE QUANTUM HALL REGIME

Y. Baba[1*], R. Sanchez[1], A. Levy Yeyati[1], and P. Burset[1]

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A two-dimensional electron gas (2DEG) in the presence of a strong magnetic field exhibits the quantum Hall (QH) effect, supporting chiral 1D conducting states at the edges. The proximity to a superconductor (SC) leads to the formation of chiral Andreev edge states (CAES), see Figure 1: hybridized electron-hole states with promising potential applications in quantum metrology and topologically protected quantum computing. Although the strong magnetic fields required for the QH effect are detrimental for superconductivity, recent experiments have achieved QH-SC hybrid junctions based on InAs 2DEGs [1] and graphene [2]. Using conventional superconductors where Cooper pairs are formed by electrons with opposite spins, experimental evidence for emerging CAES has been found even at the lowest QH edge states where spins are polarized from ultra-strong Zeeman coupling.

In this work we theoretically study the formation of CAES in QH-SC hybrid junctions on a 2DEG. We investigate the emergence of spin-polarized triplet Cooper pairs by considering the effect of the Rashba spin-orbit coupling [3], which may be important in the case of 2DEG devices [Figure 1(c)]. Furthermore, we also consider the impact of the geometry on the edge states propagating along the interface between the 2DEG and the SC [4]. Using numerical simulations in Kwant [5], we identify the optimal conditions for the creation of triplet Cooper pairs and their signatures on non-local electron transport.

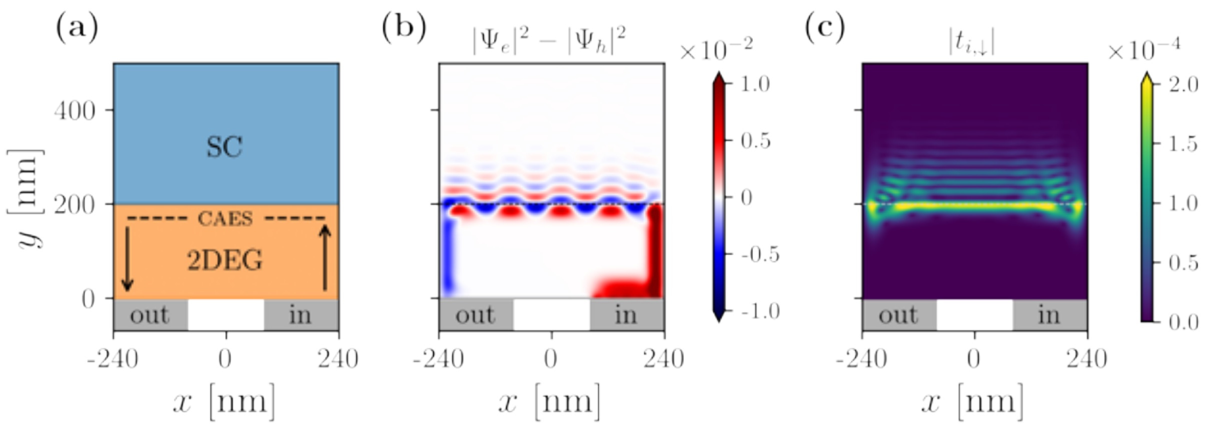

Figure 1. (a) Sketch of the QH-SC junction showing the chiral channels (black arrows) and the CAES (dotted line) forming near the SC interface. (b) Electron and hole probabilities of the scattering wavefunction in a two-lead device in the QH regime with filling factor ν=2. (c) Spin-polarized triplet paring for the same setup.

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THEORY OF LOCAL Z2 TOPOLOGICAL MARKERS FOR FINITE AND PERIODIC SYSTEMS

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Topological invariants are global properties of the ground-state wave function, typically defined as winding numbers in reciprocal space. Over the years, a number of topological markers have been introduced, allowing to probe the topological order locally in real space even for disordered and inhomogeneous systems [1]. In this talk, I will address time-reversal symmetric systems in two dimensions and introduce two local Z2 topological markers [6]. The first formulation is based on a generalization of the spin-Chern number [2] while the second one is based solely on time-reversal symmetry [7]. Then, I will introduce a formulation of the local Chern marker for extended systems with periodic boundary conditions [3], and I extend it to the aforementioned Z2 markers [6]. Finally, I will show numerical simulations to validate the approach, including pristine disordered and inhomogeneous systems, such as topological/trivial heterojunctions.

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STM STUDIES ON THE WEYL-SEMIMETAL AND SUPERCONDUCTOR TRIGONAL $PtBi_2$

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We report a comprehensive study of the type-I Weyl-semimetal $PtBi_2$, exploring its topological and superconducting properties through low-temperature scanning tunneling microscopy and spectroscopy.
Quasi-particle-interference measurements confirm the topological nature through the presence of Fermi-arcs. Spectroscopic investigations reveal sample dependent electronic structure near the Fermi-level, ranging from metallic characteristics to the presence of particle-hole symmetric energy gaps implying superconductivity. Most notably, the largest observed energy gap suggests a critical temperature T_c in the range of 120 K, two orders of magnitude above the previously reported T_c measured via bulk-sensitive methods. The data also provide indications that the superconductivity possibly arises out of topological surface states. This would make trigonal $PtBi_2$ a potential candidate for an intrinsic topological superconductor with a T_c above liquid nitrogen temperatures, highlighting it as a promising material for technological applications in quantum computing.

VORTEX LATTICE PINNING AT 20 K IN THE STOICHIOMETRIC PNICTIDE SUPERCONDUCTOR $CaKFe_4As_4$

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Superconductors bring macroscopic quantum coherence into concrete applications, such as levitating trains, superconducting quantum interferometric devices, quantum computers or magnetic resonance imaging. The advent of large-scale liquid hydrogen temperatures (20 K) faces superconductivity with a new frontier. 20 K is a temperature low enough to use robust and malleable metallic superconductors as $CaKFe_4As_4$ (Tc=35 K) [1]. The upper critical field of this superconductor is close to 100 T, for which it is very promising for applications. It is however important to understand the behavior of the vortex lattice in this temperature range. The vortices are arranged in an ordered vortex lattice, but when a current is applied to the superconductor, the vortices begin to move due to the effect of the Lorentz force and the property of dissipation-free current is lost [2]. Vortices are pinned by impurities and imperfections. The collective pinning of vortices depends on the elasticity of the vortex lattice. Macroscopic measurements suggest that the lattice is soft at 20 K, which allows to establish improved pinning properties. Here, we critically analyze this by imaging the vortex lattice as a function of temperature and magnetic field. We establish the phase diagram, including the optimal pinning range and observe directly the transition to the vortex liquid.

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NANOSCALE MANIPULATION OF PB NANO-ISLANDS ON GRAPHENE FOR PRECISE CONTROL OF LOCALIZED SUPERCONDUCTIVITY

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In recent years, there has been significant interest in introducing and controlling superconductivity in graphene, a non-superconducting 2D material. This is due to graphene's unique electronic properties and the ability to tune its carrier density through electrostatic gating. However, selectively introducing superconducting properties to graphene has been experimentally challenging. To achieve that, we evaporated Pb nano-islands of ~100 nm of size on top of an epitaxially grown graphene sample. Due to the proximity effect, such Pb nano-islands, which are superconducting below 7.2K, induce superconductivity locally, in the graphene regions around them. To selectively control where graphene superconductivity is induced, we devised a new method to laterally manipulate the Pb nano-islands over the graphene surface using a scanning tunneling microscope (STM) tip. The method works at temperatures as low as 4 K and allows us to laterally move the Pb nano-islands in any direction, with nanometer-scale precision, over distances of hundreds of nanometers, thus selecting where graphene superconductivity is induced. We show that the nano-islands can be displaced over long distances, while keeping their integrity, allowing us to form larger superconducting nanostructures by fusing many of them together. When crossing a domain boundary, the nano-islands rotate to match the graphene domain on which they rest, even at 4K, the lowest temperature we can measure. Our results provide a comprehensive study of the manipulation process, paving the way to the controlled formation of graphene-superconductor hybrids.

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SUPERCONDUCTING WRe THIN FILMS

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Tungsten Rhenium (WRe) in the form of thin film has been shown to be an interesting superconducting material, which can have multiple crystalline phases each one with their own superconducting characteristics [1, 2]. My research currently delves into the synthesis and characterization of thin and ultra-thin superconducting films for applications in superconducting gated-controlled three-terminal devices and superconducting nanowire single photon detectors (SNSPDs). In addition, in the near future, I plan to extend my research to explore possible WRe-based superconductor/ferromagnetic (S/F) hybrids.
Here, I study the superconducting properties of WRe thin films (from 3 to 100 nm of thickness), aiming at both investigating the fundamental physics in this material and explore its potential for applications. In particular, I focused on increasing the critical temperature (T_c) and the resistivity of sputtering-deposited WRe thin films (at 25% Rhenium) by fine-tuning the sputtering parameters and the consequential modifications of the films' crystalline structure.
Our experimental measures revealed that WRe films can exhibit both alpha and beta phases, similarly to what is observed in pure W films [3]. I explored the effect of the films thickness (d_s) and the incorporation of N_2 on these crystalline phases during the deposition. The results highlight a significant correlation between the crystalline phase, d_s, and T_c. I found that the fine-tuning of the deposition parameters, particularly the use of an Ar/N_2 gas mixture, leads to a shift in the phase composition, as confirmed by X-Ray Diffraction (XRD) analysis. Consequently, both T_c and resistivity are also altered. This accurate study of the sputtering process provides new insights into tailoring the superconducting properties of WRe thin films.

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MAGNETIC MOMENT OF THIN FILM SUPERCONDUCTORS: WHEN THICKNESS MATTERS

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The variation of magnetic moment as a function of external magnetic field for a superconducting material is usually described by the so-called Bean-Kim model. We show here that this model fails to explain the magnetic response of conventional type-II superconductor films to a field applied perpendicular to the film plane, when their thickness is below 100 nm. In the present contribution, we report on the study of magnetic moment of thin films of various conventional type-II superconductors (MgB_2, NbN, Nb and V) with thicknesses ranging from 100 nm down to 5 nm, as a function of magnetic field (H_{ex}) and temperature. When an external magnetic field, H_{ex}, is applied perpendicularly to the film plane, SQUID measurements enlighten an inverted $M(H_{ex})$ loops as compared to typical curves for films thicker than 100 nm or bulk samples. Especially, after zero-field cooling below the critical temperature, a positive moment forms in ascending field and an increasing negative moment develops when sweeping the field back to zero. We systematically analyzed the influence of film thickness and temperature on the stability of the observed field-induced "paramagnetic-like" state. We infer that such an inverted loop behavior in the case of low thickness film originates from a combination of low pinning, large penetration depth and large edge demagnetization field. From relaxation experiments, we demonstrate that the magnetic states along the inverted magnetization versus field loop are stable equilibrium states. Our findings provide some hints to further understand the High-Field Paramagnetic Meissner Effect (HFPME) reported in thin films [1] and prove that field-cooling is not requested to produce a paramagnetic-like response.

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ADVANCEMENTS IN MOLECULAR ELECTRONICS AT ROOM CONDITIONS THROUGH MCBJ APPROACH - NEW DEVELOPMENTS AND ENHANCEMENT

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The most commonly used techniques to measure electronic transport in atomic or molecular junctions are the Mechanical Controllable Break Junction (MCBJ) and the Scanning Tunneling Microscopy in BJ configuration (STM-BJ). In this work, we introduce three new advancements in the MCBJ technique. The first improvement involves the use of a controlled stepper motor to automatically and carefully break the sample. Once the rupture occurs, the motor is stopped and disconnected, allowing the piezo-system to take over and form the junction with subatomic resolution. The second improvement is the use of polylactic acid (PLA) as a substitute for the typical phosphor bronze substrate, which can be done massively in a 3D printer, making to PLA a better option due to its cost-effectiveness and malleability. Additionally, over the PLA substrates we can evaporate thin layers of gold without lithographic process in order to realize electromigrated junctions. The third improvement is the development of a logarithmic amplifier with offset control and variable amplification window, which allow us to measure conductance between 1 Go and 1x 10^{-6} Go.

DETECTION OF THE TWO-DIMENSIONAL VALENCE BOND SOLID STATE WITH SCANNING TUNNELING SPECTROSCOPY

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The AKLT model plays a prominent role in the study of quantum magnetism. In 1D, the AKLT model provides a paradigmatic case of exactly solvable Hamiltonian with a topological phase. In two dimensions (2D), particularly in the case with S=3/2 spins on a honeycomb lattice, it manifests a unique ground state with a gap, representing a valence bond solid. This ground state has proven to be a universal resource for measurement-based quantum computation[2].
For a hypothetical finite-size system described within a general class of models with both linear and non-linear couplings, we investigate how to determine if it conforms to the AKLT model using inelastic tunnel spectroscopy implemented with scanning tunnel microscopy (IETS-STM). We propose two approaches: for a dimer, utilizing non-equilibrium IETS-STM to acquire various excited states and deduce both linear and non-linear exchange interactions. In the case of finite-size clusters, we argue that edges host zero modes, that could give rise to Kondo. The use of Neural-Netwrok Quantum States (NNQS) for deriving such ground states numerically for larger systems and the potential of nanographene based structures to obtain such models[3] is also briefly discussed.

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VORTICES IN THE ULTRA-THIN LIMIT

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Characterizing the behavior of superconducting order parameters in the ultra-thin limit is essential to developing comprehensive physical models and harnessing these materials for diverse applications. The nature of the order parameter behavior may be probed through the analysis of the local perturbations such as vortices. Vortices consist of a core where the superconductivity is locally suppressed on the scale of the coherence length ξ where the magnetic field can penetrate. This field is screened by the surrounding superconducting currents and results in magnetic flux quantization. In bulk superconductors, the magnetic field is screened exponentially with a characteristic scale of the London penetration depth λ_L. By contrast, for a film of thickness $d<\lambda_L$, screening is less effective and is governed by the Pearl length $\Lambda=2\lambda^2_L/d$. In this limit, the magnetic field decays as $1/\Lambda r$ near the vortex core and Λ/r^3 for distances greater than Λ, where r is the distance from the vortex's center. Therefore, near the vortex core, there is no characteristic length scale for the magnetic field screening. We have measured the thickness dependence of the Pearl length in NbSe2 flakes with varying thickness. For this purpose, we employ a highly sensitive microscopy technique of SQUID-on-tip coupled to a tuning fork designed to measure gradients in minute magnetic signals emitted by a vortex, this technique allows us to acquire images of vortices and fit them to the Pearl model to extract the Pearl lengths at different thicknesses. Such characterization will show to which extent the Pearl model can describe the ultra-thin behavior as well as other underlying order parameters.

QUANTUM TRANSPORT IN DIRAC SEMIMETAL Cd_3As_2

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Observation of Majorana Zero Modes (MZM) have been in the heart of the condensed matter physics for last 20 years since Kitaev's well-renowned paper[1]. In our work, by inducing superconductivity in a Dirac Semimetal, Cd_3As_2 Josephson junctions, we are hunting for signatures for MZMs and topological superconductivity. Linear dispersion relation in zero energy range, high spin-orbit interaction and possible higher order topological states (HOTS) can be found in DSMs, which are promising features for this type of materials[2]. It is also known that it is possible to observe the Fermi Arcs on surface by breaking the inversion symmetry and transform DSM into Weyl Semimetal form (WSM)[2]. Our aim is to discover the topological effects on electronic transport behavior of these phases of Cd_3As_2 devices with higher order Fermi arcs (HOFA) [3] and utilize these states in order to obtain topological superconductivity. These signatures can only be found in superconducting regime, also by investigating the superconducting properties of nanowire/nanoplate devices such as Josephson Diode Effect (JDE), the missing odd Shapiro Steps and Fraunhofer patterns.

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NANOSCALE MAGNETIC IMAGING OF FEW-LAYER 2D MAGNETIC MATERIALS

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Two-dimensional (2D) magnetic materials have recently emerged as a promising platform for data storage, computing, and sensing. To advance these developments, it is vital to gain a detailed understanding of how magnetic order evolves on the nanometer-scale. We employ scanning superconducting quantum interference device (SQUID) microscopy as a magnetic imaging technique, which combines high field sensitivity with nanometer-scale spatial resolution. Our SQUID-on-cantilever sensor facilitates magnetic and thermal imaging capabilities provided by an on-tip SQUID with tip-sample distance control and topographic contrast of an atomic force microscope [1].

Here, I will discuss the layer-dependent evolution of magnetic domains in few-layer $Cr_2Ge_2Te_6$ [2] and strain-induced ferromagnetic behavior in inhomogeneously strained flakes of antiferromagnetic CrSBr, studied using a SQUID-on-cantilever scanning probe. In both materials, we image the magnetic stray-field on the nanometer-scale as a function of applied magnetic field, revealing the material's local behavior and its dependence on layer thickness, strain, or defects. Using micromagnetic models, we correlate measured stray-field maps with the underlying magnetization configurations. These findings show the importance of local measurements and how they can provide information on length scales, inhomogeneity, and interactions that are not available using bulk measurements. The understanding of the magnetic ground states and their tunability that are gained from such measurements represent an important step towards building 2D spintronic devices, whose spin configurations can be engineered and controlled by external fields.

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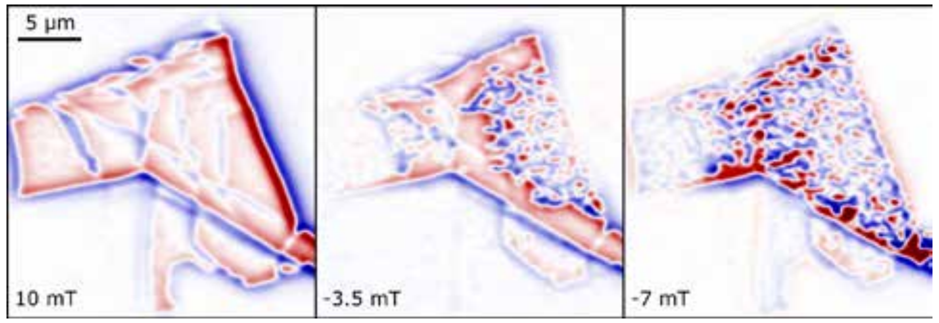
Layer-dependent domain formation in $Cr_2Ge_2Te_6$. Magnetic field gradient images for progressively decreasing applied out-of-plane magnetic fields of a $Cr_2Ge_2Te_6$ flake with 2 to 16 layers. The flake shows a local magnetic hysteresis and domain formation depending on the number of atomic layers. [2]



NEW MATERIALS FOR SUPERCONDUCTING SPINTRONICS

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This project aims to theoretically explore, and engineer enhanced and entirely new spintronics functionalities using superconducting hybrid structures, with a particular focus on both avoiding the need for complicated ferromagnets and raising operating temperatures. To achieve these goals, this project will investigate novel spin-orbit coupled materials and high-temperature superconductors by using analytical and numerical methods within a quantum mechanical description.

We theoretically model a heterostructure constructed by placing a monolayer of a transition metal dichalcogenide (TMD) on top of a conventional superconductor using a tight-binding model. The combination of high spin-orbit coupling in the TMD and the proximity induced superconductivity allows us to engineer and generate both local and non-local spin-triplet correlations.

HIGH DENSITY ELECTRON DOPING IN BORON-DOPED TWISTED BILAYER GRAPHENE: A LADDER TO EXTENDED FLAT-BAND

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Realizing Von Hove singularity (VHS) and extended flat bands of graphene near the Fermi level (E_F) is of great significance to explore many-body interactions, with a high tendency towards superconductivity. In this study, we report that the VHS of π^* bands near E_F can be realized by high-density lithium intercalation in p-type doped twisted bilayer graphene (tBLG). First, a method to predict the highest lithium intercalation in tBLG systems with arbitrary twist angle was established which proves that the interlayer twisting leads to the clustering of lithium ions in the AA-region but reduces the overall concentration. Second, we show that the p-type doping (1.35% boron) in tBLGs enhances their electron acceptance capability by increasing lithium intercalation up to 47%. In this situation, the electron doping by lithium intercalation is sufficient to shift E_F near the VHS which offers a strategic path to realize extended flat bands, and to investigate the strong correlations in the tBLG systems.

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LECTURE 5

Prof. Milorad Milosevic is expert in high-performance computations for material physics problems (in the past applied to superconducting, magnetic, metal-semiconductor hybrid materials, as well as soft-hard matter hybrids, e.g. large biomolecules with metallic ions/atoms/nanoparticles). Description of quantum effects in atomically-engineered functional materials for specific electronic, magnetic, and/or optical performance. Design, engineering and characterization of electronic devices based on new functional materials.

GINZBURG-LANDAU THEORY OF SUPERCONDUCTIVITY: FROM BASICS TO APPLICATIONS

Abstract:
In this lecture, we will review the basic concepts behind the most used phenomenological theory of superconductivity to date, and show its practical applications. We will discuss its upgrades in relation to the improved temperature dependence and the microscopic origin of all relevant parameters, that ultimately enable excellent agreement of its results with experimental findings and modelling of advanced superconducting devices. With that in mind, we will simulate hands-on the behavior of a mesoscopic superconductor in the presence of external excitations, and discuss what we expect in such a case, what we obtain, and what could be further improved and how.

LECTURE 6

Dieter Koelle is a professor in experimental solid-state physics and co-director of the center for light-matter interaction, sensors & analytics (LISA+) at Univ. Tübingen. He received his PhD from the Univ. of Tübingen in 1992 and his habilitation degree from the Univ. of Cologne in 1999.

JOSEPHSON JUNCTIONS AND SUPERCONDUCTING QUANTUM INTERFERENCE DEVICES (SQUIDS)

Abstract:
Josephson junctions are the basic elements of superconducting electronics, and play an important role both for applications in the classical and quantum regime. In this lecture, I will introduce basic concepts on the properties of Josephson junctions in the classical regime. These concepts form the basis for understanding electric transport and noise characteristics of Josephson junctions; proper modeling of such characteristics is important for developing and optimizing Josephson based devices for various applications. In the second part of the lecture, I will introduce superconducting quantum interference devices (SQUIDs) as the most sensitive detectors of magnetic flux. Their operation is based on the combination of fluxoid quantization and Josephson effects in superconductors. I will introduce basic concepts that are used to describe and optimize the properties of direct current (dc) SQUIDs, with focus on thermal noise and sensitivity. Furthermore, techniques for SQUID readout, and some applications of SQUIDs will be described.

LECTURE 7

Elena Hassinger is a professor at TU Dresden in Germany. She received her PhD in 2010 at Grenoble University, France, on pressure studies of uranium-based superconductors. During her postdoc, she worked at Sherbrooke university, Canada, on thermal and thermoelectric transport in unconventional superconductors. Between 2014 and 2022 she led an Independent Max Planck Research Group at MPI CPfS in Dresden as well as a a Tenure Track Professorship at TU Munich.

THERMODYNAMIC AND TRANSPORT EXPERIMENTS ON THE GROUND STATE OF STRONGLY CORRELATED ELECTRON SYSTEMS

Abstract:
In this lecture I will discuss what we can learn from thermodynamic and transport experiments on the ground state of strongly correlated electron systems. Starting from essential basics on Fermi liquids, I will show what unconventional behavior looks like. I will also use example groundstates to illustrate the expected thermodynamic and transport properties, namely

- Unconventional superconductivity
- Ordered phases
- Quantum critical systems

In the second part of this lecture, I will explain superconductivity in locally non-centrosymmetric materials exemplified by results on $CeRh_2As_2$.

<u>Learning outcomes</u>
After hearing this lecture, the participants will

- Have an insight into different macroscopic experimental techniques and methods
- Be able to interpret experimental data from these techniques
- Relate the thermodynamic and transport properties to the ground state
- Explain superconductivity in locally non-centrosymmetric materials

LECTURE 8

Aline Ramires obtained her Ph.D. from Rutgers University, USA, in 2015. She was an ITS Fellow at ETH Zurich, Switzerland, and a Distinguished Postdoctoral Fellow at the MPI-PKS, Germany. Since 2020, Aline Ramires has been an Ambizione Fellow in the Condensed Matter Theory group at the Paul Scherrer Insitute, Switzerland. She was the recipient of the Nevill F. Mott Prize in 2022.

STANDARD CLASSIFICATION OF SUPERCONDUCTING ORDER PARAMETERS FROM THE POINT GROUP PERSPECTIVE

Abstract:
Superconductivity usually emerges as an electronic instability in crystalline solids following specific symmetry properties. The symmetries of a crystalline lattice are characterized by the corresponding space group, the group of transformations that leave the lattice invariant. These transformations can include translations, rotations, reflections, and their combinations. If we focus on transformations that leave one point of the lattice invariant, we have a point group, which includes rotations and reflections (but excludes translations). In this lecture, I am going to introduce the minimum set of concepts from group theory necessary to understand the standard classification of superconducting order parameters from the point group perspective. In the end, I hope to mention novel aspects that emerge if one extends this classification considering the full space group symmetry, including translations, particularly relevant to nonsymmorphic systems and modulated order parameters.

POSTER SESSION II

by alphabetical order

ID	SURNAME, Name
23_P01	KÓTI, David Attila
23_P02	LOCOVEI, Claudiu
23_P03	LUPI, Greta
23_P04	MARTÍNEZ-GARCÍA, Andrés
23_P05	MATHIALAGAN, Shanmugasibi K.
23_P06	MERCEBACH, Phillip
23_P07	MIDEI, Giovanni
23_P08	FERNÁNDEZ-LOMANA, Roberto
23_P09	PAYÁ, Carlos
23_P10	RENIERS, Stijn
23_P11	RODRÍGUEZ, Sara
23_P12	RUMEU, Jaime
23_P13	SARDINERO, Ignacio
23_P14	ŠKRLEC, Adam
23_P15	VERVOORT, Senne
23_P16	VOLAVKA, Dominik
23_P17	JURASZEK, Jarosław

MEASURING THE CURRENT-PHASE RELATION IN INAS 2DEG JOSEPHSON JUNCTION USING EPITAXIAL AL RESONATORS

Zoltán Scherübl[1,2], Dávid Attila Kóti[1*], Csaba Horváth[1], Máté Sütő[1,2], Gergő Fülöp[1,2], Endre Tóvári[1,3], Magdhi Kirti[4,5], Giorgio Biasiol[4], Péter Makk[1,3], Szabolcs Csonka[1,2]

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Two-dimensional electron gases (2DEG) are promising platform for future quantum electronics applications. Some of the main directions, such as qubit applications, require microwave capabilities. Microwave experiments in two-dimensional electron gases are significant in the preparation of the Kitaev transmon qubit. In this study, we investigated an InAs 2DEG-based RF SQUID coupled to a microwave coplanar resonator similar to a future qubit architecture. The Josephson junction was formed in the InAs two-dimensional electron gas. Both the superconducting loop and the resonator were fabricated in the in-situ deposited Al layer on top of the 2DEG. We demonstrated that the current-phase relation can be measured by the frequency shift of the resonator while the phase was tuned by a small external magnetic field. We also demonstrated the suppression of the supercurrent by depleting the junction via gating. When a larger out-of-plane magnetic field is applied , an interference similar to the Fraunhofer pattern is demonstrated. An anisotropy dependent on the magnetic field direction was observed in both the current-phase relation and the interference pattern when an in-plane magnetic field was applied.

PHYSICAL PROPERTIES OF CRO THIN LAYERS FOR STIMULATED CONTROL OF MAGNETIZATION

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In the multiple studies in which the metal oxide $CaRuO_3$ has been characterized, a paramagnetic behavior was observed that require a non-Fermi liquid (NFL) theory to properly describe the strongly correlated electrons within the thin layer. In contrast, $SrRuO_3$ (SRO) is an iso-structural ferromagnetic metal analogous to CRO, with a Curie temperature of about 165 K and compatible with the FL formalism. Recently, in thin metallic layers of $CaRuO_3$, the modification of the magnetic behavior for certain values of the lattice parameters was highlighted. Thus, for a narrow range of deposition parameters we obtain epitaxial layers of CRO on STO <001> substrate with appropriate stress associated with the lattice constants that gives a non-zero magnetic moment to the free electrons. These free electrons will mediate the long-range exchange interaction which finally is responsible for the ferromagnetic character. Besides the fact that this band ferromagnetism was detected in CRO layers at room temperature, since CRO is a metal oxide with strongly correlated electronic structure, it is an optimal candidate to highlight the stimulated control of magnetization. A compressive set of samples was prepared and analyzed at SQUID, XRD and SEM to show the interplay between the morpho-structural parameters and magnetic properties.

HAMILTONIAN LEARNING SPINORBITRONIC QUANTUM MATTER

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Extracting the Hamiltonian from direct experimental measurements represents one of the open problem in quantum materials. While specific Hamiltonian parameters may be extracted from specific observables in specific cases, the extraction of complex terms, especially those dominated by spin-orbit coupling effects, represent a much bigger challenge. Here [1] we present a machine learning methodology to perform Hamiltonian learning of quantum matter driven spin-orbit coupling effects, both single particle and many-body states. Our algorithm exploits non-trivial features of dynamical excitations measured in real space with scanning tunneling spectroscopy around impurities, leveraging both real-space and frequency resolution. In particular, our methodology shows that dynamical excitations induced by local scatterers allow to extract non-trivial Hamiltonian parameters driven by spin-orbit coupling. Our results provide a starting point to extract Hamiltonian parameters of spinorbitronic quantum materials, including topological states and quantum magents, directly from real-space scanning tunneling spectroscopy experiments.

[1] Greta Lupi and Jose L. Lado, to appear (2024)

CHIRAL INDUCE SPIN SELECTIVIY IN MOLECULAR AND ATOMIC JUNCTIONS

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Break junction experiments have reliably measured electronic transport through a molecule trapped between two electrodes for more than three decades. This technique has been applied to Scanning Tunneling Microscopy (STM) and Mechanically Controllable Break Junction (MCBJ) methods to study numerous molecules [1], often in conjunction with computational techniques. In recent years, there has been a shift in interest towards chiral molecules, as they have been found to induce spin polarization in the current [2]. This phenomenon, known as Chiral Induced Spin Selectivity (CISS), is not yet fully understood.

In light of this, our research focuses on dithia[9]helicene, a chiral molecule with a helical structure, to investigate both its electron transport and spin polarization properties. To this end, we have conducted Density Functional Theory (DFT) calculations and utilized the ANT software [2] to perform transport calculations with resolved spin polarization.

Furthermore, it has been observed that the symmetry breaking of a pure metallic atomic junction can polarize a current [4]. This observation suggests a more generalized concept of CISS, where defects or symmetry-breaking points in a perfectly symmetric metallic contact can induce similar effects to those observed with chiral molecules.

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DESIGNING ORGANOLANTHANIDE SANDIWCH COMPLEXES BY ON-SURFACE SYNTHESIS

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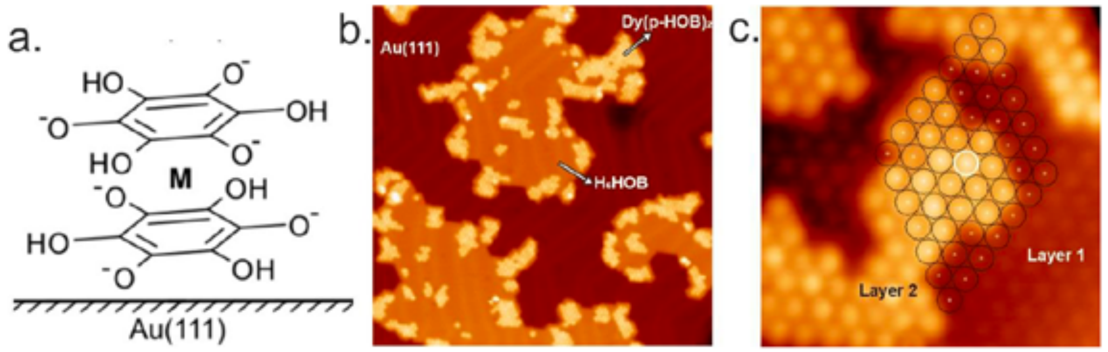
Organometallic compounds are structures made up of metal atoms and organic molecules with at least one chemical bond between a carbon and metal atom. Surface chemistry permits their synthesis and local studies down to the single molecule level. However, when these complexes are adsorbed on metallic surfaces, hybridization of orbitals due to the proximity of the metal atoms to the substrate and charge transfer can change their properties [1], reducing the magnetic moments [2] and inducing interface states [3]. A possible strategy to overcome this problem is to isolate the metal atoms by sandwiching them in between the organic complexes. Lanthanide-based organometallic sandwich compounds exhibit high blocking temperatures, remanence, high anisotropy, and slow relaxation times [4] and are highly intriguing as a potential for single molecule magnetism with possible applications in nanomagnetism, data storage, spin-based devices, among many other applications [5].



In this work, we report the design of two new organolanthanide mononuclear sandwich complexes adsorbed on a Au (111) surface. We have studied their structural, electronic, and chemical properties using scanning tunnelling microscopy and spectroscopy and X-ray photoelectron spectroscopy. Our results show that the presented compounds are composed of partially deprotonated hexahydroxybenzene molecules sandwiching Dy or Er atoms with +3 oxidation state. The X-ray absorption spectroscopy and circular magnetic dichroism measurements reveal that the erbium-based species is magnetically isotropic, while the dysprosium-based compound has an in-plane magnetism, despite displaying similar self-assembly, showing the role of lanthanide atoms in tuning the magnetic properties. To the best of our knowledge, we present the first report of the synthesis of organometallic sandwich complexes by a bottom-up approach on a catalytic metallic surface.

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THERMOELECTRIC SIGNATURES OF BOGOLIUBOV-FERMI SURFACE IN 3DTI SUPERCONDUCTING HETEROSTRUCTURES

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A weak magnetic field applied to a superconductor (SC) can selectively close the superconducting gap, giving rise to a segmented Fermi surface. These so-called Bogoliubov-Fermi surfaces (BFSs) have been observed in recent experiments in a three-dimensional topological insulator (3DTI) in proximity to a SC. In this work, we employ a scattering matrix formalism to reveal signatures of the BFS in the thermoelectric transport properties of a superconducting hybrid junction on the surface of a 3DTI. We consider a setup with two normal probes (N) connected to a SC (N-SC-N configuration) to study local and nonlocal transport under an applied in-plane magnetic field. With a temperature gradient, the magnetic field creates equal local and nonlocal electric Seebeck currents which follow the orientation of the BFS. Furthermore, we predict a switch in the required voltage bias enabling local and nonlocal Peltier cooling, which again depends on the orientation of the BFS. As a result, our work provides novel ways of exploring unconventional superconducting phases.

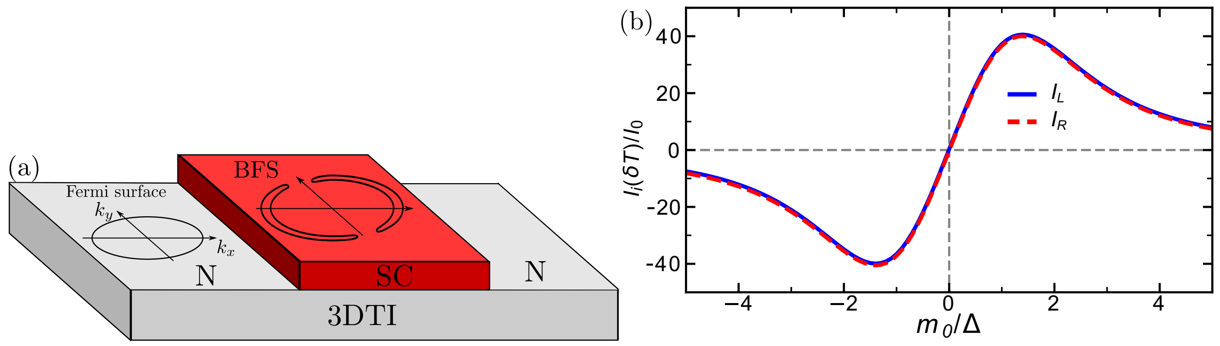

Figure 1: (a) Sketch of the N-SC-N junction where a superconductor is deposited on the surface of a 3DTI. On each region, N and SC, we show an energy contour of the bands at the Fermi level. When $m_0>\Delta$ the superconducting gap closes in a finite region creating a Bogoliubov Fermi surface: a gapless superconducting state. (b): Zero bias electric current in the normal left (I_L) and right (I_R) regions for a given temperature gradient across the junction δT, plotted as a function of applied the magnetic field, m_0, that induces the BFS. We predict a BFS induced Seebeck coefficient of $S \approx 30 \mu V/K$ in typical topological insulator-superconductor junctions.

PREDICTIVE POWER OF THE BEREZINSKII-KOSTERLITZ-THOULESS THEORY BASED ON RENORMALIZATION GROUP FOR THE BCS-BEC CROSSOVER IN 2D SUPERCONDUCTORS

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Recent experiments on 2D superconductors allow the characterization of the critical temperature and of the phase diagram across the BCS-BEC crossover as a function of density. We obtain from these experiments the microscopic parameters of the superconducting state at low temperatures by adopting the BCS mean-field approach. For LixZrNCl [1], the extracted parameters are used to evaluate the superconducting phase stiffness and the Berezinskii-Kosterlitz-Thouless (BKT) critical temperature throughout the BCS-BEC crossover, by implementing the corresponding Renormalization Group (RG) approach. In this way, we make a quantitative test of the predictive power of the BKT theory for evaluating the critical temperature. The RG flow equations turn out to give a sizable renormalization to the phase stiffness and to the critical temperature, which is crucial to obtain a satisfactory comparison between the BKT theory and the experiments, in particular in the BCS-BEC crossover regime. We predict the temperature range where RG renormalizations of the phase stiffness can be measured in LixZrNCl across the BCS-BEC crossover. Contrary to other microscopic theories of superconductivity, we find that the BKT theory can be exploited to evaluate quantitatively the critical temperature of 2D superconductors in different pairing regimes.

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DETERMINATION OF THE SUPERCONDUCTING DENSITY OF STATES OF THE PNICTIDE SUPERCONDUCTOR $LaRu_2P_2$

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The family of the pnictide superconductors has been studied for the las 15 years since high temperature superconductivity appears as a consequence of electron-electron interactions. $LaRu_2P_2$ is a member of this family although it presents a critical temperature of 4 K without doping. For that reason, the thorough study of the properties of $LaRu_2P_2$ is of such relevance. The band structure and other macroscopic measurements have been performed [1], suggesting that this compound is a phonon mediated classical superconductor. However, the microscopic superconducting properties remain largely unaddressed. Here, measurements of $LaRu_2P_2$ single crystal's density of states and the study of the superconducting gap dependence with temperature is presented. Moreover, a study of the response of the single crystals to the presence of an external magnetic field is conducted, showing the typical type II superconductor vortices. The overall conclusion of the work presented is that unlike ordinary pnictide superconductors, $LaRu_2P_2$ behaves as a classical, phonon mediated low critical temperature superconductor.

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PHENOMENOLOGY OF MAJORANA ZERO MODES IN FULL-SHELL HYBRID NANOWIRES

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Full-shell nanowires have been proposed as an alternative nanowire design in the search of topological superconductivity and Majorana zero modes (MZMs). They are hybrid nanostructures consisting of a semiconductor core fully covered by a thin superconductor shell and subject to a magnetic flux. They operate at smaller magnetic fields and low g-factor in comparison to their partial-shell counterparts, and the expected MZMs appear at well-controlled regions of parameter space. We find a very rich spectral phenomenology that combines the Little-Parks modulations of the parent-gap superconductor with flux, the presence of flux dispersing Caroli-de Gennes-Matricon (CdGM) analog subgap states and the emergence of MZMs across finite flux intervals. The phase diagrams for different models of the nanowires show that the MZMs typically coexist with CdGM analogs at zero energy, rendering them gapless, except for topologically protected parameter regions or *islands*. In consequence, the most promising candidate to obtain topologically protected MZMs is the nanowire with a tubular-shaped core.

On the other hand, radial mode mixing can act like a topological *p*-wave pairing between particle-hole Bogoliuvov partners and is therefore able to create new topologically protected MZMs in regions of the phase diagram that were originally trivial. As a result, the phase diagram is utterly transformed and exhibits protected MZMs in around half of the parameter space.

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GROWTH AND CHARACTERIZATION OF FE/NB BILAYERS ON A HIGH-PERMITTIVITY OXIDE SUBSTRATE

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Superspintronics forms an exciting field of research, in which spin-polarized supercurrents are generated and controlled in hybrid structures of ferromagnetic (FM) and superconducting (SC) materials [1,2]. Devices based on these SC-FM hybrids are generally controlled using a magnetic field. A more energy-efficient and scalable alternative is the use of an *electric* field to electrostatically modulate the ferromagnetic order, which in turn affects the supercurrent and/or critical parameters of the superconducting component. *Magnetoelectric coupling* is a well-established phenomenon that has been observed and controlled in various heterostructures of a ferromagnetic (ultra)thin film deposited on a dielectric/ferroelectric substrate, with carefully engineered interfaces and structural order [3,4]. In this study, we fabricate a potential magnetoelectric-superspintronic heterostructure by growing Fe(5 nm)/Nb(50 nm) bilayers on SrTiO3{001} single-crystal substrates using Molecular Beam Epitaxy (MBE). $SrTiO_3$ was selected due to its extremely high dielectric constant ($\varepsilon \sim 10^4$) at cryogenic temperatures and relatively good lattice match with bcc-Fe. Both these features are expected to enhance the interfacial magnetoelectric coupling. X-ray characterization shows epitaxial Fe{002} and strongly {011}-textured Nb films (Fig. 1a and 1c), with rather well-defined interfaces (Fig. 1b). SQUID-VSM measurements (Fig. 1d) reveal regular ferromagnetic hysteresis at temperatures above the superconducting transition (8.3K). Room-temperature LMOKE-measurements indicate pronounced magnetocrystalline cubic anisotropy of the epitaxial Fe reference films. The observation of high structural quality, coexistence of superconductivity with robust ferromagnetic order and presence of native magnetic anisotropy are promising features to investigate the electric-field gating of the MBE-deposited laminar Fe/Nb hybrid in cryogenic transport measurements as our next step.

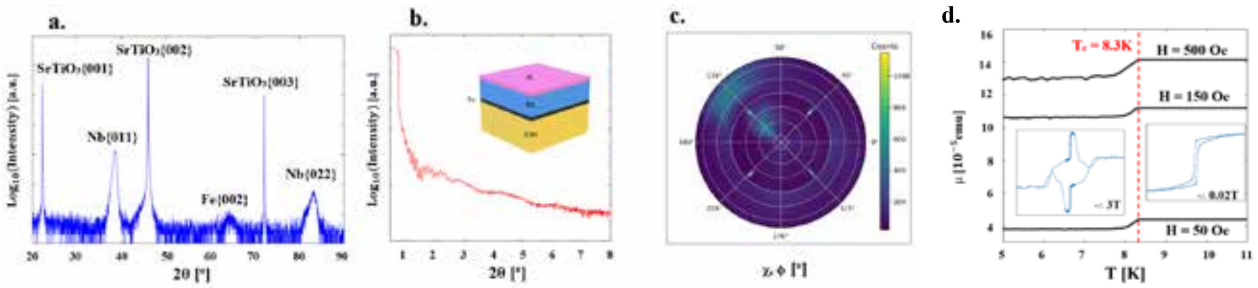

Fig. 1: ***(a)*** θ-2θ *XRD scan, indicating the epitaxial nature of the Fe-film and strong {011}-texture of Nb.* ***(b)*** *XRR scan exhibits clear Kiessig fringes with distinct periodicities and moderate decay profile (fit not shown), the thin film stack is depicted schematically in the inset.* ***(c)*** *Pole figure measurement of Fe{002} reflection reveals the π/4-rotated epitaxial relation to the substrate.* ***(d)*** *SQUID-VSM M(T) measurements, displaying the Meissner-response of Nb at different in-plane applied fields. M(H) behavior above (10 K) and below (5 K) T_c are shown in the right and left insets, respectively.*

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ENGINEERING MAGNETIC TEXTURES IN THE BARRIER OF LSMO/YBCO JOSEPHSON JUNCTIONS

Sara Rodríguez[1], David Sánchez-Manzano[1], Fabián Cuéllar[1], Sergio Valencia[2], Carlos León[1] and Jacobo Santamaría[1]

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In ferromagnetic Josephson junctions spin-singlet Cooper pairs penetrate the barrier over very short distances, which depend on the spin polarization in the ferromagnetic layer. Recently a long-range Josephson effect driven by equal spin-triplet pairs [1] has been shown between two superconducting YBa2Cu3O7 (YBCO) banks separated by micron-wide ferromagnetic La0.67Sr0.33MnO3 (LSMO) spacer. Due to the spin polarized nature of the pairing amplitude, the Josephson coupling between the superconductors can be drastically influenced by modifications of the magnetic domain state of the LSMO barrier. Previously, we demonstrated the control nucleation and manipulation of a single domain wall in a LSMO micro wire-cross, as well as its magnetoresistance response under a magnetic field applied along the nanowire [2]. In this work we aim at engineering magnetic textures in the ferromagnetic barrier and probe them with Spin resolved Photoemission Microscope (SPEEM). We pursue Electron Beam Lithography (EBL) nanofabrication of a LSMO cross between two cuprate electrodes and measure the modulation of the critical current. The external control of the magnetic textures in the barrier may find interesting applications in superconducting spintronics and in the design of quantum memories [3].

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DISSIPATION IN A SUPERCONDUCTOR VIEWED BY IMPEDANCE MEASUREMENTS

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A resistance can be measured by applying an AC current and recording the real part of the AC voltage drop. When measuring the resistance as a function of temperature, a sufficiently large AC current might produce a self-heating effect that leads to a delay in the voltage response. The delay depends on the thermal conductivity between the sample and the heat reservoir and the specific heat of the sample. The delay can be measured by recording the imaginary part of the AC voltage. This effect is, for nearly all purposes, negligible in a usual metal, where the resistance changes by a very small amount per Kelvin. However, in a superconductor the resistance drops abruptly to zero in a temperature range of just a few mK. This abrupt temperature dependence produces a strong imaginary component [1-4]. Here we show that the imaginary component persists below the superconducting transition, even when the real part is nearly zero. We associate the newly observed imaginary component to the heat dissipated from vortex motion in a current carrying wire. We discuss vortex motion in presence of a current and the associated generation of voltage and heat. We will also discuss efforts to build a new ultra small STM for studying superconductors in tilted magnetic fields.

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CURRENT-PHASE RELATION IN FIBONACCI JOSEPHSON JUNCTIONS

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Quasicrystals (QCs), lattices displaying long-range order without translational periodicity, have been shown to be topologically nontrivial [1]. They feature energy gaps linked to topological invariants, harbouring edge modes under specific conditions [2]. The Fibonacci quasicrystal (FQC), a prototypical example of a one-dimensional QC, comprises an aperiodic sequence of two alternating parameters.

We consider Josephson junctions where superconductors with a finite phase difference are subjected to chemical potentials arranged in a Fibonacci sequence. The FQC arrangement, which may be implemented using local gates, introduces gaps and edge modes above the superconducting energy gap (Fig. 1a). We show that these edge modes develop superconducting correlations, with an intriguing dependence on the super-conducting phase difference (Fig. 1b). This effect gives rise to a finite Josephson current which can even dominate the contribution from common Andreev bound states (ABS), see Fig. 2.

The interplay between FQCs and the Josephson effect opens new avenues for exploring exotic phenomena with important consequences in topological super-conductivity.

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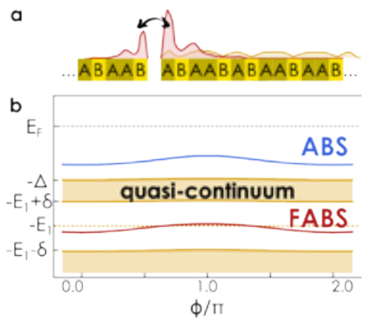

Figure 1: **a** Sketch of a one-dimensional FQC Josephson junction, showing a delocalized quasicrystal mode (yellow) and a localized Fibonacci-Andreev bound state (FABS) (red). **b** Energy levels as a function of the superconducting phase ϕ.

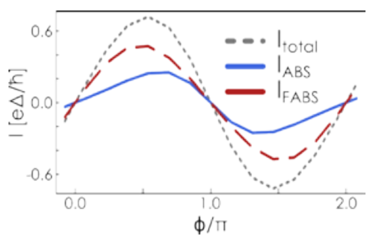

Figure 2: The FABS contribution to the supercurrent can dominate over the conventional ABS one.

FINGERPRINTS OF LOW-ENERGY SCATTERING IN THE SUPERCONDUCTING STATE

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The anomalous properties of many correlated metals of current interest are believed to be caused by singular low-energy scattering processes. The latter should be most clearly observable in the limit of low temperatures. However, in this limit, the situation is often complicated by the transition of the metal to the superconducting state. Motivated by this state of affairs, in this work we search for experimentally observable fingerprints of low-energy scattering processes in superconductors.

In the first part of the presentation, we will introduce our recent work[1] dealing with the interplay between inelastic processes, described within the self-consistent Born approximation, and elastic scattering on strong magnetic disorder, treated within the coherent-potential approximation. Using the resulting Eliashberg-like formalism, we have shown that the tunneling density of states at low energies can be characterized by the Dynes formula with the pair-breaking parameter Γ. We will discuss how the temperature dependence of Γ could be used to extract information about inelastic processes in the limit of low energies.

In the second part, we will introduce our ongoing work on a new type of scattering, distinct from both elastic scattering on disorder and inelastic scattering on bosonic modes. Namely, motivated by the recent study[2] of the low-temperature London penetration depth in niobium, we examine the interaction between electrons and two-level systems, which are known to be ubiquitously present in structurally disordered systems. We will present the results of the microscopic theory, and compare them to experimentally observed behavior.

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MoGe/Au JOSEPHSON JUNCTION ARRAYS FOR ON-CHIP GIGAHERTZ FREQUENCY EMISSION

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The control and readout of superconducting qubits conventionally relies on signals within the 4-8 GHz frequency range [1]. However, existing systems face challenges, as the high-frequency signal is typically generated at room temperature and transmitted through multiple attenuation stages to the cryogenic environment, inducing noise and lacking scalability [2]. Addressing these issues, it is more beneficial to situate the control circuits near the qubit devices. To achieve this, we leverage weak link Josephson junctions as on-chip signal generators capable of converting DC voltage into AC current, emitting voltage-tunable radiation [3]. Phase locked arrays of Josephson junctions have advantages, such as a decrease in the Full Width at Half Maximum (FWHM) of the signal and an increase in output power with the number of junctions, compared to single junctions. Moreover, the impedance of the array can be tuned by adjusting the number of junctions, facilitating easy impedance matching [4]. Our research group has successfully fabricated such arrays, utilizing superconducting MoGe islands with dimensions of 500 nm by 500 nm, that are placed on Au, as the weak link material. Experimental results demonstrate the generation of signals within the 4-8 GHz regime, exhibiting complete tunability with the applied bias voltage, in accordance with the second Josephson equation illustrated in Figure 1. The measured FWHM of the Josephson radiation is approximately 200 MHz and further investigation is necessary to reach an overall phase locked superradiant response resulting in a reduced linewidth.

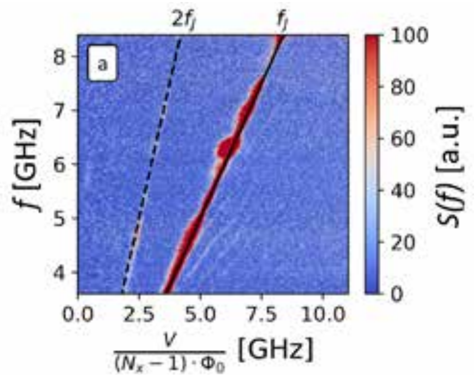

Fig. 1: Emitted radiation (frequency and power) as a function of applied DC voltage for 56 junctions. The DC voltage is shown in GHz via the Josephson relation [5].

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LEAD DOPING AND ITS EFFECT ON THE PROPERTIES OF MISFIT LAYERED MATERIALS

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Ising superconductivity occurs in the $NbSe_2$ monolayer due to a combination of broken inversion symmetry and spin-orbit coupling that locks the spins of the electrons out-of-plane. We demonstrate that bulk misfit compound superconductors, consisting of monolayers and bilayers of NbSe2 within $(LaSe)_{1.14}$ $(NbSe_2)$ and $(LaSe)_{1.14}$ $(NbSe_2)_2$, unexpectedly show Ising protection comparable to monolayer $NbSe_2$, despite having formal inversion symmetry [1, 2].
The stability of such misfit compounds is partially ensured by charge transfer from the LaSe to the $NbSe_2$ layer. The change of the properties of the LaSe layer, using a suitable dopant, will also affect the amount of charge transferred to the $NbSe_2$ layer, which will allow us to tune the physical properties of the resulting structures.
We focus on $(LaSe)_{1.14}(NbSe_2)$ and $(LaSe)_{1.14}(NbSe_2)_2$ structures doped with lead and investigate i. a. the actual dopant location in the crystal lattice, how it affects charge transfer and how this change affects the resulting electronic properties and superconductivity.

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LOW-FIELD BARDEEN-COOPER-SCHRIEFFER STATE IN $CeRh_2As_2$ FROM LOCAL MAGNETIZATION

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The arguably most promising avenue for creating Majorana bound states relies on spin-triplet odd-parity superconductivity, yet this long-sought state of matter has remained elusive. The recently discovered superconductor $CeRh_2As_2$ with a critical temperature $T_c \approx 0.34$ K is thought to be the first and currently the only known material demonstrating a field-induced transition between spin-singlet even-parity and spin-triplet odd-parity superconducting states when subjected to a magnetic field of ≈ 3 T aligned parallel to the *c*-axis of its tetragonal crystal structure [1]. Under ambient pressure and in zero field, this heavy-fermion compound also undergoes a phase transition of an unknown origin at $T_0 \approx 0.5$ K and exhibits signs of antiferromagnetism below 0.25 K [2]. Here, we examine a low-field even-parity state of $CeRh_2As_2$ using micro Hall probe magnetometry for local magnetization measurements down to $0.02T_c$. We observe a relatively small anisotropy of the lower critical field, the temperature dependencies of which for both crystallographic directions display a single-band isotropic *s*-wave behavior predicted by the Bardeen-Cooper-Schrieffer theory. Furthermore, we observe a small but distinct increase in *a*-axis magnetization starting around T_0, although attempts to detect a magnetic signal along the *c*-axis have been unsuccessful. Our findings impose important constraints on the superconducting and normal-state order parameters of $CeRh_2As_2$.

This work was supported by the Polish National Science Centre NCN (Project OPUS23 No. 2022/45/B/ST3/04117).

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INVITED TALK 1

Eugenio Coronado is the Director of the Molecular Science Institute (ICMol) at the University of Valencia and of the European Institute of Molecular Magnetism (EIMM). His career has always been characterized by a high interdisciplinarity and impact in chemistry, physics and materials science. Coronado has been at the forefront of Molecular Magnetism during the last 25 years making seminal contributions in the chemical design, physical characterization and theoretical modelling of molecular nanomagnets and multifunctional materials. He leads two ERC AdG in Molecular Spintronics and 2D materials.

2D MAGNETIC HETEROSTRUCTURES: FROM TWISTED MAGNETS TO SMART MOLECULAR/2D HETEROSTRUCTURES

Abstract:
The controlled assembly of 2D materials in van der Waals heterostructures provides the opportunity to design unconventional materials with novel properties. Here I will illustrate this concept through two examples:

1) Artificial magnets obtained by creating a twisted 2D heterostructure formed by two ferromagnetic monolayers of CrSBr twisted by an angle of 90º [1] Magneto-transport measurements in this new material show a multistep spin switching with the opening of hysteresis, which is absent in the pristine bilayer case (angle of 0º) [2], as a consequence of the competition between the inter-layer exchange interactions (which favour an antiparallel orientation of both spin layers), the local spin anisotropies (which tend to orient the spins along the easy axis of each monolayer, x and y) and an external magnetic field applied along one of these easy axes.

2) Smart molecular/2D heterostructures obtained by interfacing stimuli-responsive magnetic molecules with graphene, semiconducting layers (MoS2 and WSe2), a superconducting layer (NbSe2), or the magnetic layer CrSBr. A tuning of the properties of the "all surface" 2D material is achieved via an active control of the hybrid interface. As smart-molecular systems, I will choose magnetic spin-crossover materials able to switch between two spin states upon the application of an external stimulus (temperature, light or pressure) [3]. This spin transition is always accompanied by a significant change of volume in the material (by ca. 10%). Hence,

it can generate strain over the 2D material leading to a reversible change in its physical properties triggered by temperature or light upon the spin transition [4-6].

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INVITED TALK 2

Yulia Maximenko received a Ph.D. in Physics from the University of IL at Urbana-Champaign (2020) and both M.S. and B.S. in Physics and Applied Math from Moscow Institute of Physics and Technology. After PhD, Yulia worked with Joseph Stroscio at the National Institute of Standards and Technology as a postdoctoral researcher using a state-of-the-art mK transport and probe microscopy instrument. As an assistant professor at Colorado State University, Dr. Maximenko focuses on scanning probe microscopy, molecular beam epitaxy, and device nanofabrication, which are used to create exotic solid-state platforms and investigate the emergent quantum phases with atomic resolution at ultralow temperatures.

QUANTIFYING UNCONVENTIONAL MAGNETISM IN DEVICES USING SCANNING TUNNELING MICROSCOPY

Abstract:
I will demonstrate how scanning tunneling microscopy (STM) evolved from studying single crystals to measuring tunable quantum platforms, such as multi-contact heterostructures of 2D materials. Besides providing atomic resolution, STM is crucial in investigating stacked devices, because it provides atomically precise topographic information and is the main tool to measure energy-resolved local density of states. I will demonstrate how using a traditional STM technique of Landau level spectroscopy on tunable twisted graphene devices results in precise energy-resolved measurements of emergent orbital magnetic moment and magnetic susceptibility.

ORAL COMMUNICATION 1

ENGINEERING UNDERDOPED CuO_2 NANORIBBONS IN nm-THICK *a*-AXIS $YBa_2Cu_3O_{7-\delta}$ FILMS

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Many of the intricate phases of cuprate high Tc superconductors (HTS) take place in CuO_2 which host local orders and symmetry-breaking states in the underdoped region of the phase diagram. Confining the CuO_2 planes can therefore provide an interesting platform to shed light on the physics of these phases and their interplay with superconductivity.
By growing *a*-axis oriented $YBa_2Cu_3O_{7-\delta}$ films, we have confined the CuO_2 planes by film thickness, and by using an *ex-situ* annealings we have been able to change the oxygen content and span the entire underdoped region of the phase diagram. The films have been studied using X-ray diffraction and resistance vs temperature measurements. We have observed two significant findings: first, we find the suppression of the orthorhombic-to-tetragonal transition at very low dopings; second, we find a very high anisotropy of the normal state resistance in the *b-c* plane –in agreement with the bulk material– which is connected to a weak coupling between adjacent CuO_2 planes. This study presents *a*-axis oriented $YBa_2Cu_3O_{7-\delta}$ films as a novel system that can provide further insights on the physics of HTS and new possibilities for practical applications.

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ORAL COMMUNICATION 2

STRUCTURAL AND ELECTRONIC CHARACTERIZATION OF ATOMIC DEFECTS IN $FeSe_{1-x}S_x$ SUPERCONDUCTOR: STM AND DFT STUDY

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In this work we focus on the impact of atomic defects on the electronic states and structural properties of FeSe and $FeSe_{1-x}S_x$ superconducting crystals. By means of scanning tunneling microscopy measurements, we reveal the type of defects present in the surface of the samples and characterize the entailed structural modifications. In both materials, we report the presence of dumbbell defects composed of two brighter spots in the STM topographies. The density of these defects is similar in both samples, constituting ~2% of the total spots in the topographies. Applying DFT simulations considering the inter- and intra-layer van der Waals interactions and the magnetic moments of Fe atoms we elucidate that the dumbbell defects lead to a redistribution of the electron cloud of the surrounding atoms. However, these defects do not induce a significant modification of the distance between the Fe and the anion atoms. In the $FeSe_{1-x}S_x$ samples, the presence of depressions in the regular chalcogen lattice is detected in the surface with a density similar to the sulfur doping. The results of DFT calculations indicate that S atoms replace Se atoms on the crystal structure and enable us to estimate the sulfur doping. Furthermore, S atoms are located closer to the Fe plane than Se atoms. Considering the large volume of evidence in the literature regarding the correlation between the critical temperature of Fe-based pnictogens and chalcogens with the distance between the Fe and the anion atoms, the results from simulations explain that for low densities of dumbbell defects the T_c of these materials is not affected and elucidate the slightly increase of the T_c in $FeSe_{1-x}S_x$ samples.

ORAL COMMUNICATION 3

TEMPERATURE AND THICKNESS DEPENDENCE OF THE THERMAL CONDUCTIVITY IN 2D FERROMAGNET Fe_3GeTe_2

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The search for materials with low thermal conductivity is key in thermoelectric conversion. Tunneling-like materials by means of their magnetic behavior can allow a precise control of electric transport. Here, we present both experimental measurements and ab-initio calculations of the dependence of the out-of-plane thermal conductivity ($\kappa_\perp$) in the van der Waals (vdW) ferromagnet Fe_3GeTe_2 with thickness and temperature. We observe through Frequency Domain Thermoreflectance (FDTR) measures an increase in $\kappa_\perp$ with thickness indicating a diffusive transport regime with ballistic contributions, consistent with the values of the accumulated thermal conductivity obtained through the resolution of the Boltzmann Transport Equation (BTE) which show an important contribution of phonons with mean free paths between 10 and 200 nm. Furthermore, we also show a reduction in $\kappa_\perp$ in the ferromagnetic transition (200 K) that can be associated to a decrease in the group velocities of the acoustic phonons and an increase in the phonon-phonon Raman modes that couple to the magnetic phase.

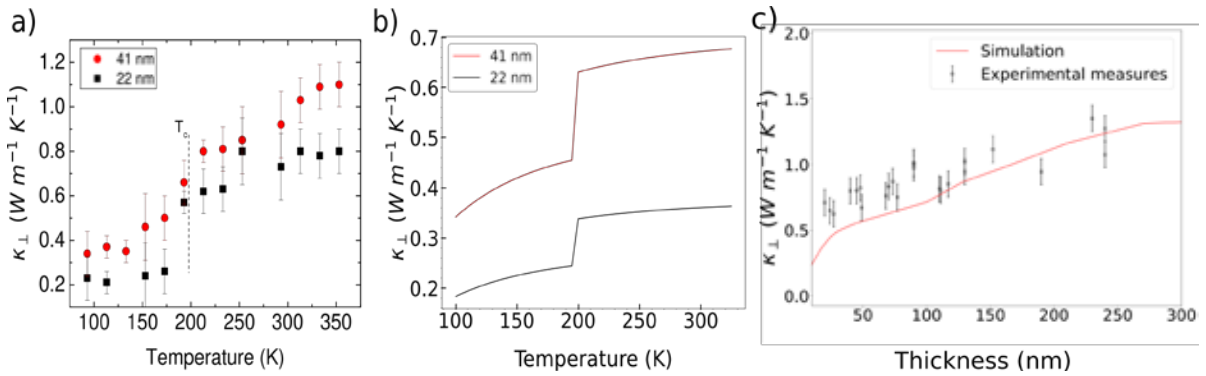

Figure 1 a) Experimental and b) simulated thermal conductivity dependence of Fe_3GeTe_2 with temperature and c) with thickness. The ferromagnetic transition is observed in a) and its behaviour matches with the change in the thermal conductivity simulated in b). The great agreement is highlighted in c) between many different samples and the calculated thermal conductivity.

ORAL COMMUNICATION 4

PROBING SPIN FRACTIONALIZATION WITH ABSOLUTE MAGNETOMETRY ESR-STM

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One dimensional chains of antiferromagnetically coupled spins have gathered significant attention due to their distinct properties, particularly the realization of symmetry protected topological phases. These phases manifest as a gap in the bulk excitation spectrum and the emergence of effective degrees of freedom with fractional spin values at the edges of the chain [1,2]. Recent progress in on surface nanographene Haldane spin chains, studied by means of scanning tunneling inelastic spectroscopy, has provided indirect evidence of fractionalization via the observation of Kondo peaks at the chain edges [3].

In this work, we propose a new approach to study these fractional degrees of freedom using scanning tunneling microscopy electron-spin resonance (STM-ESR)[4] by mapping the stray field generated by the Sz= ±1 states of the low energy manifold in the Haldane spin chain [5]. We use machine learning techniques to invert the Biot-Savart equation and obtain the expectation value of the local spin operators. This provides a direct measurement of two emergent properties: the fractional magnetic moment and the localization length ξ.

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LECTURE 9

Peter Liljeroth is a professor at the Department of Applied Physics, Aalto University. Liljeroth has received the ERC Starting (2011) and Advanced (2018) grants. His research group focusses on probing the atomic scale structure and electronic properties of van der Waals heterostructures, metal-organic frameworks and engineered atomic lattices using low-temperature scanning tunnelling microscopy (STM) and atomic force microscopy (AFM).

VISUALIZING DESIGNER QUANTUM STATES IN VAN DER WAALS HETEROSTRUCTURES

Abstract:
I will introduce how scanning tunneling microscopy can be used to visualize magnetic, ferroelectric and multiferroic orders in monolayer van der Waals (vdW) materials on the atomic scale [1,2]. Subsequently, I will introduce van der Waals (vdW) heterostructures that have emerged as a playground for realizing and engineering exotic quantum states not readily found in naturally occurring materials. Due to the weak bonding between the layers, it is possible to combine materials with very different physical properties in heterostructures. I will highlight these concepts through the examples of realizing topological superconductivity and heavy-fermion physics in vdW heterostructures [3,4].

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LECTURE 10

Alfredo Levy Yeyati is full professor at the Condensed Matter Theory department at Universidad Autónoma de Madrid. His main research interest is on the theory of quantum transport in meso and nano scale systems with special focus on effects due to superconductivity and electronic correlations.

MESOSCOPIC SUPERCONDUCTIVITY: FROM ANDREEV TRANSPORT TO ANDREEV QUBITS

Abstract:
Traditionally, mesoscopic superconductivity has been associated with the exploration of quantum transport in various types of devices including point contacts, weak links and quantum dots with superconducting electrodes. A fundamental concept in this field is that of Andreev reflection, describing the conversion of dissipative currents into supercurrents in a normal/superconducting interface and leading to bound states in hybrid nanostructures. In recent years, the field has witnessed a great evolution with the integration of circuit-QED detection techniques, leading to the demonstration of qubits based on Andreev bound states. In this lecture I will first review the basic theory of Andreev transport, illustrating its application to systems like atomic contacts and hybrid nanowires. In a second part I will discuss the insight on these systems provided by the novel microwave techniques and how to describe them theoretically.

ORAL COMMUNICATION 5

EX-SITU TECHNIQUES FOR GRAIN BOUNDARY-BASED JOSEPHSON JUNCTION OPTIMIZATION

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Superconducting QUantum Interference Device (SQUID) based magnetometers are an established technology with diverse application fields, including Magnetoencephalography, for which extremely high magnetic field sensitivity, in the order of tens of $\mathrm{fT}/\sqrt{\mathrm{Hz}}$, is required.
High-Temperature Superconductor-(HTS)-based systems show promise with lower operation costs and reduced magnetometer distance when compared to Low-Temperature (LTS) counterparts. However, they are not yet mature enough to compete with LTS magnetometers, mainly due to the low yield of sensitive HTS SQUIDs based on cuprates, such as $YBa_2Cu_3O_{6+x}$ (YBCO). The superconducting characteristics of YBCO are indeed influenced by the loss of oxygen, which unavoidably occurs during the fabrication process. In the case of SQUID magnetometers, this process usually implies multiple lithography steps.
Two approaches were taken to work around this issue.
First, the fabrication process was modified to reduce the number of lithographies and therefore mitigate degradation of thin film and junction properties. An increase of 5-6 times the junctions' original critical current densities was achieved.

Secondly, based on the work done previously in [1] on thin films, and in [2] for nanowire-like junctions and Groove Dayem Bridges, we explored oxygen content manipulation of Grain-Boundary based SQUIDs, therefore transport properties tuning, through various ex-situ techniques, particularly ozonation and oxygen annealing.
Our findings indicate that low-temperature (250 °C) annealing in oxygen effectively reduces the critical current density and overall doping of the thin film. Instead, ozonation increases the current density, effectively converting degraded non-superconducting SQUIDs at 77 K into functional SQUIDs with voltage modulation depths of up to 40 µV and outstandingly low flux noise $4.1\,\mu\Phi_0/\sqrt{\mathrm{Hz}}$ corresponding to a magnetic field noise of $30\ \mathrm{fT}/\sqrt{\mathrm{Hz}}$ for a 9x9 mm^2 pick-up loop. Furthermore, the impact of ozonation persists across numerous cooldown cycles and for over a month, indicating its potential for long-term utilization.
Further research is needed, but these initial findings are promising and potentially leading to a more reliable HTS processing technology for magnetometers in biosensing.

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ORAL COMMUNICATION 6

QUANTUM THERMODYNAMICS WITH A SINGLE SUPERCONDUCTING VORTEX

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The idea of using vortices as information carriers holds great promise for quantum computing and superconducting electronics. This is mainly due to the topological protection of the vortices combined with their fast dynamics which can be controlled with electric current, and the possibility of engineering their placement. For progress in vortex electronics, the dissipation arising from manipulation of a single vortex must be understood. We measure the heat released as a result of the vortex expulsion from a single vortex box (SVB).

Recently we have shown that a Dayem nanobridge can be used both as a fast nanosecond resolving thermometer [1] and a sensitive vortex detector [2]. Combining the bridge with a nanosquare thus allows to study the state of a single vortex trap along with its electron temperature. This combination makes it possible to track thermal processes originating from the motion of a single vortex in a type II superconductor [3].

Using current pulses, we demonstrate complete control over a single vortex: trapping it on demand, verifying its presence and expelling it from the SVB. We track thermal transients resulting from vortex expulsion using nanoscale switching thermometry. We measure the energy of $4*10^{-19}$ J dissipated during the expulsion. Such energy release at low temperature leads to significant rise in the electron temperature of ~200 mK. The cooling time of the box is about 400 ns, in agreement with electrons thermalizing with phonons. We observe the current threshold for vortex expulsion and see its magnetic field dependence. The asymmetry of this threshold for two current polarizations manifests the vortex diode effect.

The proposed vortex testing and manipulation comprises the basis of a fast superconducting memory cell, with the rate of operation determined by the thermodynamics of the vortex. We anticipate that such memory is compatible with superconducting qubits and rapid single flux quantum circuits.

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ORAL COMMUNICATION 7

RESISTIVITY AND HEAT CAPACITY STUDIES UNDER HYDROSTATIC PRESSURE IN THE LOCALLY NON-CENTROSYMMETRIC SUPERCONDUCTOR $CeRh_2As_2$

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The heavy-fermion superconductor $CeRh_2As_2$, $T_c = 0.35$ K, has attracted a lot of attention due to the existence of two different superconducting states in magnetic field applied along the crystallographic *c* axis of the tetragonal crystal structure [1]. The two superconducting states are currently understood as even- and odd- parity states [2]. In addition, the compound hosts an ordered phase below $T_0 = 0.5$ K, proposed to be a quadrupole density wave order [3].

We apply hydrostatic pressure to study the unconventional nature of the superconductivity and its interplay with the T_0 order by conducting electrical resistivity measurements on $CeRh_2As_2$ down to 30 mK, in magnetic fields up to 18 T and at hydrostatic pressures up to 2.7 GPa [4]. We trace the pressure evolution of the superconducting phases for the magnetic field applied in the basal plane and along the crystallographic *c* direction as well as of the T_0 order. After an initial increase, the superconducting transition temperature T_c decreases down to 0.23 K at 2.7 GPa, and both superconducting phases persist. The T_0 order is highly sensitive to lattice compression and is completely suppressed around 0.5 GPa [5]. The rate of suppression determined by electrical resistivity measurements is about -1 K/GPa, which is confirmed by complementary heat capacity measurements under pressure in zero magnetic field.

The fact that both superconducting phases persist well above the pressure where T_0 is suppressed suggests that the T_0 order is not responsible for the phase switching from the even to the odd parity state. However, superconductivity in $CeRh_2As_2$, as in other unconventional superconductors, emerges around a quantum critical point induced by the suppression of the T_0 order.

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ORAL COMMUNICATION 8

EVALUATING CRITICAL TEMPERATURES FOR FERROMAGNETIC ORDER IN SOLIDS: BEYOND THE RANDOM PHASE APPROXIMATION

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This research work investigates thermodynamic properties of magnetic materials using the Heisenberg model with localized interacting spins. As the mean field theory for magnetism fails in 2D by contradicting Mermin-Wagner theorem, we resort to the Green's function methods and the Holstein-Primakoff(HP) bosonization method. Even though the Green's function based Random Phase Approximation(RPA) is a common approach to determine critical temperatures, it underestimates the critical temperature for larger spin regimes and predicts the wrong ground state behavior for 2D materials. In this work, we try to compare the performance of RPA to a much more accurate scheme for Green's function method proposed by Herbert Callen[1] and as well as to HP bosonization with interacting magnons for ferromagnetic systems in both bulk and 2D. We start by considering a model with nearest neighbour interactions and show that the Callen's method yields much better agreement with the HP approach as well as the classical limit obtained from Monte Carlo(MC) simulations. We then apply the method to the cases of bcc Fe, fcc Ni and fcc Co with exchange interactions obtained from first principles and show that the Callen's method yields better agreement with experimental Curie temperatures than RPA. Finally, we consider 2D materials where magnetic anisotropy is crucial for magnetic order. We first address the ambiguity of single ion anisotropy associated with RPA. It is shown that in contrast to RPA, the treatmet of single ion anisotropy by Callen's method and HP bosons with higher order terms always yields the correct lack of order for $S = 1/2$ materials. For nearest neighbour 2D lattices(square, hexagonal and honeycomb), we follow the same approach as in cubic by comparing the classical limit of critical temperature by all methods to the classical MC simulations for a range of anisotropies. To validate the predictions, we apply these methods to the monolayer CrI3. Considering the ambiguity in first principle exchange parameters of CrI3, we rely on experimental magnon energy and spin wave gap to obtain the exchange parameters. We observe that the HP method yields closer agreement to the experimental critical temperature of 45 K.

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ORAL COMMUNICATION 9

SUPERCONDUCTING PHASE DIAGRAM AND SPIN DIODE EFFECT VIA SPIN ACCUMULATION

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Spin-split superconductors offer new functionality compared to conventional superconductors such as diode-effects and efficient thermoelectricity. The superconducting state can nevertheless only withstand a small amount of spin-splitting. Here, we self-consistently determine the spin transport properties and the phase diagram of a spin-split superconductor in the presence of an injected spin accumulation. Energy and spin relaxation are accounted for in the relaxation time approximation via a single effective inelastic scattering parameter. We find that the spin-splitting field in the superconductor enables a spin diode effect. Moreover, we consider the superconducting phase diagram of a system in contact with a spin accumulation and in the presence of spin relaxation, and find that the inclusion of energy and spin relaxation alters the phase diagram qualitatively. In particular, these mechanisms turn out to induce a superconducting state in large parts of the phase diagram where a normal state would otherwise be the ground-state. We identify an FFLO-like state even in the presence of impurity scattering which can be controllably tuned on and off via the electrically induced spin accumulation. We explain the underlying physics from how the superconducting order parameter depends on the non-equilibrium modes in the system as well as the behavior of these modes in the presence of energy and spin relaxation when a spin-splitting field is present.

ORAL COMMUNICATION 10

CONTROLLING MAGNETIC INTERACTIONS BETWEEN S=1/2 SPINS AT UNUSUALLY LARGE DISTANCES

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The control of the coupling between spins is key for future technological applications in the fields of spintronics and quantum information, providing as well an opportunity for fundamental studies and the exploration of exotic physics [1,2]. However, conventional magnetic coupling, present in *d* and *f* transition metal atoms, is generally restricted to the atomic scale and exchange energies are of the order of a few meV, limiting thermal stability and practical implementations.

In this work, we put forward graphene as a platform where atomically tailored magnetic moments extend and interact significantly beyond the atomic scale. Using inelastic electron tunneling spectroscopy we reveal, and atomically resolve, the long range magnetic coupling that takes place in this material when modified by the chemisorption of H atoms. Although graphene is non-magnetic in its pure form, single H atoms introduce a spin ½ magnetic moment on the graphene lattice [3]. We study the spin excitations of magnetized graphene states, tailored with different atomic arrangements of H (see Figure 1). The measured exchange energies (J) of both ferromagnetic and antiferromagnetic configurations of H pairs on graphene are in the range of 5-80 meV, indicating a robust thermal stability of the quantum states. We demonstrate the large spatial extension of the magnetic coupling (at least up to 9 nm) and the ability to spatially map the spin excitation probability with atomic resolution.

Our results present this physical system as a potential platform for quantum simulation or for realizing two level systems that could be exploited in quantum information technologies.

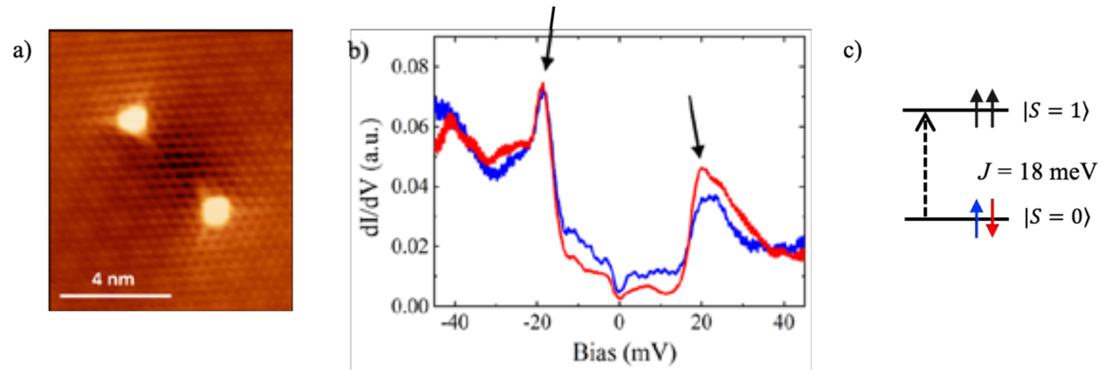

Figure 1. a) STM image of 2 H atoms adsorbed on opposite graphene sublattices. b) dI/dV spectra measured on each of the H atoms. Black arrows indicate inelastic tunneling peaks associated with the energy of the spin excitation. c) Energy levels of the configuration. By IETS we are probing the singlet (S=0) to triplet (S=1) transition.

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ORAL COMMUNICATION 11

EXPLORING MAGNETIC INSULATOR PROXIMITY EFFECT IN 2D BIPHENYLENE NETWORK FROM FIRST-PRINCIPLES CALCULATIONS

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On-surface chemistry has gained a lot of interest since in the last years has become a powerful tool to the realization of new emerging low-dimensional materials.[1,2] Here, we report a first-principles investigation of the magnetic proximity effect on the recently synthesized 2D sp^2-hybridized carbon allotrope biphenylene network (BPN)[3] (Figure 1a), caused by the deposition on an yttrium iron garnet (YIG) magnetic surface (Figure 1b). Our calculations reveal a robust hybridization between the BPN p_Z orbitals and the surface states of YIG at the interface with a non-homogeneous electron transfer due to the complexity of the surface (Figure 1c). Besides, the proposed methodology has been demonstrated to reproduce accurately the complex magnetic interactions in the well-known magnetic insulator YIG, so we explore the effect of the contact with the atomic thin BPN sheet in the magnetic properties of the substrate for the first time. On the other hand, as the applied external pressure to a heterostructure has been proved to be a useful method to vary the van der Waals distance on the interface,[4] we study the effect of this distance in the electronic and magnetic properties of BPN where we find a different charge transfer distribution of the electronic density and an enhancement of the magnetic proximity effect.

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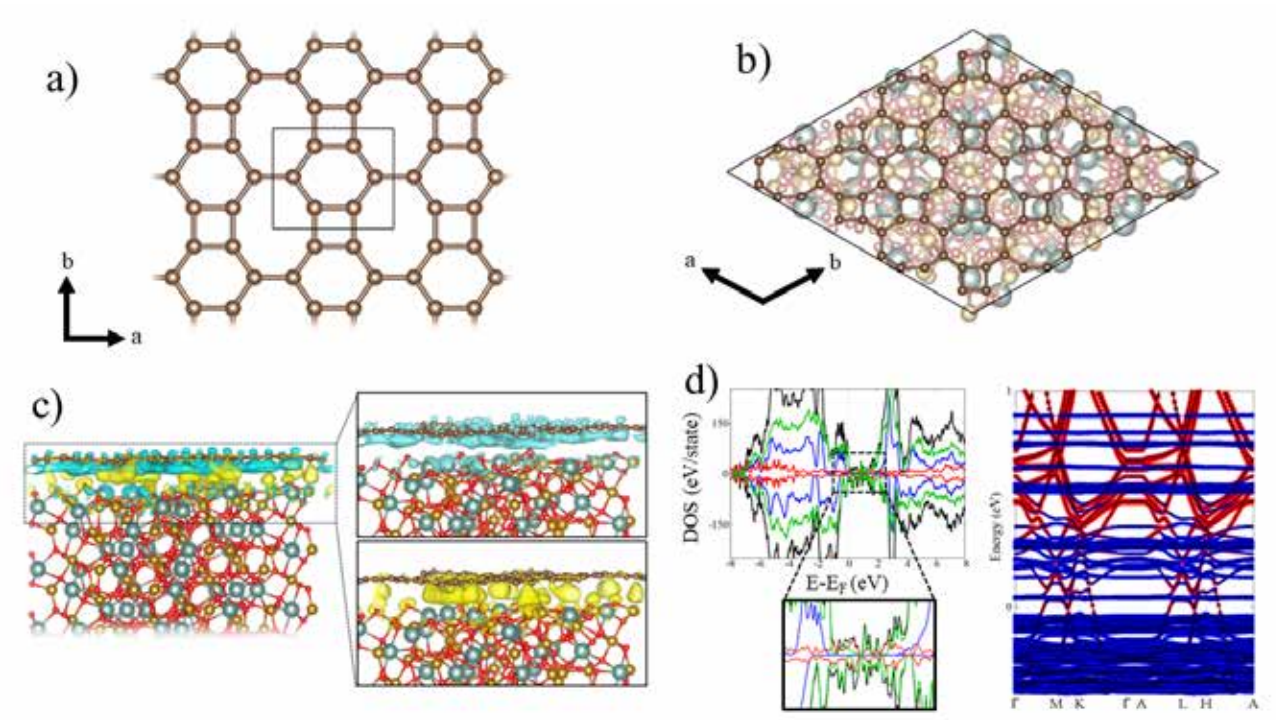
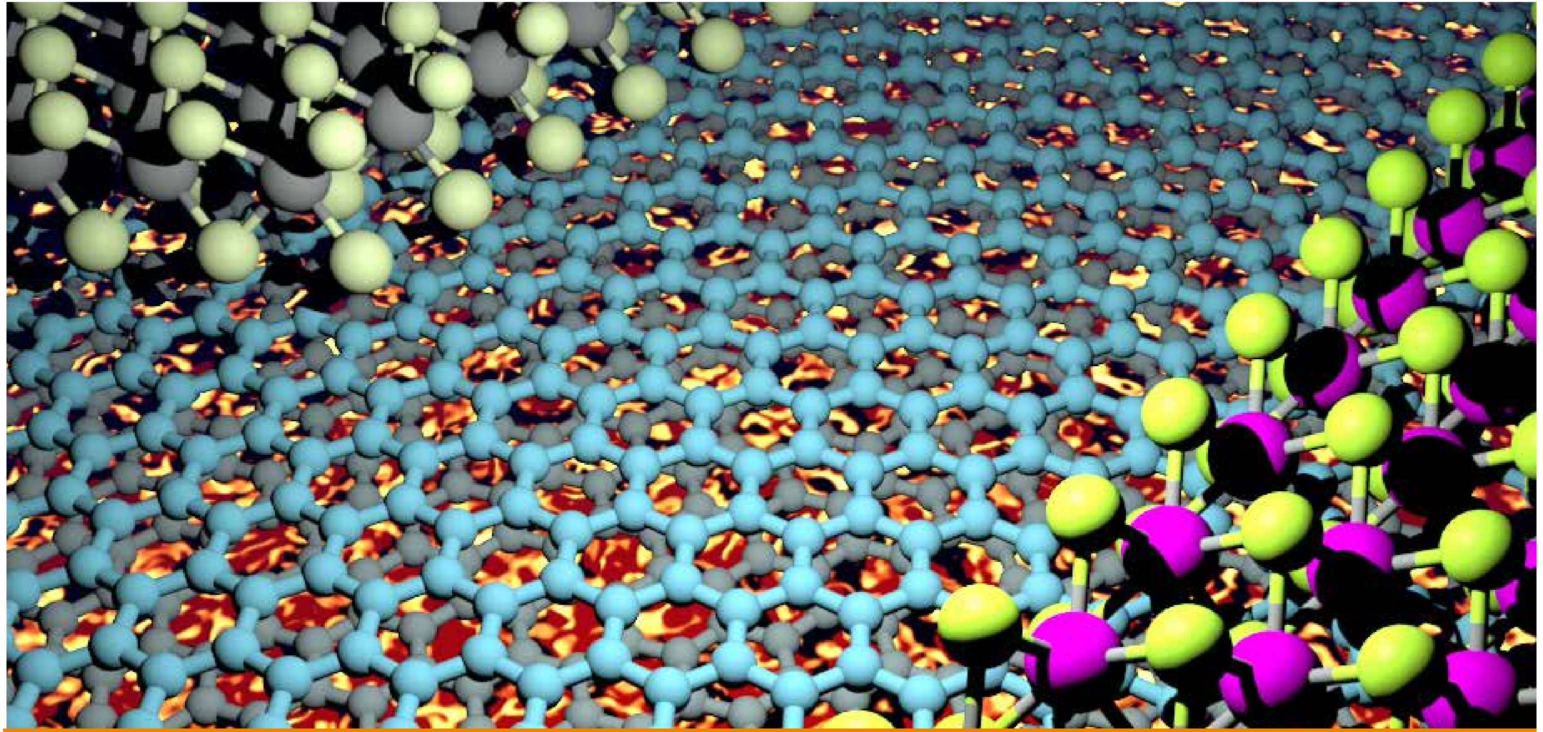


Fig 1. (a) BPN monolayer structure and its conventional unit cell. (b) Top view of the BPN – [111] YIG surface heterostructure. (c) Charge density difference after BPN deposition on [111] YIG surface. Color code: blue (yellow) regions represent charge depletion (accumulation). Zoom sections show separately the charge depletion (top) and accumulation (bottom). Isosurface is set to 0.001 e/A^3. (d) Density of states (DOS) of the BPN – YIG heterostructure (left). Color code: Total DOS (black), YIG bulk-like atoms (blue), YIG surface atoms (green) and BPN C atoms (red). Electronic band structure of the BPN – YIG heterostructure (right). The blue (red) color indicates the contribution of the YIG (BPN) atoms.



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