School on quantum materials and workshop on vortex behavior in unconventional superconductors

7-12 October, 2018

“Bom Jesus” site, Braga (Portugal)

Abstract Book

www.nanocohybri.eu

NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Contents

Aims and Scope

The School on quantum materials and the accompanying workshop on vortex behavior in unconventional superconductors brings together experts in the synthesis, modeling and characterization of materials showing radically new behavior, together with those that use or would like to use quantum materials to produce novel functionalities in devices. During the school, speakers will cover the Physics of quantum materials from a pedagogical point of view providing a guideline for young students and postdocs to advance in their work. The workshop includes outstanding contributions about specific applications of quantum materials of topical significance and allows young researchers to present and discuss their results to their peers.

This meeting is organized by the COST Action "Nanoscale coherent quantum hybrid devices for superconducting quantum technologies" (www.nanocohybri.com) and takes place at the "Bom Jesus" site close to the city of Braga, in Portugal (www.hoteisbomjesus.pt) from the 8th to 12th October 2018.

Themes of the meeting include:

- Design and characterization of quantum materials.
- Strong correlations in quantum materials.
- Quantum transport and SQUID technologies.
- Topological properties of quantum materials.
- Quantum computation.
- 2D materials.
- Proximity devices.
- Interface superconductivity.
- Vortex behavior in thin films.
- Vortex pinning in d-wave superconductors.
- Unconventional and topological superconductors.
- Superconducting sensors and devices.

Organizers

- Szabolcs Csonka (Budapest)
- Elvira González (Madrid)
- Alicia Gómez (Madrid)
- Isabel Guillamón (Madrid)
- Gleb Kakazei (Oporto)
- Dieter Kölle (WG Leader, Tübingen)
- Brigitte Leridon (WG Leader, Paris)
- Floriana Lombardi (Goteborg)
- Anna Palau (Barcelona)
- Jose Gabriel Rodrigo (Madrid)
- Hermann Suderow (Chair, Madrid)
- Francesco Tafuri (Vice Chair, Napoli)

Grant Manager and Organization support: Irene González (Madrid)

The scientific committee consists of the Management Committee members of the COST Action and their substitutes. The list is available at http://www.cost.eu/COST_Actions/ca/CA16218?management

Sponsors & Supporters

Lecturers and Invited Speakers

NAME	FIRST NAME	ORGANISATION
BLACK-SCHAFFER	**Annica**	*Uppsala University*
BUCHACEK	**Martin**	*ETH Zurich*
CANFIELD	**Paul**	*Ames Lab and Iowa State University*
CARUSO	**Roberta**	*Università di Napoli Federico II*
CAYAO	**Jorge**	*Uppsala University*
CRISAN	**Ioan Adrian**	*National Institute For Materials Physics*
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FORN-DIAZ	**Pol**	*Barcelona Supercomputing Center*
GALVIS	**Jose Augusto**	*Universidad Central*
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HASSANIEN	**Abdou**	*Jozef Stefan Institute*
HERRERA VASCO	**Edwin**	*Universidad Autónoma de Madrid*
KADOWAKI	**Kazuo**	*University of Tsukuba*
KATO	**Masaru**	*Osaka Prefecture University*
KÖLLE	**Dieter**	*Eberhard-Karls-Universität Tübingen*
LOMBARDO	**Joseph**	*Université de Liege*
MACCARI	**Ilaria**	*"La Sapienza" University*
MASSAROTTI	**Davide**	*Universita' Federico II di Napoli*
MAÑAS-VALERO	**Samuel**	*University of Valencia*
MIRKOVIC	**Jovan**	*Montenegrin Science Promotion Foundation PRONA*
MOILANEN	**Antti**	*Aalto University*
MOSHCHALKOV	**Victor**	*KU Leuven*
PALAU	**Anna**	*Institut de Ciència de Materials de Barcelona (ICMAB-CSIC)*
PALYI	**Andras**	*Budapest University of Technology and Economics*
PANGHOTRA	**Ritika**	*KU Leuven*
RAMOS	**Miguel Angel**	*Universidad Autónoma de Madrid*
RIBEIRO	**Raquel**	*Ames Lab and Iowa State University*
ROCHET	**Antonine**	*Laboratoire Nanophotonique Numérique et Nanosciences*
RODITCHEV	**Dimitri**	*ESPCI-ParisTech*
ROLLANO	**Victor**	*IMDEA Nanociencia*
SAMUELY	**Peter**	*Institute of Experimental Physics, Slovak Academy of Sciences*
SILAEV	**Mikhail**	*Jyvaskyla University*
TAFURI	**Francesco**	*Universitá di Napoli Federico II*
TAMEGAI	**Tsuyoshi**	*University of Tokio*

TOSI	**Leandro**	*Commissariat à l'énergie atomique et aux énergies alternatives*
TRAINER	**Dan**	*Temple University*
TRAN	**Lan Maria**	*Institute of Low Temperature and Structure Research, Polish Academy of Sciences*
VALENTI	**Roser**	*Goethe University Frankfurt*
VARLAMOV	**Andrey**	*CNR-SPIN*
VINOKOUR	**Valerii**	*Argonne National Laboratory*
WISSBERG	**Shai**	*Bar Ilan University*
ZYUZIN	**Alexader**	*Aalto University School of Science*

Venue and travel information

VENUE

The Bom Jesus site has an astonishing view of the city of Braga. In the hilltop there is the XVIII century sanctuary surrounded by a large park with several gardens, artificial lakes, and other infrastructures.

The meeting will start on the 7th of October afternoon, with registration and dinner at the Sala Colunata. The scientific program will start on the 8th in the morning and continue till the 12th of October around lunch time. Talks will be given at the Sala Torre, in the first floor of the Colunata building. Lunch and dinner will be served at the Sala Colunata (except on Monday, where dinner will be served at the Sala Arcada close to the garden of the Hotel Elevador). Further information about the site can be found at www.en.hoteisbomjesus.pt/otros-eventos

Map of the surroundings of the site

TRAVEL INFORMATION

How to get to Bom Jesus, Braga

By Car

Address

Bom Jesus do Monte
4715-056 Braga
Portugal

GPS coordinates

41°33'14.59"N
8°22'40.69"W

By Plane

Oporto's Airport

The closest airport to Braga is the Oporto's Airport (called Francisco Sá Carneiro Airport). It is 50 km away from Braga.
We strongly advise to flight to this airport.

Others

If you plan to take the train or bus to get to Braga by your own, you will arrive at Braga city centre.
Bom Jesus do Monte, the workshop venue, is located about 7 km away from Braga city centre.
The taxi between Braga city centre and Bom Jesus do Monte costs approximately 10€.

Braga bus station can be conveniently reached from Porto (Francisco Sa Carneiro) Airport using the direct shuttle service GetBus www.getbus.eu . Taxis from and to Braga bus and train station are the most convenient option to reach the meeting place afterwards.

For those participants travelling by car, there is a free of charge parking place near the hotels. Nevertheless, to enter the park is required the payment of €1.00 per car. Please ask for the respective ticket in order for the hotel to return that value.

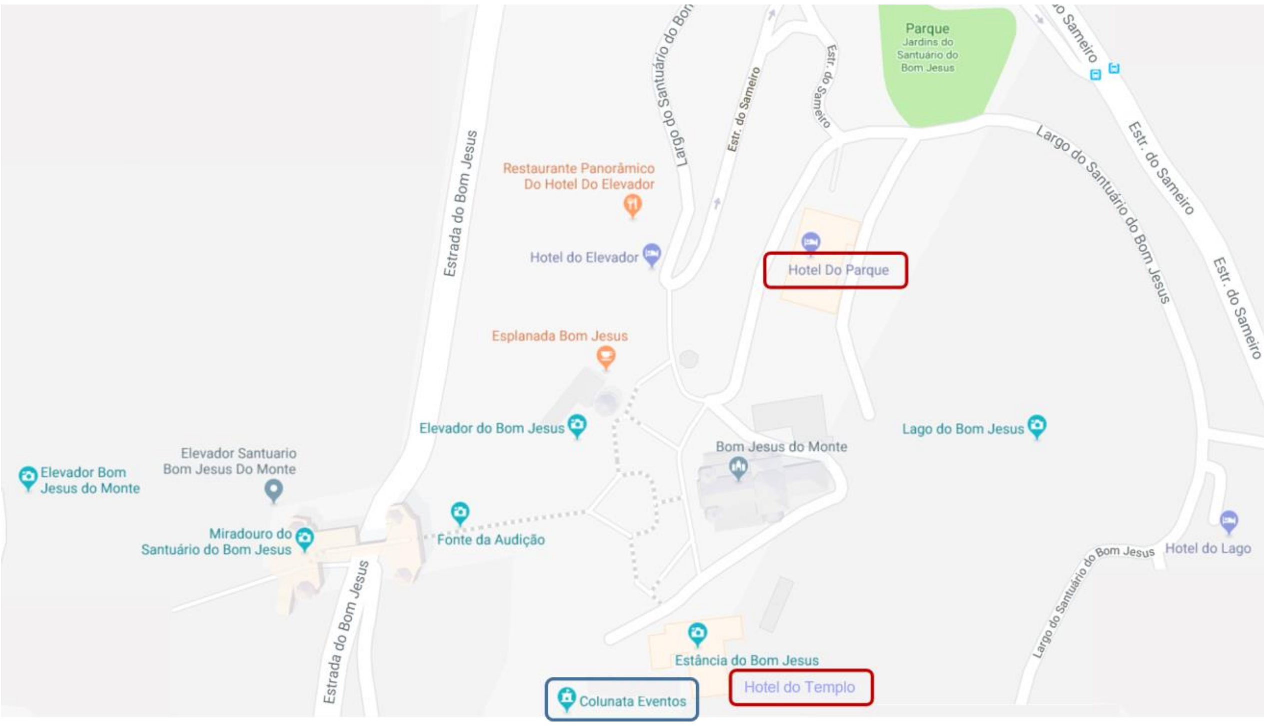
ACCOMMODATION

Most of the participants will stay at the Hotel do Parque and at the Hotel do Templo:

https://en.hoteisbomjesus.pt/hotel-do-parque-in-braga/

https://en.hoteisbomjesus.pt/hotel-do-templo-in-braga/

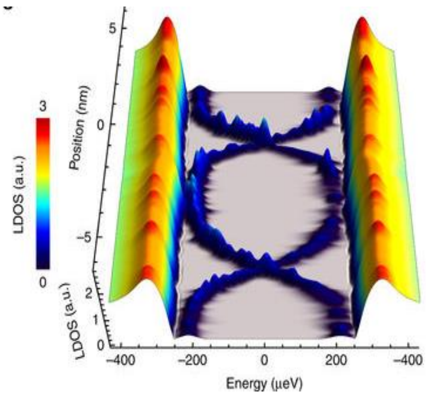
There is a short walk between these hotels and the conference room (Sala Colunata)



Colunata de eventos

The COST Action Nanocohybri

The COST Action Nanocohybri is open to scientists from 27 European countries and collaborators all over the world. Nanocohybri kicked-off in November 2017 and will last until end of April 2021. Nanocohybri provides instruments for networking activities aimed to fulfil the objectives of the Action and managed using simple rules. Nanocohybri organizes approximately two meetings each year, promotes exchanges through short term visits and provides opportunities for young researchers to present work related to the Action in other meetings. The Management Committee approves activities following COST excellence and inclusiveness policy. All details, including time and budgetary frames as well as eligibility issues are available at the COST Vademecum.

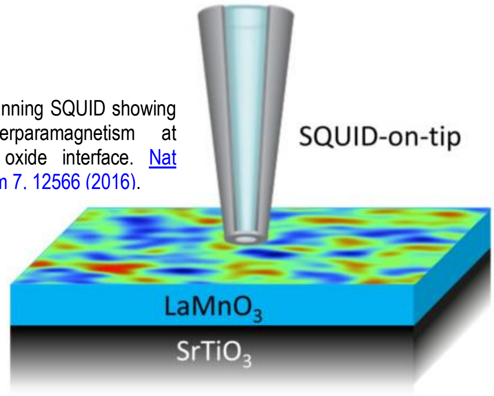


Topological superconductivity in monolayer of Pb covering Co-Si islands, see Nat Comm 8, 2040 (2017).

Nanocohybri is triggered by the amount of fundamental knowledge obtained in superconducting systems and the recently acquired ability to control magnetic flux, electron charge and spin in devices. Much of the topical research in this area is being carried out all over Europe in the subfields of low dimensional systems, hybrids between superconductors and magnets or semiconductors, and nanoscale engineering for current carrying applications. The scientific and methodological approaches in these fields are similar and there is an important potential for cross-fertilization. The challenge is to use the understanding achieved and control the main superconducting parameters in devices to produce radically new behaviour. The Action has three working groups:

- Working group 1 (WG1). Low dimensional and hybrid systems. WG1 deals with two-dimensional and ultra-thin film superconductors. Nanofabrication techniques include lithography, controlled constrictions, exfoliation and systems capable to produce devices composed of layers of different materials. Characterization is made through photoemission spectroscopy, tunnelling microscopy, micro-Raman, quantum transport or ultrafast optics. New imaging techniques available at large-scale infrastructures (such as X-ray holography at synchrotron radiation sources) are also used. Theory analyses quantum transport from numerical studies using standard systems for superconductivity and ab-initio calculations. WG1 is lead by Brigitte Leridon.

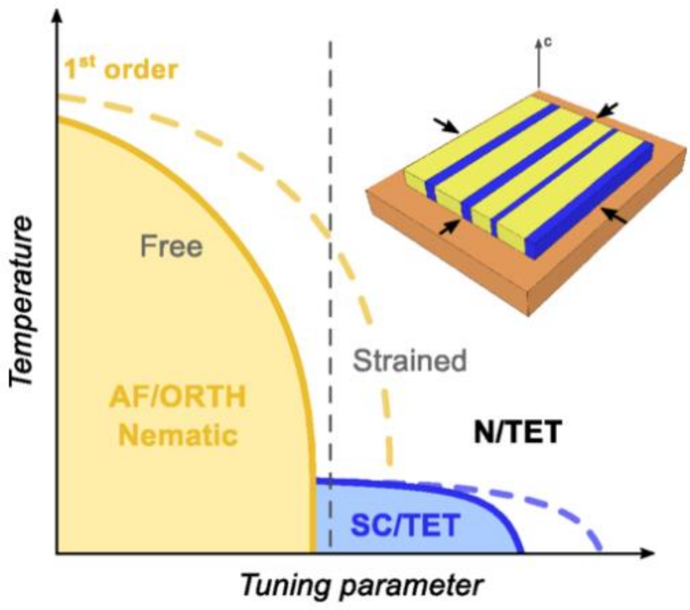
Scanning SQUID showing superparamagnetism at an oxide interface. Nat Com 7. 12566 (2016).



- Working group 2 (WG2). Novel devices from hybrid interfaces. The involved groups aim to integrate materials where the Cooper pair wave function has a sign change into devices, for example cuprates or topological insulators and other materials with topologically non-trivial surface states into Josephson junction circuits. We also study superconductor/ferromagnetic hybrids in detail, looking at novel modulated phases. Techniques include microscopic bandstructure calculations and measurements of the Josephson effect using transport experiments. We use advanced microscopies, including SQUID-on-a-tip and magnetic force. WG2 is lead by Alexander I. Buzdin.

- Working group 3 (WG3). Hybrids with nanoscale vortex pinning and nanofabrication for high magnetic fields. We explore vortex pinning and current transport at low temperatures and high magnetic fields, in cuprate as well as in pnictide superconductors. We control fabrication techniques allowing to make pinning on demand and to study the collective behaviour of the vortex lattice in presence of patterned arrays of nanostructures. We also address the influence of

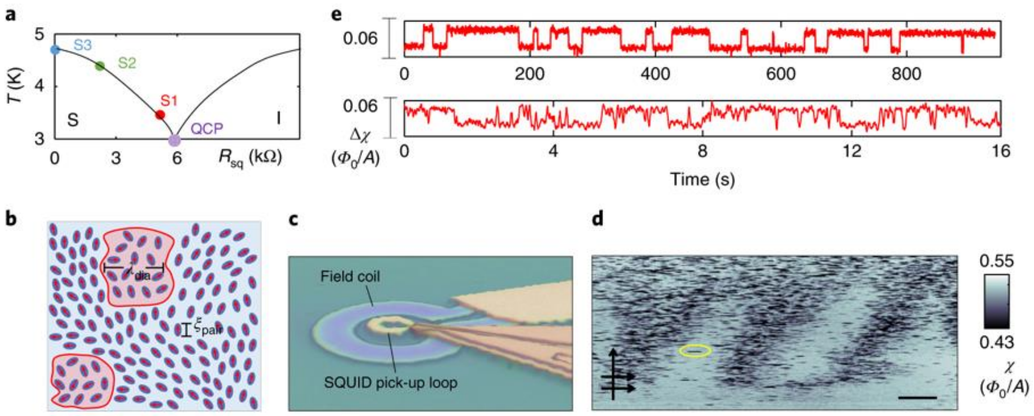
Strain induced normal and superconducting stripes in a pnictide superconductor, Phys Rev B 97, 014505 (2018).



structural or electronic distortions (such as nematicity), particularly close to quantum criticality, in the enhancement of superconducting parameters. Working methods include microscopy, correlated with transport calculations in superconductors, three-axis nanoSQUID and vortex manipulation. WG3 is lead by Dieter Kölle.

The Action's short term visits and conference grants are examined by a committee lead by Gleb Kakazei. The Action includes working groups responsible for dissemination (lead by Yonathan Anahory), collaboration with industrial partners (lead by Teresa Puig), gender monitoring (lead by Floriana Lombardi) and a virtual laboratory to promote exchanges among participants (lead by Daniela Stornaiolo).

Quantum fluctuations near criticality. Nat Phys (2018)



The Action started by organizing a workshop entitled "Coherent superconducting hybrids and related materials", in France, in March 2018, organized by Dimitri Roditchev and Brigitte Leridon. The workshop brought together leading research groups working in the area of quantum superconducting devices, finely tuned Josephson junctions and networks, THz emitters and antennas, single particle photon detectors or qu-bits etc. The present School and workshop is the second large meeting of the Action. It aims to provide students with the basic tools to work through the objectives of the Action. To this end, it includes lectures with ample time to explain basic aspects. Themes have been selected to provide the needed basics and include quantum materials, simulation, quantum transport, applications in form of q-bits, magnetism, topology in quantum systems, nanostructuring and microscopy. Immediately following the lectures, we have organized a program including many young researchers and a few members of the Action, particularly working in WG1 and WG3. Participants will discuss latest advances and the format will allow young people to present their work in form of talks (at the level of senior researchers) or posters (for the younger students).

Schematic Program

Time	Monday	Tuesday	Wednesday
	Design and properties of Quantum Materials	Design and properties of Quantum Materials	Topology in Quantum Materials
8:50	Opening		
9:00	Canfield	Canfield	Palyi
10:00	Valentí	Valentí	Palyi
	Coffee Break		
	Josephson junctions and SQUID for Quantum Materials	Josephson junctions and SQUID for Quantum Materials	Topology in Quantum Materials
11:30	Kölle	Tafuri	Black-Schaffer
12:30	Kölle	Tafuri	Black-Schaffer
	Lunch break and time for discussions		
	Quantum devices and computation	Quantum devices and computation	Nanoscale superconductivity and magnetism
15:00	Tosi	Tosi	Moshchalkov
16:00	Forn	Forn	Guslienko
	Coffee Break		Excursion
	Nanoscale techniques	Nanoscale superconductivity and magnetism	
17:30	Roditchev	Moshchalkov	
18:30	Roditchev	Guslienko	
	Dinner		

Time	Thursday	Friday
	Low dimensional systems	Coexisting orders in superconductors
8:50	Vinokur	Galvis
9:20	Varlamov	Ribeiro
9:40	Moilanen	Mañas
10:00	Hassanien	Herrera
10:20	Wissberg	Tran
10:40	Trainer	Samuely
	Coffee Break	
	Vortices	Multiband and hybrid superconductivity
11:30	Buchacek	Csonka
11:50	Massaroti	Silaev
12:10	Mirkovic	Cayao
12:30	Crisan	Caruso
12:50	Maccari	Rollano
13:10	Rochet	Zyuzin
	Lunch break and time for discussions	13: 30 Closure
	Mesoscopic superconductivity	Lunch at 13:40 and departure
15:00	Palau	
15:20	Tamegai	
15:40	Ramos	
16:00	Kato	
	Coffee Break	
16:50	Lombardo	
17:10	Panghotra	
17:30	Kadowaki	
18:00	Flash poster session and discussion	
	Dinner	

Detailed Program

Monday, 8th October 2018		
08:50-9:00	**Opening**	**H. Suderow**, Chairman
9:00-11:00	Session I *Design and properties of quantum materials*	
09:00	*Design and growth of novel materials*	**Canfield** Ames Laboratory, US
10:00	*Microscopic Modelling of Quantum Materials from First Principles*	**Valentí** Goethe-Universität Frankfurt, Germany
11:00-11:30	**Coffee Break**	
11:30-13:30	Session II *Josephson junctions and SQUID for Quantum Materials*	
11:30	*Basic properties of Josephson junctions*	**Kölle** Universität Tübingen, Germany
12:30	*Superconducting quantum interference devices : basic properties and applications of SQUIDs*	**Kölle** Universität Tübingen, Germany
13:30-15:00	**Lunch**	
15:00-17:00	Session III *Quantum devices and computation*	
15:00	*Mesoscopic Superconductivity*	**Tosi** CEA-Saclay, France
16:00	*Superconducting quantum circuits for quantum information processing*	**Forn** Barcelona Supercomputing Center, Spain
17:00-17:30	**Coffee Break**	
17:30-19:30	Session IV *Nanoscale techniques*	
17:30	*Scanning Methods in the studies of superconductors*	**Roditchev** ESCPI, France
18:30	*Scanning Methods in the studies of superconductors*	**Roditchev** ESCPI, France
20:30	**Dinner**	

Tuesday, 9th October 2018		
9:00-11:00	**Session V** ***Design and properties of quantum materials***	
09:00	*Synthesis as the heart of New Materials Physics*	**Canfield** Ames Laboratory, US
10:00	*Hands on Quantum Materials Simulations*	**Valenti** Goethe-Universität Frankfurt, Germany
11:00-11:30	**Coffee Break**	
11:30-13:30	**Session VI** ***Josephson junctions and SQUID for Quantum Materials***	
11:30	*The Josephson effect: quantum & material issues, and extreme conditions*	**Tafuri** Università di Napoli Federico II, Italy
12:30	*The Josephson effect: quantum & material issues, and extreme conditions*	**Tafuri** Università di Napoli Federico II, Italy
13:30-15:00	**Lunch**	
15:00-17:00	**Session VII** ***Quantum devices and computation***	
15:00	*Mesoscopic Superconductivity*	**Tosi** CEA-Saclay, France
16:00	*Superconducting quantum circuits for quantum information processing*	**Forn** Barcelona Supercomputing Center, Spainb
17:00-17:30	**Coffee Break**	
17:30-19:30	**Session VIII** ***Nanoscale superconductivity and magnetism***	
17:30	*Nanostructured superconductors: quantum matter at low temperatures*	**Moschalkov** KU Leuven, Belgium
18:30	*Magnetic Skyrmions in Restricted Geometry: Stability and Dynamics*	**Guslienko** Ikerbasque, Spain
20:30	**Dinner**	

Wednesday, 10th October 2018		
9:00-11:00	**Session IX** ***Topology in quantum materials***	
09:00	*Topological insulators in 1D and 2D*	**Palyi** Budapest University of Technology and Economics, Hungary
10:00	*Topological insulators in 1D and 2D*	**Palyi** Budapest University of Technology and Economics, Hungary
11:00-11:30	**Coffee Break**	
11:30-13:30	**Session X** ***Topology in quantum materials***	
11:30	*Topological superconductivity*	**Black-Schaffer** Uppsala University, Sweden
12:30	*Topological superconductivity*	**Black-Schaffer** Uppsala University, Sweden
13:30-15:00	**Lunch**	
15:00-17:00	**Session XI** ***Nanoscale superconductivity and magnetism***	
15:00	*Nanostructured superconductors: quantum matter at low temperatures*	**Moschalkov** KU Leuven
16:00	*Magnetic Vortex Stability, Reversal and Dynamics in Restricted Geometry*	**Guslienko** Ikerbasque
17:00-20:00	**Excursion**	
20:30	**Conference Dinner**	

Thursday, 11th October 2018		
8:50-11:00	**Session XII** *Low dimensional systems*	
8:50	*Gauge Theory of the Superconductor-Insulator Transition*	**Vinokour** Argonne National Laboratory, US
09:20	*Formation of Abrikosov's lattice due to quantum fluctuations above Hc2(0)*	**Varlamov** SPIN-CNR, Italy
09:40	*Bose–Einstein condensation in a plasmonic lattice*	**Moilanen** Aalto University, Finland
10:00	*Interactions of Two Dimensional Electron Gas with a Nanoscale Superconductor Investigated at the Atomic Scale*	**Hassanien** Jozef Stefan Institute, Slovenia
10:20	*Local view of superconducting fluctuations*	**Wissberg** Bar Ilan University, Israel
10:40	*Electronic properties of one or few-layers MoS2 films*	**Trainer** Temple University, US
11:00-11:30	**Coffee Break**	
11:30-13:30	**Session XIII** *Vortices*	
11:30	*Strong pinning theory of thermal vortex creep*	**Buchacek** ETH Zurich, Switzerland
11:50	*Electrodynamics of tunnel-ferromagnetic Josephson junctions*	**Massaroti** Università Federico II di Napoli, Italy
12:10	*Vortex States in Layered $Bi_2Sr_2CaCu_2O_{8+\delta}$ Superconductors in Tilted Magnetic Fields*	**Mirkovic** PRONA, Montenegro
12:30	*Anomalous Vortex Dynamics in Isovalent Optimally Doped Pnictide Superconductor $BaFe_2(As_{0.68}P_{0.32})_2$ revealed by AC and DC magnetic measurements*	**Crisan** National Institute of Materials Physics Bucharest, Romania
12:50	*Vortex physics in 2D disordered superconductors*	**Maccari** La Sapienza University, Italy
13:10	*Optical generation of single vortex/anti-vortex pairs in superconducting films*	**Rochet** Université de Bordeaux, France
13:30-15:00	**Lunch**	

15:00-16:20	**Session XIV** *Mesoscopic superconductivity*	
15:00	*Electrochemical Modulation of Metal Insulator Transition in High Temperature Superconductors*	**Palau** ICMAB-CSIC, Barcelona
15:20	*Critical States of Three-dimensional Nanostructured Superconductors*	**Tamegai** University of Tokio, Japan
15:40	*Superconductivity in boron-doped diamond by ion-beam irradiation*	**Ramos** UAM, Spain
16:00	*Molecular Dynamics Simulation on Vortex Motion in Mesoscopic Superconductors*	**Kato** Osaka Prefecture University, Japan
16:20-16:50	**Coffee Break**	
16:50	*Shaping the superconducting properties of nanoscale junctions by electromigration*	**Lombardo** Université de Liège, Belgium
17:10	*Scanning tunnelling spectroscopy on lithographically defined mesoscopic structures*	**Panghotra** KU Leuven, Belgium
17:30	*On the higher power THz emitters from IJJ mesa structures of Bi2212 single crystals and their applications for THz spectroscopy*	**Kadowaki** University of Tsukuba, Japan
18:00-20:00	**Flash poster session and discussion**	
20:30	**Dinner**	

Friday, 12th October 2018		
8:50-11:00	**Session XV** *Coexisting orders in superconductors*	
8:50	*Quantum criticality at the heart of a high-temperature superconductor*	**Galvis** Universidad Central, Colombia
09:20	*Pressure-induced multiple phase transitions of BaBi3 superconductor*	**Ribeiro** Iowa State University, US
09:40	*Superconductivity and magnetism in layered materials: the cases of 2H- and 1T-TaS2*	**Mañas** Universidad de Valencia, Spain
10:00	*Electronic and structural properties in the superconducting phase of URu2Si2*	**Herrera** UAM, Spain
10:20	*Unconventional behavior in Co- and Ca-doped EuFe2As2 magnetic-superconductors*	**Tran** Polish Academy of Sciences, Poland
10:40	*Ising superconductivity in bulk (LaSe)1.14(NbSe2)m=1,2 misfit layer compound*	**Samuely** Slovak Academy of Sciences, Slovakia
11:00-11:30	**Coffee Break**	
11:30-13:30	**Session XVI** *Multiband and hybrid superconductivity*	
11:30	*Spin-orbit coupling induced Weyl points and topologically protected Kondo effect in a two-electron double quantum dot*	**Csonka** Budapest University of Technology and Economics, Hungary
11:50	*Structure and dynamics of vortex states in multiband superconductors*	**Silaev** University of Jyväskylä, Finland
12:10	*Odd-frequency superconducting pairing in junctions with spin-orbit coupling*	**Cayao** Uppsala University, Sweden
12:30	*Low temperature characterization of low-dissipation ferromagnetic Josephson junctions*	**Caruso** Università Federico II di Napoli, Italy
12:50	*Topologically protected superconducting ratchet effect generated by spin-ice magnets*	**Rollano** IMDEA Nanociencia, spain
13:10	*Topological excitations in two-component superconductor*	**Zyuzin** Aalto University, Finland
13:30	**Closure**	**H. Suderow** Action Chairman
13:40	**Lunch and Departure**	

Abstracts

Paul C. CANFIELD

Ames Laboratory, Ames, Iowa 50011, USA and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

Design and growth of novel materials

The ability to design, discover and grow single crystals of new materials is the starting point of a New Materials Physics research effort. In this talk I will introduce the conceptual as well as experimental tools needed for the discovery and growth of single crystals via solution growth. An emphasis will be placed on the need to understand compositional phase diagrams. Examples of a large number of growths will be given.

Synthesis as the heart of New Materials Physics

Humanity needs to find the materials that will ease its growing needs for reliable, renewable, clean, energy and/or will allow for greater insight into the mysteries of collective and, in some cases, emergent states. The design, discovery and growth of novel materials is the heart of the research effort that will, hopefully, address these needs. In this talk I will present a broad overview of New Materials Physics and describe how a practitioner can go from staring at the periodic table to deciding what ``the next growth will be''. I will present and discuss the three basic motivations for making a growth: wanting a specific compound; wanting a specific ground state; searching for known and unknown unknowns. Materials discussed will span superconductors, quasicrystals, heavy fermions, fragile magnets, topological electronic systems, local moment magnets and a few other lost puppies. The goal of this talk is to inspire and entertain, any resemblance to persons living or dead is coincidental.

Email: canfield@ameslab.gov

Roser VALENTÍ

Institut für Theoretische Physik, Goethe-Universität Frankfurt, 60438 Frankfurt am Main, Germany

Microscopic Modelling of Quantum Materials from First Principles

In this lecture we will introduce quantum materials from a first principles perspective. We will present the basic concepts of density functional theory and apply them to obtain a microscopic description of quantum materials. We will then show how to extract electronic and magnetic properties and how to use the method for material design. Finally we will discuss the strengths and limitations of such an approach.

Hands on Quantum Materials Simulations

In this lecture we will present step by step examples of material simulations from first principles (Fe-based superconductors, transition-metal-oxide heterostructures) and will introduce various complementary methods to improve upon density functional theory in order to describe correlations and quantum effects.

Email: valenti@itp.uni-frankfurt.de

Dieter KOELLE

Physikalisches Institut and Center for Quantum Science in LISA+, Universität Tübingen, 72076 Tübingen, Germany

Basic properties of Josephson junctions

Josephson junctions are the basic elements of superconducting electronics, and they play an important role both for applications in the classical and quantum regime. In this lecture, I will introduce basic concepts that are used to describe the properties of Josephson junctions in the classical regime. These concepts form the basics for understanding the electric transport and noise characteristics of Josephson junctions, and proper modeling of such characteristics is important for developing and optimizing Josephson based devices vor various kinds of applications.

Superconducting quantum interference devices : basic properties and applications of SQUIDs

SQUIDs are the most sensitive detectors of magnetic flux, and their operation is based on the combination of fluxoid quantization and Josephson effects in superconductors. In this lecture, I will introduce basic concepts that are used to describe and optimize the properties of SQUIDs, with focus on thermal noise properties and sensitivity of direct current (dc) SQUIDs. Furthermore, techniques for SQUID readout, and some appliations of SQUIDs will be described.

Email: koelle@uni-tuebingen.de

Leandro TOSI

Quantronics Group, SPEC, CEA-Saclay

Mesoscopic Superconductivity

Superconductivity at the mesoscopic scale has been an extremely active field of research in the last 30 years. I will present some of the basic concepts which help understanding recent experiments and allow fabricating new types of quantum devices. The following subjects will be treated:Superconductivity in conductors with a small number of transport channels: can a supercurrent flow through a single atom? What is the mesoscopic description of the Josephson effect?

Quantum bits based on Andreev Bound States: Which fundamental experiments do they allow to perform? What are the differences with other superconducting quantum bits?

A large part of the lectures will be devoted to the description of experimental methods used for probing the transport and spectroscopic properties of superconducting devices: circuits fabrication, measurements of current-voltage characteristics, of small supercurrent, of the local density of states, circuit quantum electrodynamics (c-QED) setups…

Email: leandro.tosi@cea.fr

Pol FORN

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Superconducting quantum circuits for quantum information processing

Superconductivity is a manifestation of macroscopic quantum effects. The wave function of a block of superconducting material therefore exhibits collective properties, allowing the whole superconductor to be considered as an individual quantum system. This macroscopic property of the wavefunction allows one to design lossless circuits where the degrees of freedom behave as quantum operators with their corresponding quantum fluctuations. At sufficiently low temperatures, these quantum fluctuations dominate over all other kinds of fluctuations -particularly temperature- leaving the circuit to obey the laws of quantum mechanics in a unitary way. Using this basis, it has become possible to realize superconducting circuits which exhibit anharmonic spectra and can be treated as an atom artifically engineered whose quantum state can be initialized, controlled and read out with extremely high accuracy. The scalability of these circuits to grow into large-size devices has turned them into one of the strongest contenders to build the first quantum processor.

At the core of superconducting circuits lies a nonlinear, nondissipative element known as the Josephson junction. These junctions are responsible for the non-harmonicity of the circuit resonances, which is the key element to manipulate the quantum state of the circuit at will. Josepshon junctions can be fabricated with high quality and reproducibility thanks to three decades of investigation of this superconducting technology.

The first lecture will be dedicated to explain the rules of circuit quantization and the physics of different types of superconducting qubits. A short introduction on Josephson physics will be needed to present the qubit family.

The second lecture will be focused on microwave quantum optics, with particular emphasis on the light-matter interaction models used to describe the interaction between superconducting qubits and resonators. This qubit-resonator system is the basis of building scalable superconducting quantum processors.

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Scanning Methods in the studies of superconductors

Since the invention of the Scanning Tunneling Microscopy (STM) in 1981 a variety of scanning microscopies and spectroscopies appeared, enabling a deeper insight into electronic, magnetic, structural and other relevant properties of materials with a nanometer or even atomic spatial resolution. In the field of superconductivity these methods are particularly powerful, as they access directly several relevant spatial and energy scales of the quantum phenomenon.

In the first part of the lecture, I will give a minimalistic yet necessary theoretical basis of the Scanning Tunneling Microscopy and Spectroscopy (STM/STS), and will present the essential steps and requirements of its implementation. Other scanning methods, such as Magnetic Force Microscopy, Scanning SQUID Microscopy will be introduced. Some well-known experimental achievements in the condensed matter physics using STM/STS will be presented. Finally, several important results of STM/STS and other scanning studies of superconductors will be discussed.

In the second part of the lecture, I will focus on recent achievements: proximity phenomena, vortex matter, electron confinement, effects of impurities on superconductivity. Finally, the trends in scanning methods will be discussed.

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The Josephson effect: quantum & material issues, and extreme conditions

An integrated quantum device can be better than the sum of its ingredients. Only a smart combination of different platforms can provide transformational solutions, useful for a variety of quantum applications. A key issue is to make use of the best characteristics of different quantum systems. Photons can efficiently and durably transmit quantum information (QI), superconducting qubits can be rapidly manipulated to enable fast QI processing, while solid-state spin ensembles are particularly suited for long-lived quantum memories. Josephson junctions play a crucial role for all superconducting circuits and are the key elements for most types of superconducting qubits.

We will revise concepts and technologies of Josephson junctions of different types and materials down to the nanoscale when applicable, focusing on their quantum features. Searching in the richness of the properties of materials or of controlled hybrid hetero - structures, innovative solutions can be found to face novel challenges also in view of interfacing superconducting modules with other platforms and of new avenues in coupling schemes between the qubit processor and SC waveguide cavities. We classify some significant behaviors of hybrid and unconventional junctions through a comparative study of fluctuations and electro-dynamical properties.

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Nanostructured superconductors: quantum matter at low temperatures

Lecture 1. Nanostructured superconductors provide a unique opportunity to use quantum-mechanical principles to obtain properties needed for applications, by using nanostructuring to modify and control the coherent condensate of the Cooper pairs responsible for the appearance of superconductivity. Designing specific properties through the application of quantum mechanics is *"quantum design"* – a key idea in nanosciences. Superconductors, with their inherent quantum coherence over even macroscopic scale, not to mention nanoscale, are in that respect superior to semiconducting or normal metallic nanomaterials, where quantum coherence is much more difficult to achieve. In that respect nanostructured superconductors is the best choice for the demonstration of applicability of *quantum design* to tailor specific properties.

Like for a particle in a box, properties of the confined condensate in nanostructured superconductors can be designed using quantum laws. In contrast to the classical approach, which relied upon the search for new bulk materials each time a specific combination of their physical properties was required; nanosciences rely upon the modification of the properties of the same material through its nanostructuring and the optimization of the confinement potential and topology. Importantly, developing and applying systematically principles of quantum design of superconducting critical parameters will bridge the *"paradigm gap"* from superconductors by serendipity to superconductors by design. This is certainly a groundbreaking challenge in basic sciences with potentially very high impact for technology. Controlling the vortex behavior and creating a guided vortex motion via nanoengineering, makes it possible to develop new devices like micronet superconducting transistors, vortex lenses, switches, etc. This paves the way for designing new generation of fluxonics devices based on the controlled behavior of vortices (fluxons).

Lecture 2. An brief overview will also be given of recently discovered new forms of exotic vortex matter in superconductors: Karman vortex streets, giant vortices, vortex chains and vortex clusters and chains in type-1.5 superconductors, symmetry-induced antivortices. Direct experimental observation of magnetic dipoles generated by the Meissner current at topological defects (antidots) in superconducting film will be also discussed. Each magnetic dipole can be considered as a pair of fluxoids with opposite polarities. Remarkably, the magnetic flux of each pole and antipole is not necessarily quantized and can carry all non-integer momenta between integer values. However, the total magnetic flux of each dipole remains zero, which fully complies with the quantum character of superconductivity. The magnetic dipoles also provide an efficient way to measure the local intensity and direction of flowing supercurrent, which is rather difficult to realize in any other way. (Nature Com. 6, Article No: 6573, 2015; NANO LETTERS Volume: 17 Issue: 8 Pages: 5003-5007, 2017; Nature Communications Volume: 7 Article Number: 13880, 2016)

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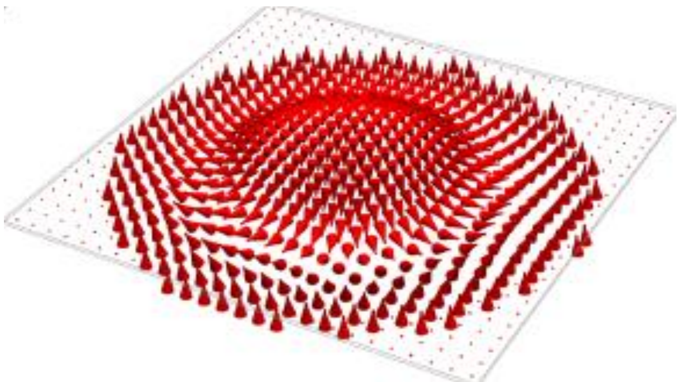
Magnetic Skyrmions in Restricted Geometry: Stability and Dynamics

Magnetic skyrmion is a kind of topological soliton, a non-trivial inhomogeneous magnetization texture on the nanoscale. Skyrmions can be manipulated by spin polarized currents of extremely low density in comparison with the densities used in traditional spintronics[1]. Recently the individual skyrmions were experimentally obsreved at room temperature in Co/Pt, Ir/Co/Pt etc. ultrathin multilayer structures, including magnetic dots. To achieve efficient manipulation of the nanosized spin textures and realize skyrmion-based new brand spintronic devices, it is essential to understand skyrmion stability and dynamics in restricted geometries.

In this talk I focus on the skyrmion stability and spin excitations in ultrathin cylindrical magnetic dots. The skyrmion can be stabilized at room temperature due to interplay of the isotropic exchange, interface Dzyaloshinskii-Moriya (DMI), perpendicular magnetic anisotropy and magnetostatic interaction[2]. We consider Bloch- and Neel- skyrmions (see Figure) and calculate their stability/metastability phase diagrams. The chiral DMI induced on the interfaces of heavy metals with ultrathin ferromagnetic layers (0.5-1 nm) is crucial for the Neel skyrmion stabilization. The calculated spin wave eigenfunctions/ eigenfrequencies are classified according to number of nodes of the dynamical magnetization in the radial and azimuthal directions[3]. The low-frequency skyrmion gyrotropic modes are in sub-GHz frequency range[4] and can be exploited in spin-torque nano-oscillators. The skyrmion eigenfrequencies are represented as functions of the skyrmion equilibrium radius, dot radius and the dot magnetic parameters. Recent experiments on magnetic skyrmion stabilization and dynamics in multilayer films and nanodots are discussed.



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Magnetic Vortex Stability, Reversal and Dynamics in Restricted Geometry

Magnetic vortices are typically the ground states in geometrically confined ferromagnets with small magnetocrystalline anisotropy [1]. In this talk I review static and dynamic properties of the magnetic vortex state in small particles with nanoscale thickness and sub-micron lateral sizes (magnetic dots). Magnetic dots made of soft magnetic material shaped as flat circular and elliptic cylinders are considered. Such mesoscopic dots undergo magnetization reversal through successive nucleation, displacement and annihilation of magnetic vortices. The reversal process depends on the stability of different zero-field magnetization configurations with respect to the dot geometrical parameters and application of an external magnetic field.

Magnetic vortices reveal rich, non-trivial dynamical properties due to existence of the vortex core bearing a topological charge [1]. The vortex ground state magnetization leads to a considerable modification of the nature of spin excitations in comparison to those in the uniformly magnetized state. Magnetic vortex possesses a characteristic excitation known as a translational (gyrotropic) mode that corresponds to spiral-like precession of the vortex core around its equilibrium position. There are, above the translation mode eigenfrequencies, several magnetization eigenmodes localized outside the vortex core whose frequencies are determined principally by dynamic demagnetizing fields appearing due to restricted dot geometry. The vortex excitation modes are classified as translation modes and radially or azimuthally symmetric spin waves over the vortex ground state. The vortex core polarization can be reversed if the core velocity is above some critical value [2]. We consider also nonlinear vortex spin torque oscillator dynamics in a circular magnetic nanodot induced by a spin-polarized current perpendicular to the dot plane [3]. We use a generalized nonlinear Thiele equation including spin-torque term by Slonczewski for describing the vortex core transient and steady orbit motions.

Typically the vortex dynamics studies are focused on thin dots with thickness 5–50 nm and only uniform across the thickness vortex excitation modes are observed. Spin excitation modes related to the thickness dependent vortex gyrotropic dynamics were detected in GHz frequency range in relatively thick (50–100 nm) dots and interpreted as exchange dominated flexure oscillations of the vortex core string with nodes along the dot thickness [4]. The fundamental mode frequency cannot be explained without introducing a giant vortex mass, which is a result of the vortex distortion due to interaction with azimuthal spin waves [5]. Studying the spin eigenmodes in such systems provides valuable information to relate the magnetic particle dynamical response to geometrical parameters.

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Topological insulators in 1D and 2D

A key goal with one-dimensional topological insulators is to realize robust, noise-tolerant quantum computing. The noise tolerance can be illustrated with a simple non-superconducting tight-binding model, called the Su-Schrieffer-Heeger model. I will introduce this model, highlight its topological properties (edge states, bulk topological invariant), and discuss its connection to quantum computing.

Two-dimensional topological insulators are known for the robust electronic transport: their edge states are insensitive to disorder, leading to quantized edge conductance. Starting from the concept of adiabatic pumping in one dimension, I will introduce two-dimensional Chern insulators (where time-reversal symmetry is broken) and time-reversal invariant topological insulators. I will demonstrate the robustness of the edge states, and discuss the experimental results showing quantized conductance.

Lecture notes:
J. K. Asboth, L. Oroszlany, A. Palyi
A Short Course on Topological Insulators: Band-structure topology and edge states in one and two dimensions
https://arxiv.org/abs/1509.02295

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Topological superconductivity

Topological states of matter have emerged in the last few years as one of the absolute most vibrant areas of condensed matter physics. These range from topological insulators and Weyl semimetals but also an abundance of different topological states in superconductors. The defining property for all these phases of matter is a global non-trivial topology of their electronic structure. This is fundamentally different from the traditional Landau paradigm traditionally used to classify matter, where local order parameters appearing due to spontaneous symmetry breaking 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, that can be viewed as half electron quasiparticles offering unique possibilities to realize robust quantum computation.

In these two talks I will cover the basic theory of topological superconductivity. Starting from an elementary understanding of conventional BCS superconductivity and topological insulators, I will discuss several different topological superconducting states, focusing especially on how and why Majorana fermions appear as topological protected edge states.

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Gauge Theory of the Superconductor-Insulator Transition

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The standard model of particle physics is extraordinarily successful at explaining much of the physical realm. Yet, one of the most profound aspects of that model, the mechanism of confinement, that binds quarks into hadrons and is supposedly mediated by chromo-electric strings in a condensate of magnetic monopoles [1-3], is not thoroughly understood and lacks direct experimental evidence. We demonstrate that the infinite-resistance superinsulating state [4-7], emerging at the insulating side of the superconductor-insulator transition (SIT) [8-12] is an easy accessible experimental desktop realization of the quark confinement. We show that the mechanism ensuring the infinite resistance of superinsulators is the binding of Cooper pairs into neutral “mesons” by electric strings and establish a mapping of quarks onto Cooper pairs in superinsulators. We derive the linear confinement of Cooper pairs in both two- and three dimensions and generalize the concept of superinsulation onto 3D systems. We calculate the deconfinement temperature, which in 2D coincides with the Berezinskii-Kosterlitz-Thouless (BKT) transition temperature. We reveal a Cooper pair analogue of the asymptotic freedom effect [13] implying that systems smaller than the string scale appear in a quantum metallic state. We construct the phase diagram of the critical vicinity of the SIT and find the criterion for realizing either the direct SIT or the transition via an intermediate Bose metal phase which is shown to be a bosonic topological insulator. Our findings offer a powerful laboratory to explore fundamental implications of confinement, asymptotic freedom, and the related quantum chromodynamics (QCD) phenomena via desktop experiments on superconductors.

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Formation of Abrikosov's lattice due to quantum fluctuations above $H_{c2}(0)$

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Basing on the uncertainty principle we propose a simple qualitative picture of both thermal and quantum fluctuations valid in the whole fluctuation region above the upper critical field $H_{c2}(T)$ [1,2,3]. Focusing on the vicinity of the quantum phase transition near zero temperature, we demonstrate that as the magnetic field approaches the line near $H_{c2}(0)$ from above, a peculiar dynamic state consisting of clusters of coherently rotating fluctuation Cooper pairs forms and estimate the characteristic size and lifetime of such clusters.

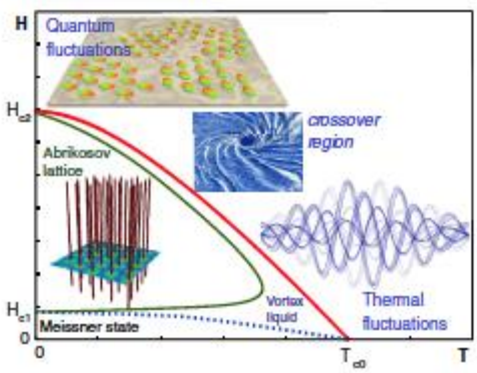

Fig. 1 Schematic phase diagram of type-II superconductors, showing the domains of qualitatively different physical behavior.

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Bose–Einstein condensation in a plasmonic lattice

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A metal nanoparticle array gives rise to quasi-particles called surface plasmon polaritons (SSPs) which are a mixture of light and electron movement in metal. We demonstrate the first Bose-Einstein condensate (BEC) of SPPs in a lattice of gold nanoparticles [1]. Interaction of the SPPs with organic dye molecules placed on top of the array induces thermalization by subsequent absorption and re-emission cycles. With suitable array periodicity this interaction leads to condensation, which occurs at room temperature. The new condensate is also ultrafast, forming in a picosecond timescale. The dynamics are studied in an experiment that utilizes the propagation of the modes and the open cavity character of the system. Linewidth narrowing and increase of the spatial coherence of the mode is observed in response to onset of condensation. Transition from BEC to lasing [2] is observed when the periodicity of the lattice is changed. This new form of condensate has also technological potential due to its ultrafast, room-temperature and on-chip nature.

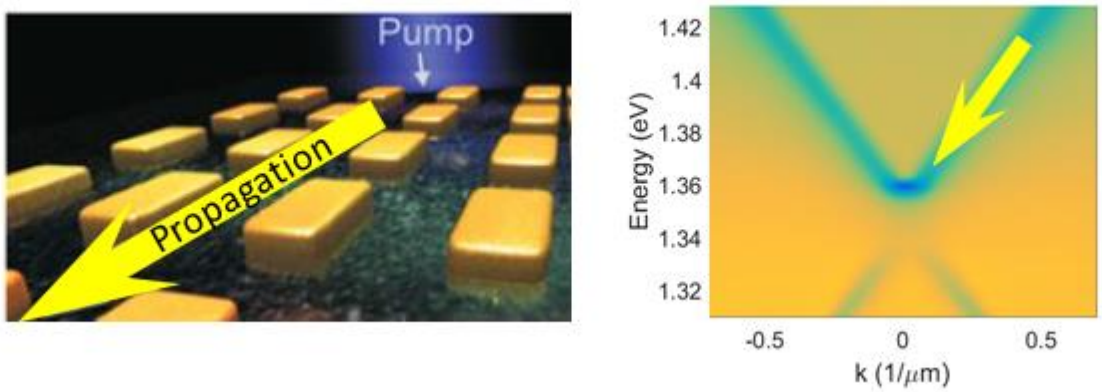

Figure 1. A typical nanorod sample and pump configuration is presented on the left. The transmission spectrum of a nanoparticle array is presented on the right, showing the dispersion bands (darker color). The upper dispersion band is continuous and has a band bottom and band gap at k = 0. Propagating surface plasmon polariton modes undergo a redshift (decrease in energy) due to the absorption and re-emission by fluorescent molecules placed on top of the array, and eventually condense to the bottom of the energy band.

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Interactions of Two Dimensional Electron Gas with a Nanoscale Superconductor Investigated at the Atomic Scale

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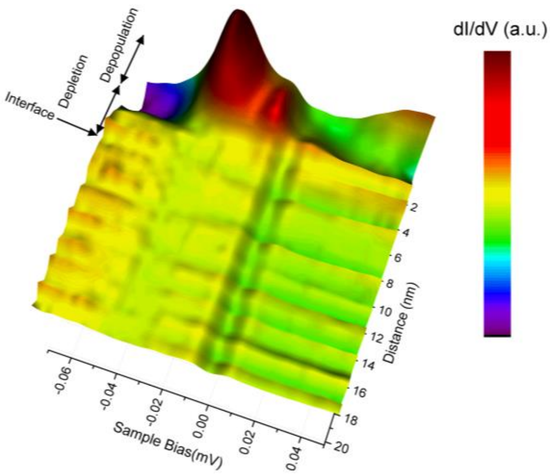
How a d-wave superconductor tolerates interactions with two dimensional electron gas, especially at the atomic scale, is an intriguing question but has yet to be explored. Here, the interfacial phenomena occurring at the interface between an epitaxial monolayer of (BETS)2GaCl4 superconductor and Ag(111) surface is investigated at the atomic limit. Although there is a charge injection from Ag(111) surface, scanning tunneling spectroscopy and density functional theory calculations reveal that BETS dimer still lose a net charge to GaCl4 molecules to generate a superconducting state below a critical temperature of ~ 10K. Interestingly, on bare Ag(111), a spatially dependent gap is still detected at a distance of 4 nm from the interface. Concurrently, a monotonous quenching of surface state electrons is observed before total depletion in the interfacial region. This behavior weakens significantly near the transition temperature causing surface states electrons to induce antiproximity effect which points to their use in manipulating the superconducting ground state properties.



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Local view of superconducting fluctuations

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Superconducting transitions are driven by thermal fluctuations close to the transition temperature, Tc. These fluctuations are averaged out in global measurements, leaving imprints on susceptibility and resistance measurements. We use a scanning superconducting quantum interference device to image thermal superconducting fluctuations in Nb, a conventional BCS superconductor. We observe fluctuations in both space and time which manifest themselves as grains of weaker and stronger diamagnetic response, exhibiting telegraph-like noise as a function of time. Local fluctuations are also found in the imaginary component of the susceptibility demonstrating that the local vortex dissipation can also be used as a probe of the fluctuations. An important outcome of our measurements is the observation and realization that the susceptibility decrease to zero as the temperature is raised towards Tc always occurs in quantized steps irrespective of the sample geometry.

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Electronic properties of one or few-layers MoS2 films

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Atomically thin materials such as single layer Molybdenum Disulfide (MoS2) have emerged as promising candidates for next generation flexible 2D electronics. We report on structural and electronic properties of defects in chemical vapor-deposited monolayer and few-layer MoS2 films. Scanning tunneling microscopy, Kelvin probe force microscopy, and transmission electron microscopy were used to obtain quantitative measurements of the local density of states, work function and nature and mobility of defects. These defects include point defects such as S and Mo vacancies as well as extended defects such as film edges and grain boundaries.

Furthermore, few studies to date have investigated the electronic properties of these materials as a function of applied strain. In this work we use low temperature scanning tunneling microscopy and spectroscopy (STM/STS) to elucidate the effect of strain on the quasiparticle band-gap of monolayer MoS2.

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Strong pinning theory of thermal vortex creep

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Vortex pinning in type-II superconductors is usually described within two distinct frameworks: the weak collective pinning due to fluctuations in the density of weak defects or strong pinning due to independent action of strong point-like defects, applicable in the case of low defect density. We study the effects of finite temperature and vortex creep in the second scenario and calculate the current-voltage characteristic of a type-II superconductor. Our results challenge the common perception of vortex creep and depinning as we predict that the pinning force and effect of thermal activation is visible even well beyond the critical current, where the characteristic is linear and keeps the overall shape calculated for the zero-temperature case [1]. At subcritical drives, creep is characterised by Arrhenius-type motion with activation barriers scaling non-linearly with the driving currents and finally, at very small drives we find thermally assisted flux flow (TAFF) with finite activation barriers.

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Electrodynamics of tunnel-ferromagnetic Josephson junctions

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The continuous progress in material science and nanotechnology has led to the realization of novel types of hybrid Josephson junctions (JJs). These devices are promoting novel solutions, especially in the fields of superconducting electronics and qubits based on JJs. Among different types of hybrid devices, in the last twenty years superconductor-ferromagnet-superconductor (SFS) JJs have emerged, promising advances in the fundamental understanding of the competition between superconducting and magnetic ordering, as well as new device with additional functionalities based on dissipationless spintronics [1, 2].

We will report on the electrodynamic characterization of spin filter JJs [3], composed by a ferromagnetic-insulator GdN barrier, and of SIFS JJs with a barrier composed by an insulating layer and a ferromagnetic layer [4]. Underdamped behaviour, high values of the I_cR_n product, being I_c the critical current and R_n the normal state resistance of the junction respectively, observation of 0-π transitions and the first evidence of macroscopic quantum phenomena [5] through measurements of switching current distributions, make these JJs quite appealing for possible use both in quantum circuits and as cryogenic memories. The low dissipation levels in these junctions and the magnetic properties of the barrier offer new tools for the manipulation of the junction properties. In particular, the capability to control the relevant scaling energy by using magnetic field pulses and microwaves [6], suggests new solutions of hybrid JJs in transmon qubits.

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Vortex States in Layered $Bi_2Sr_2CaCu_2O_{8+\delta}$ Superconductors in Tilted Magnetic Fields

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In extremely anisotropic layered superconductors of $Bi_2Sr_2CaCu_2O_{8+\delta}$ the stacks of vortex pancakes (PV) and the Josephson vortex (JV) interpenetrate, and due to PV–JV mutual pinning energy, weakly interact and form various tilted and crossing lattice structures including vortex chains [1], stripes, mixed chain + lattice phases, etc. In order to enlighten the structure of vortex matter and to detect the dominant phases and transitions, the interaction of Josephson vortices and Abrikosov pancake vortices was investigated by means of the local ac-magnetic permeability measurements by using the miniature local coils and by in-plane resistivity measurements. The vortex matter phase diagram has been established for the whole angular range, in particular, within a few degrees from the *ab*-plane in detail. The first-order vortex melting phase transition [2] has been clearly observed in magnetic fields tilted away from the *c*-axis, indicating the crossing lattice structures [3]. The transition anomaly, separating the strong pinning phase and the weak pinning vortex phase was found by both techniques deep in the vortex solid phase solid near *ab*-plane, indicating crossover from the mixed vortex chains + lattice phase to chains tilted vortex phase. However, at 0.2° from the *ab*-plane, a distinct anomaly was found, suggesting the possibly two-stage melting phase transition in parallel magnetic fields: the vortex-lattice – smectic – liquid phase transition. Another anomaly, in the temperature dependence of resistance in the parallel magnetic fields, indicated the revival of the first-order nature of the transition occurring very close to T_c. While the columnar defects affect strongly the first-order vortex-lattice melting transition, the magnetic permeability anomaly, associated with the crossover from vortex chains + lattice phase to tilted lattice, is surprisingly still clear, quite deep in the vortex solid phase. However, the stronger columnar defects eventually affect the crossover anomaly that it disappears too.

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Anomalous Vortex Dynamics in Isovalent Optimally Doped Pnictide Superconductor $BaFe_2(As_{0.68}P_{0.32})_2$ revealed by AC and DC magnetic measurements

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We have investigated high-quality single crystals of isovalent optimally doped pnictide superconductor $BaFe_2(As_{0.68}P_{0.32})_2$ using DC magnetization, DC relaxation and frequency and amplitude dependent AC susceptibility measurements. Such single crystals have a very rich diagram of vortex matter with a pronounced second magnetization peak [1]. Our DC magnetization measurements up to 14 T revealed intersections between various isothermal magnetization curves, meaning that, for a fixed H, there is an increasing magnetization with increasing temperature, in a certain temperature range. In addition, AC susceptibility measurements show impressive anomalies, as seen in Fig. 1.

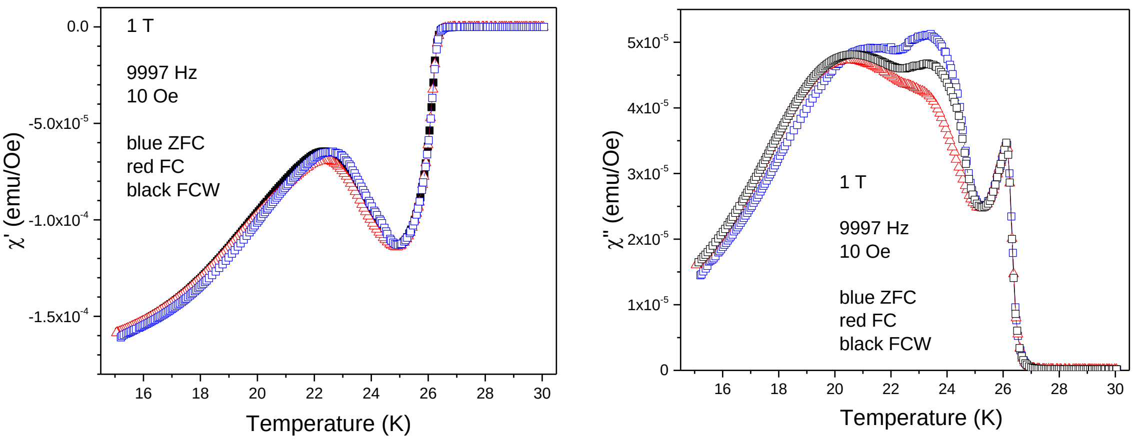

Fig. 1: *Temperature dependence of in-phase (left) and out-of-phase (right) susceptibility in 1 T.*

It can be seen that, in 1T, the diamagnetic response have a clear anomalous decrease with decreasing temperature between 25 and 22 K. Dissipation response has a complex feature, depending on the cooling/warming regime. Measurements done with a lower ac field amplitude revealed a Campbell regime, in which the movement of vortices is within the pinning potential well. Such measurements were performed also at 3, 5, and 7 T, the features being reproduced qualitatively (at 7 T the height of the anomalous peak decreasing), as well as on a different crystal from the same batch, with similar results. Magnetic relaxation measurements also showed anomalous behavior, suggesting various elastic/plastic creep regimes of vortex dynamics.

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Vortex physics in 2D disordered superconductors

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The study of quasi-two-dimensional (2D) superconductors can hardly avoid to take into account the presence of vortices. Many real systems, of both conventional and unconventional superconductors, undergoes the superconductor-insulator transition via the Brezinskii-Kosterlitz-Thouless (BKT) transition, at which the phase coherence of the condensate is destroyed by means of free-vortices proliferation. Quite interesting, the interplay between the vortex-unbinding and the electron inhomogeneity, which spontaneously emerges in thin SC films, makes the role of vortices even more crucial for a deeper understanding of the BKT signature. Indeed, in[1] we have shown, by means of Monte Carlo simulations, that the disorder-induced granularity of the SC state, being spatially correlated, modifies the nucleation mechanism for vortex-antivortex pairs leading to a considerable smearing of the universal superfluid-density jump, as compared to the paradigmatic clean case, in agreement with experimental observations. An other interesting issue concerns the fate of the SC transition in the presence of a finite flux of magnetic field. Indeed, in this case the transition is no longer driven by the vortex-antivortex unbinding, but rather by the melting of the 2D Abrikosov lattice. Such melting, as predicted by the BKT theory, afterwards refined by Halperin, Nelson and Young (BKTHNY), can occur in two steps via an intermediate state called hexatic phase. In real systems, the observation of the two-step BKTHNY melting could be hindered by the presence of additional ingredients, such as random pinning, and also competing phases. In [2], we have shown that the 2-dimensional vortex lattice in a-MoGe thin film follows the BKTHNY sequence of melting as the magnetic field is increased. Identifying the signatures of various transitions on the bulk transport properties of the superconductor, we construct a vortex phase diagram for a 2D superconductor.

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Optical generation of single vortex/anti-vortex pairs in superconducting films

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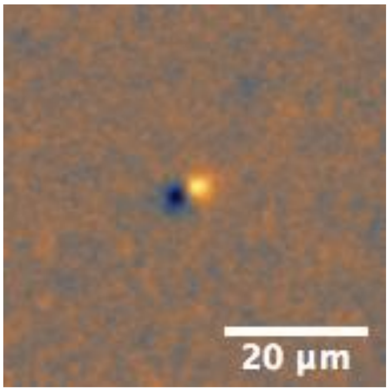

Magneto-optical image of a vortex/anti-vortex pair in a superconducting film of niobium

The penetration of vortices into a superconducting film is usually limited to the edges of the superconductor and is triggered by an external magnetic field or an electrical current. The generation of single vortices at any desired place deep inside a superconductor is thus challenging. This presentation will be dedicated to the first generation of a single vortex/anti-vortex pair inside a superconductor using far field optics. This new method is based on the generation of topological defects via the Kibble-Zurek effect which results from fast cooling after focusing a single laser pulse on a superconducting film initially free of vortex. Combined with the fast and precise optical manipulation of a single vortices [1], this result is promising in the view of ultrafast optical operation of superconducting devices such as Josephson junctions [2].

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Electrochemical Modulation of Metal Insulator Transition in High Temperature Superconductors

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Modulation of carrier concentration in strongly correlated oxides offers the unique opportunity to induce different phases in the same material, which dramatically change their physical properties. Specially, the possibility to reversibly modify the critical temperature transition in high temperature superconductors by means of an electric field, as the external control parameter, is a very active area of research in condensed matter physics and a promising technique to generate new solid-state devices with exciting functionalities.

Here we report on the electric manipulation of the superconducting to insulator phase transition in high temperature superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) films by electrochemical oxygen doping [1]. Vertical and lateral oxygen mobility may be finely modulated, at the micro- and nano-scale, by tuning the applied bias voltage and operating temperatures, thus providing the basis for the design of homogeneous and flexible transistor-like devices with loss-less superconducting drain-source channels. We analyse the experimental results in light of a theoretical mode, which incorporates thermally activated and electrically driven volume oxygen diffusion.

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Critical States of Three-dimensional Nanostructured Superconductors

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We have been studying electromagnetic response of various nanostructured superconductors using magneto-optical (MO) imaging method [1-4]. In the present study, we investigated the flux penetration and critical state in simple three-dimensional bi-layer nanostructured superconductors, such as orthogonal strips ("Crosses") and stacks of squares and rectangles ("Strips"). In these three-dimensional nanostructured superconductors, critical state field profile is not a simple superposition of critical state in each layer. Instead, flux penetration in one layer strongly modifies that of another layer. As an example, MO images of flux penetration into "Strip" structure are shown in Fig. 1. In addition to the ordinary current discontinuity lines (*d*-lines) expected in square and rectangular films, a novel horizontal *d*-line shows up at the center of the structure at low fields. Possible origin of this novel *d*-line will be discussed.

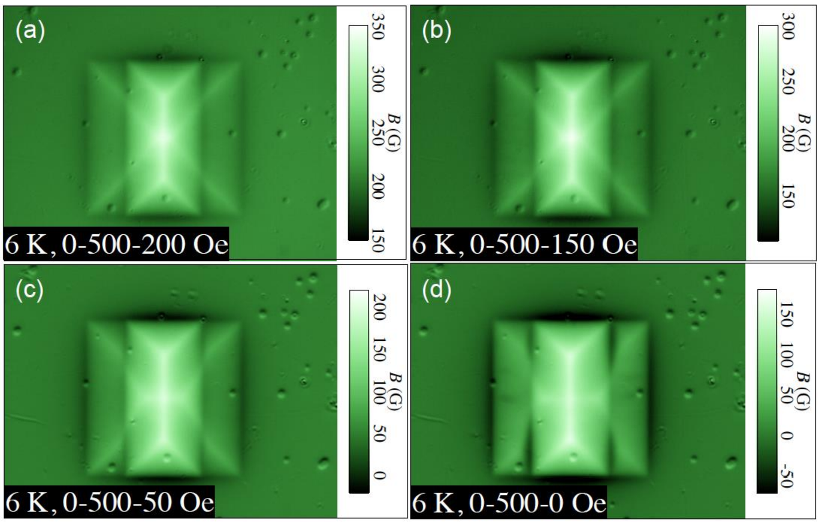

Fig. 1 Magneto-optical images of the bi-layer "Strip" structure consisting of square and rectangular Nb films (200 nm) separated by SiO_2 layer (200 nm) at 6 K and (a) 200 Oe, (b) 150 Oe, (c) 50 Oe, and (d) 0 Oe after applying maximum field of 500 Oe.

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Superconductivity in boron-doped diamond by ion-beam irradiation

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Diamond is a material well known for its exceptional physical properties. It is a good electrical insulator (with a bandgap of 5.45 eV) with extreme hardness, together with a very high thermal conductivity and high charge-carrier mobility. For modest concentrations of boron, which acts as a charge acceptor, insulating diamond becomes a p-type semiconductor. Furthermore, at higher boron concentrations it becomes a bulk superconductor at a few K [1]. The boron-diamond system exhibits a metal-insulator transition for a boron concentration of $\sim 4.5\times 10^{20}$ cm^{-3} [2], above which both electrical conductivity σ and superconducting critical temperature T_c increase. For a concentration of around 4.5×10^{21} cm^{-3}, $T_c \approx 3$K has been reported [1,2], though higher critical temperatures have also been claimed [3]. Boron-doped diamond (BDD) appears to be a classical type-II, BCS superconductor [4].

We have reported preliminary studies on the possibility to fabricate deeply-buried (≈ 5 μm), micrometric-size conductive channels in ultrapure synthetic <100> diamond crystals, by employing focused high-energy (typically 9 MeV) boron ion implantation, with fluences in the range 4×10^{14} – 1×10^{17} ions/cm^2 [5]. In a previous work, we studied by means of micro-Raman and photoluminiscence spectra the damage produced in diamond by similar carbon ions (easier to study than with boron) and its eventual recovery [6]. Here we will present in-depth bidimensional maps of micro-Raman and photoluminiscence spectra, obtained before and after annealing at 1000 ºC as a function of irradiation fluence, to assess the changes in the BDD lattice produced by the creation of vacancies and defects and their degree of recovery after annealing. Finally, we will also present ongoing four-probe electrical resistance measurements conducted at low temperatures to study the corresponding behavior (from semiconducting to metallic and eventually superconducting) for different irradiated micro-stripes in the diamond samples with different boron concentrations.

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Molecular Dynamics Simulation on Vortex Motion in Mesoscopic Superconductors

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Vortex dynamics has been widely studied. Especially, after the discovery of cuprate high-Tc superconductors, vortex liquid state and melting of vortex lattice have been studied.

Recently, Ooi et al studied melting transition of vortex lattice in a mesoscopic square high-Tc superconductor [1]. They found that melting temperature oscillates with increasing applied field. When vortex number is a square number, the melting temperature becomes maximum. It is a kind of matching effect.

We use a molecular dynamics method [2,3] for investigating this melting transition in confined vortices. We numerically solve following equations of motion of vortices,

$$\eta \, d\boldsymbol{r}_i / dt = \boldsymbol{f}_{pi}^{imp} + \boldsymbol{f}_{vi} + \boldsymbol{f}_{fi}.$$

Here, $\boldsymbol{r}_i$ is i-th vortex position and $\boldsymbol{f}_{pi}^{imp}$ and $\boldsymbol{f}_{fi}$ are pinning force and thermal fluctuation force. $\boldsymbol{f}_{vi} = f_0 \sum_j K_1 \left(r_{ij} / \lambda \right) \hat{\boldsymbol{r}}_{ij}$ is vortex-vortex interaction. Temperature dependence of vortex motion comes from temperature of $\boldsymbol{f}_{fi}$ and $\boldsymbol{f}_{vi}$. The melting temperature can be identified from temperature dependence of the standard deviation of vortex positions. In Fig.1, examples of temperature dependence of standard deviation are shown. We discuss the vortex number dependence of vortex lattice melting transition temperature.

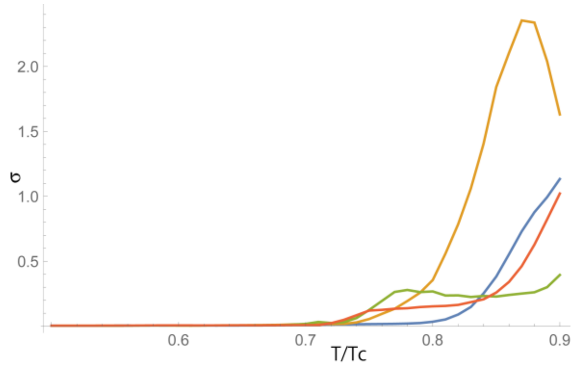

Fig.1 Temperature dependence of vortex motion.

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Shaping the superconducting properties of nanoscale junctions by electromigration

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High current densities in small metallic junctions can produce electron-assisted atomic diffusion known since the 60's as responsible for failures in metallic interconnections. Controlling and using this phenomena permits one to tune the material superconducting properties at the nanoscale. Here we demonstrate the control and the reversibility of such phenomena for three types of superconductors: Al, Nb and LCCO. For the latter material, we show that selective migration of oxygen atoms and the consequent doping modification induces a transition from a superconducting state to an insulating state in a reversible way. For the case of Nb, high level control of the electromigration allowed us to locally change the material properties (superconducting critical temperature and normal state resistance) and, at the end, to generate the in situ formation of tunable weak links [1] depicted in Figure 1. Numerical simulations within the Ginzburg-Landau formalism are also presented and show excellent agreement with the experimental data. These findings provide an easy method for the in situ fabrication of weak links and pave the way for a reversible control of local properties of nanowires [2, 3].

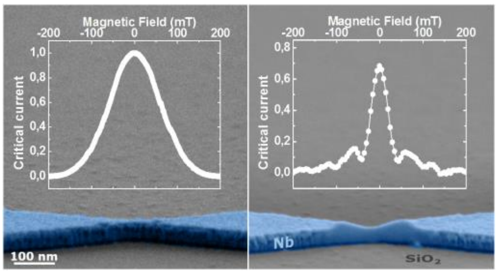

Figure 1 : Left panel shows a tilted scanning electron microscopy image of a virgin Nb nanoconstrictions. Right panel shows the constriction after electro-annealing. One can see the structural change at the center the constriction. The insets shows respectively the response of the critical current with respect to the external out-of-plane magnetic field, putting in evidence the formation of a weak link.

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Scanning tunnelling spectroscopy on lithographically defined mesoscopic structures

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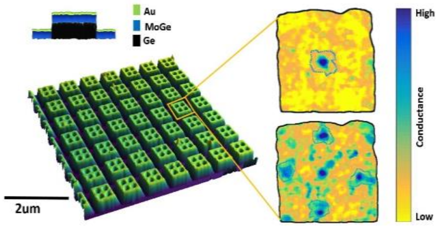
The superconducting condensate is a manifestation of quantum mechanics, characterized by a macroscopic wave function. When the region of the condensate is confined at the nanometre scale, it results in unique phenomena such as flux quantization, vortex pinning, etc. Nanostructuring superconductors by lithographic means provides the flexibility to impose well-defined boundary conditions on the condensate. Scanning tunnelling spectroscopy (STS) is a particular powerful technique to probe the condensate at small length scales. Nevertheless, high quality samples are indispensable to perform STS measurements.

Recent progress in nanofabrication tackled the aforementioned challenges and resulted in the first successful STS measurements on lithographically defined samples [1]. In this study, we continue this exploration and investigate the magnetic field evolution of the condensate by STS in mesoscopic superconducting squares of $Mo_{79}Ge_{21}$, containing an identical square array of four anti-dots at the centre. The squares are covered by a thin gold film, which safeguards the islands from oxidation and reflects the properties of the condensate via the proximity effect [1] [2]. In particular, we study the effect of confining the condensate for two particular cases. In a first square, we observe a fully developed vortex state when the antidote lattice is completely saturated. This state is commensurate with the C4 symmetry of the square. Strikingly, in a bigger square, the presence of a wider outer rim assimilates a different vortex configuration. Moreover, by monitoring the kinetic induced suppression of the condensate due to the screening currents at the sample edges and around the anti-dots, we pick-up a clear signature of the pinned vortices in the anti-dot lattice and gain insight into the vortex entry process. The possibility to study locally nanostructured superconductors can provide novel insights and is a crucial step for the future superconducting on-chip devices.



(Left) Topography of the studied nanostructures as obtained by atomic force microscopy (Right) Zero bias conductance maps as obtained by STS at T=500mK and a magnetic field of H=310 mT (upper) and H=420 mT (lower) .

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Physics of IJJ Arrays in High-T_c Superconductors and the Application for Highly Sensitive THz Spectroscopy

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Intense, continuous and coherent THz electromagnetic waves can be generated from high-T_c superconductors with highly 2D layered structures of CuO_2 plane, which is responsible for the high-T_c superconductivity, like a $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) compound after micro-engineering the single crystal into appropriate mesa structures with certain dimensions and shapes [1]. The emission frequency so far can cover a wide range of frequency domain from 0.3 THz to 2.4 THz, more or less continuously [2] and the intensity of 640 mW can be obtained in case of three mesas synchronously operated [3]. The spectrum is coherent so that it is very sharp, since a few thousands of intrinsic Josephson junctions in a stack in a mesa structure synchronize and work coherently along the c-axis. This situation resembles as a gas LASER where the individual gas atom corresponds to the superconducting IJJ in the present mesa structure. Because the THz radiation spectrum from IJJs is very sharp, the peak spectral intensity is extremely high, about 10^3-10^4 times higher than that of Hg lamp, for example, commonly used in the THz spectroscopy as a radiation source. Using this characteristic feature of IJJ THz emitters, it is possible to construct extremely high sensitive THz spectrometer. A prototype of this sort of spectrometer is constructed and tested.

As an application of the IJJ THz emitter and spectrometer, we have developed a THz spectrometer for the detection and analyses of the unknown organic compounds contained in lipids produced by algae such as Botryococcene oil from Botryococcus braunii, Squalene or Squalane from Aurantiochytrium, *etc*. It is known that some of these organic compounds are good for health and rejuvenate aged cell, but most others are not yet known well. This is a currently very important task in Japan to keep healthy human life in an extremely old aged society

Finally, I will comment on the new fascinating development of room temperature superconductors with T_c=260 K discovered recently at Megabar pressures.

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Quantum criticality at the heart of a high-temperature superconductor

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An outstanding experimental feature of the metallic behavior of all high-temperature superconductors near critical doping is the linear-in-temperature resistivity observed over a wide temperature range. Although metallic quantum criticality in these systems has been proposed to be the origin of this anomalous temperature dependence, its manifestation in the magnetoresistance of cuprate superconductors is not yet established. Given the high upper critical magnetic field, H_{c2}, the study of the cuprates normal state at low temperatures, exposed by high magnetic fields, has been limited to a narrow magnetic field range, making the interpretation of the data challenging. In this work we have performed magnetoresistivity measurements in high-quality, MBE-grown $La_{2-x}Sr_xCuO_4$ samples in magnetic fields up to 80T - well above the highest fields used in previous studies of this system - and in a wide range of temperatures. We find that the magnetoresistivity in the vicinity of critical doping is strikingly linear. Furthermore, we find that the temperature-doping phase diagram and the field-doping phase diagram, both, follow a similar behavior around optimal doping. Our measurements provide new insight into the physics of the anomalous metallic state in high temperature superconductors near critical doping[1]. The high magnetic field measurements were done at the Pulsed Field Facility of the National High Magnetic Field Laboratory (NHMFL), at Los Alamos National Laboratory[2]. In this talk I will also present the facilities, the user program and research opportunities offered by the NHMFL at Florida State University.

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Pressure-induced multiple phase transitions of $BaBi_3$ superconductor

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The temperature-dependent resistance and magnetization under hydrostatic pressure up to 2.13 GPa is reported for single-crystalline superconductor $BaBi_3$. Temperature - pressure phase diagram is constructed and our results suggest three different superconducting phases α, β and γ in the studied very low pressure range. Interesting anomalies have also been observed in our measurements. T_p, which separates phases α from β & γ, is associated with an abrupt resistance change from 0.27 GPa to 0.33 GPa. The "S-shape" anomaly in the temperature-dependent resistance curve, T_S, is associated with the transition between β and γ. A continuous resistance change with pressure at ~ 1 GPa is associated with a crossover from β to γ. These anomalies are likely related to structural degrees of freedom. We further show that occurrence of the three superconducting phases are intuitively linked to the phase transitions which are likely first order in nature, establishing $BaBi_3$ as a good candidate to study interplay of structure with superconductivity in the presence of strong spin-obit coupling. Finally, superconducting upper critical field analysis suggests a possible Liftshiz transition near 1.54 GPa in γ phase. Research was supported by the U.S. Department of Energy, Gordon and Betty Moore Foundation EPiQS Initiative (Grant No. GBMF4411) and Brazilian Foundation FAPESP (2011/19924-2).

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Superconductivity and magnetism in layered materials: the cases of 2H- and 1T-TaS_2

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Transition metal dichalcogenides are well-known layered materials that have been studied for more than 50 years. Even though, there are still several open questions and new physical phenomena that emerge in these systems such as superconductivity or spin liquid behavior.

In this work, **A)** the synthesis and characterization of transition metal dichalcogenides (TMDCs) are discussed. As an example, thickness-dependent Raman spectra of ZrX_2 (X = S, Se) and transport measurements in thin layers of 2H-TaS_2 are presented. While no thickness dependence is observed in ZrX_2 [3], in 2H-TaS_2 it is observed a superconducting temperature (Tc) enhancement by decreasing the number of atomic layers (from 0.6 K in the bulk sample to ca. 2K in a ~3 nm layer, as seen in Figure 1) [4]. This behaviour is the opposite of the one reported in other 2D superconductors, as $NbSe_2$ [5].

Moreover, B) a detailed study of 1T-TaS_2 [6] by implanted muon techniques reveals that it behaves as a quantum spin liquid (QSL) when the charge density wave is presented. Interestingly, it is observed a crossover at T_0 = 25 K between three different QSL regimes which critical exponents, as predicted by theory, can be interpreted as quasiparticles with different density of states [7].

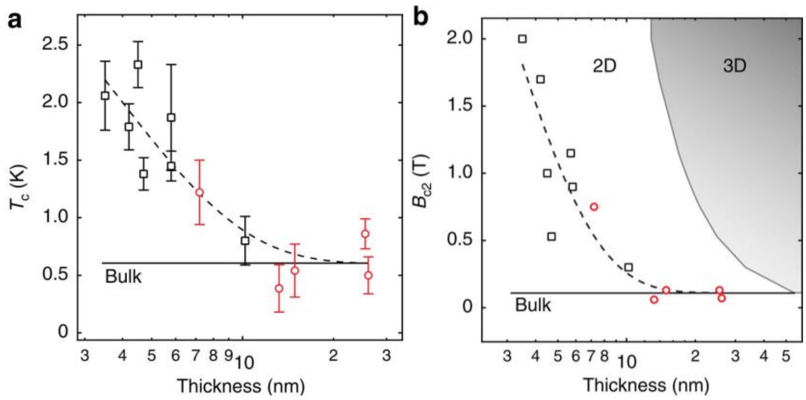

Figure 1.- (a) Variation of Tc as a function of the thickness of the 2H-TaS_2 flakes. **(b)** Variation of Bc_2 as a function of thickness. The black solid line indicates the bulk limit upper critical field of 110 mT. The grey solid line plots the Ginzburg-Landau coherence lengths, calculated from the y axis Bc_2 values, and marks the edge of the 2D limit. Devices exhibiting a non-zero residual resistance are plotted in red.

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Electronic and structural properties in the superconducting phase of URu_2Si_2

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We report high-resolution atomic size Scanning Tunneling Microscopy/Spectroscopy (STM/S) measurements on single crystals of URu_2Si_2. After cleaving the sample in-situ perpendicular to the c-axis of the tetragonal crystal structure at liquid helium temperature, we observe atomically flat terraces which we identify as U or Si terminated. We find a one dimensional (1D) spatial modulation with a wavelength of 6.5 ± 0.5 nm oriented with a small angle to an in-plane atomic axis. The modulation corresponds to tiny changes in the STM topography of at most a few pm at each period. The 1D modulation provides a microscopic feature that can related the numerous observations showing in-plane symmetry breaking in the hidden order phase of URu_2Si_2.

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Unconventional behavior in Co- and Ca-doped $EuFe_2As_2$ magnetic-superconductors

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Our study on Ca and Ca-doped $EuFe_2As_2$-based magnetic-superconductors reveal their remarkable properties, including coexistence of superconductivity and ferromagnetic order, field induced superconductivity and re-entrance of resistivity [1-3].

Physical properties of investigated compounds strongly depend on the direction of applied magnetic field, which in the boundary case leads to a possibility of switching between the superconducting and normal states. Our study imply that these properties are observed due to the possibility of alerting the influence of the orbital pair breaking effect – which is possible by changing the direction of the magnetic moment on the Eu^{2+}-ions (internal magnetic field) with the external magnetic field.

Due to a specific direction of the internal magnetic field (and its presence even in zero external magnetic field), we expect a spontaneous vortex state – with both Abrikosov and Josephson vortices – in the investigated Co- and Ca-doped $EuFe_2As_2$-based superconductors. Similar spontaneous Abrikosov-vortex state was observed in the P-doped compounds [4].

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Ising superconductivity in bulk $(LaSe)_{1.14}(NbSe_2)_{m=1,2}$ misfit layer compound

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Recently discovered Ising superconductors with strong spin-orbit coupling of a special type in monolayer TM dichalcogendides not only break all limits of the critical magnetic fields but more importantly they can be utilized in producing the still elusive Majorana fermions with a magnetic field as a tuning control parameter [1]. I will discuss possible Ising superconductivity in fully 3D albeit very anisotropic $(LaSe)_{1.14}(NbSe_2)$ [2] and $(LaSe)_{1.14}(NbSe_2)_2$ misfit layer systems.

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Spin-orbit coupling induced Weyl points and topologically protected Kondo effect in a two-electron double quantum dot

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Recent years have brought an explosion of activities in the research of topological aspects of condensed-matter systems. Topologically nontrivial phases of matter are typically accompanied by protected surface states or exotic degenerate excitations such as Majorana end states or Haldane's localized spinons. Topologically protected degeneracies can, however, also appear in the bulk. An intriguing example is provided by Weyl semimetals, where topologically protected electronic band degeneracies and exotic surface states emerge even in the absence of interactions. Here we demonstrate experimentally and theoretically that Weyl degeneracies appear naturally in an interacting quantum dot system, for specific values of the external magnetic field. These magnetic Weyl points are robust against spin-orbit coupling unavoidably present in most quantum dot devices. Our transport experiments through an InAs double dot device placed in magnetic field reveal the presence of a pair of Weyl points, exhibiting a robust ground state degeneracy and a corresponding protected Kondo effect.

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Structure and dynamics of vortex states in multiband superconductors

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In this talk I will discuss the structure and dynamics of vortex states in multiband superconductors and hybrid superconductor/ferromagnet/superconductor structures. In these systems pairing of electrons is supposed to take place in several sheets of a Fermi surface formed by overlapping electronic bands or in the spatially separated superconducting layers connected via the proximity effect. Recent experiments demonstrate unusual dependence of the vortex core size as the function of magnetic field [1] and enhanced flux-flow resistivity in multiband compounds [2]. Extended vortex core sizes in superconductor/normal metal hybrid structures have been observed [3] recently and one can expect unusual flux-flow resistivity in such systems. I will suggest the explanations of observed vortex structure anomalies and discuss predictions for the flux-flow resistivity based on the calculations done in the framework of the quasiclassical Eilenberger and Usadel theories extended to take into account the multiband pairing states [4,5,6] and the pairing modification by the unusual proximity effect in the ferromagnetic layer.

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Odd-frequency superconducting pairing in junctions with spin-orbit coupling

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We investigate the emergence and consequences of odd-frequency spin-triplet superconductivity in both topological insulator [1] and Rashba spin-orbit coupled one-dimensional nanowires [2] proximity-coupled to conventional superconductors.

In particular, we study NS and SNS junctions and consider proximity-induced conventional spin-singlet s-wave superconducting pairing with a finite in-plane gradient around the NS interface. We perform analytical and numerical calculations and show that odd-frequency spin-triplet superconductivity does not require the presence of ferromagnetic insulators but instead it naturally arises due to the unique nature of spin-orbit coupling and the non-constant pairing potential.

We further discuss the differences between the induced odd-frequency pairing in topological insulators and in Rashba nanowires as well as their relation to experimental observables such as the local-density of states and conductance in both situations.

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Low temperature characterization of low-dissipation ferromagnetic Josephson junctions

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Ferromagnetic Josephson junctions present a rich emerging physics due to the coupling between ferromagnetism and superconductivity. The interplay between the two competing phases causes an oscillation of the superconducting order parameter within the ferromagnetic barrier, which is responsible for the appearance of a ground state, and of triplet correlations in the Josephson junction [1, 2]. Because of such properties, SFS junctions are sought to have applications in the emerging field of superconducting spintronics [3] and in quantum and digital superconducting computation as phase shifters [4] or as auxiliary circuit elements for error correction, readout and memory elements [5, 6, 7, 8]. Currently, their use is limited by their metallic, highly dissipative nature. In this work we will review the properties of a specific category of SFS, namely low dissipation spin filter junctions [9,10]. In particular, we will present a low temperature characterization of such devices down to 0.3K. We measured several junction parameters as a function of thickness, focusing our attention on critical current versus temperature dependencies at different thicknesses. We developed a model to describe the anomalous behaviour and the incomplete transition found in experimental data using short-range triplet correlations. These results offer new perspectives for the study of the role of short-range triplet correlations in the transport properties of low dissipation ferromagnetic junctions.

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Topologically protected superconducting ratchet effect generated by spin-ice magnets

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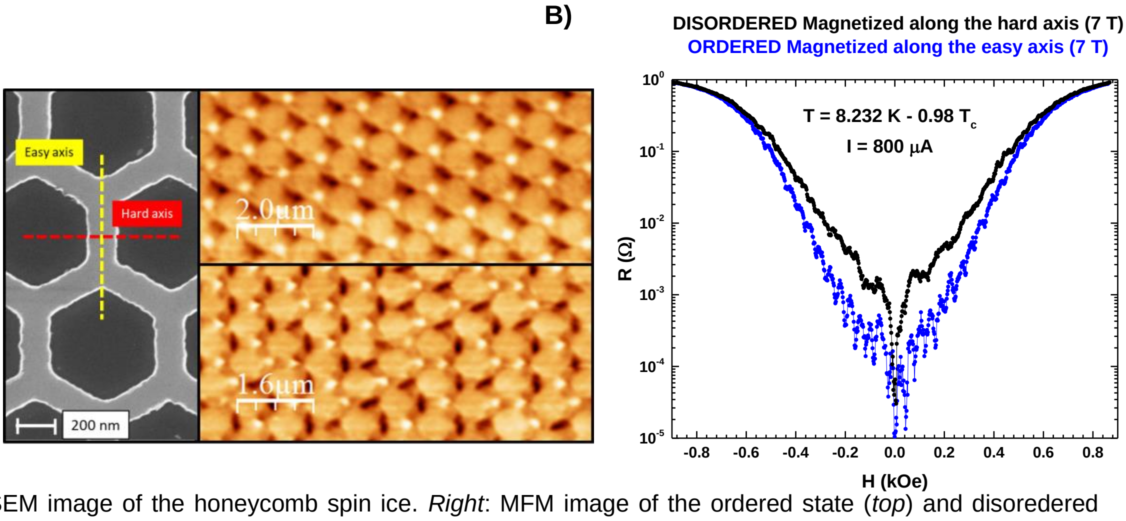
We have fabricated a hybrid spin-ice / superconductor device specially designed for testing rectified flux motion. Here, a robust superconducting ratchet arises from the interplay between the topologically frustrated magnetic texture in the spin ice and the superconducting vortex motion under alternating forces. The device consists of a Co honeycomb array embedded in a superconducting Nb film on a Si substrate. The honeycomb topology frustrates the in-plane magnetic moments in the array, yielding a magnetic charge distribution that can be ordered or disordered by applying in-plane saturation magnetic fields. These magnetic charges are originated by two Néel walls fixed, no matter the magnetic history of the nanomagnets, at each vertex. Moving on this magnetic landscape, superconducting vortices interact with the asymmetric potential provided by the Néel walls profiles. Because of this interaction, a DC voltage is always measured when and alternating current is applied. Regardless of magnetic charge distribution, a resilient ratchet effect will always appear.

A) B)



(A) *Left*: SEM image of the honeycomb spin ice. *Right*: MFM image of the ordered state (*top*) and disoredered (*bottom*). (B) Magnetorresistance measurement of the ordered state (blue) and disordered state (black).

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Topological excitations in two-component superconductor

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We study topological excitations in two-component nematic superconductors in Dirac material with a particular focus on doped Bi_2Se_3. We find that the lowest-energy topological excitations are coreless vortices: a bound state of two spatially separated half-quantum vortices.

We then study the effect of time reversal and inversion symmetry pair breaking mechanisms on the the two-component superconductivity in the doped Dirac semimetals. We show that depending on the direction and the strength of the spin-related pair breaking field, one might tune the system from a trivial state with 0-phase difference though intermediate LOFF or s+is states to the Weyl or nodal loop superconducting state with pi-phase difference. The lack of inversion symmetry might support unusual inhomogeneous LOFF states in two component topological superconductor.

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Abstracts of Posters

Superconducting order parameter fluctuations in bilayer hybrid films of NbN/NiCu and NbTiN/NiCu

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Thermodynamic fluctuations of the superconducting order parameter lead to an excess conductivity above the critical temperature T_c, the so-called paraconductivity. While superconducting fluctuations have been extensively investigated in both metallic and cuprate superconductors, little is known about their properties in superconductor/ferromagnet hybrids. We present results of our studies of superconducting order parameter fluctuations in NbN/NiCu and NbTiN/NiCu superconductor/ferromagnet (S/F) ultrathin bilayers.

The NbN and NbTiN layers were grown using dc-magnetron sputtering on chemically cleaned sapphire single-crystal substrates. After rapid thermal annealing at high temperatures, the S films were coated with $Ni_{0.5}Cu_{0.5}$ overlayers with thicknesses of few nanometers, using co-sputtering. Low-temperature magnetization tests confirmed that the NiCu films are ferromagnetic with the Curie temperature of above 30 K [1]. The temperature dependence of magnetoresistance shows an unusual negative region in the S/F bilayers that extends almost to room temperature and is not present in the S single layers. We take this behavior as an indication of remarkably different magnetotransport properties of the S/F bilayers.

The paraconductivity of the NbN and NbTiN single layer films is in excellent agreement with the parameter-free theory for order-parameter fluctuations in two-dimensional superconductors, confirming the validity of our approach. The same holds for the magnetoconductivity, which probes the suppression of superconducting fluctuations in a magnetic field and provides a measure for the Ginzburg-Landau coherence length [2]. However, the addition of a ferromagnetic top layer changes the magnetotransport properties significantly. In the S/F hybrids both paraconductivity and magnetoconductivity are significantly modified and deviate from phenomenological and microscopic theories for fluctuations in superconductors [3]. Our observations are tentatively explained by a ferromagnetic domain structure in the NiCu layer that could reduce the fluctuation amplitude even in zero external magnetic field due to the spontaneous magnetization of individual domains.

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Design and construction of support systems for scanning probe microscopy

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We describe a noise free environment consisting of concrete floating floors with springs. The resonance frequency of the springs is of 1 Hz, far below the typical resonance frequency used in similar industrial floating floor constructions. We present devices to connect

a Dewar containing a cryogenic scanning tunneling microscope to the floating floor as well as arrangements to reduce vibrations from the pumping lines. We also discuss arrangements to improve cabling of the microscopes, reduce electromagnetic noise levels and improve grounding. The environment discussed here is far more cost-effective than other available solutions (such as air damped large weight floors or active vibration control), thanks to the use of simple steel reinforced concrete and steel springs and can be implemented on flat floors located at ground level with a minimal loss of height.

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Electrical resistivity near the superconducting transition in hybrid layered superconductors of finite thickness.

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Abstract body: Thanks to continuous advances in materials science, it is today possible by numerous groups to fabricate different types of layered structures composed by high-temperature superconductor (HTS) quasi-2D planes stacked together with other functional materials. For instance, piezoelectric+HTS thin films, semiconductor+HTS intercalated multilayers, ionic liquid-gated surface superconductors, etc. In fact, it is possible to custom engineer these structures looking for novel functionalities of these hybrids. On the other hand, concerning the electrical properties, it is well known that reduced-dimensionality effects may significantly influence the shape of the resistivity versus temperature curves near the effective critical temperature, as theoretical analyzed to date in infinite, 2D and 3D periodic layered superconductors. However, less attention has been devoted to the case in which the number of active superconducting layers is not macroscopic (nor too low to consider the problem as purely 2D). In this workshop we will summarize some of our novel theoretical calculations of the resistivity roundings near the transition of such finite-thickness hybrid layered HTS.

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Computer Simulation of Electronic Device for Generation of Electric Oscillations by Negative Differential Conductivity of Supercooled Nanostructured Superconductors in Electric Field

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We use the formerly derived explicit analytical expressions for the conductivity of nanostructured superconductors supercooled below the critical temperature in electric field. Computer simulations reveal that the negative differential conductivity region of current-voltage characteristic leads to excitation of electric oscillations. We simulate a circuit with distributed elements. This gives a hint that a hybrid device of nanostructured superconductors will work in terahertz frequencies. If the projected setup is successful, we consider the possibility for it to be put in a nanosatellite (such as a CubeSat). A study of high temperature superconductor layers in space vacuum and radiation would be an important technological task.

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Josephson junction of d-wave superconductors through ferromagnetic barrier with with noncollinear magnetizations

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We study Josephson junction with d-wave superconducting electrodes and ferromagnetic barrier that consists of two ferromagnets with angle α between their in-plane magnetizations. We generalize Furusaki-Tsukada formula [1] to calculate Josephson current by using probability amplitudes of Andreev reflection for junctions with d-wave superconductors [2]. We solve the scattering problem based on Bogoliubov–de Gennes equation for arbitrary relative orientation of in-plane magnetizations and in case of transparent interfaces [3]. We take into account both spin-singlet and spin-triplet superconducting correlations [4]. The Josephson current is calculated as a function of thickness of ferromagnetic barrier for different orientations of d-wave superconductors. For junctions with symmetric orientations of d-wave electrodes, we find that results are similar to those with s-wave superconductors, where both 0 and ğ states appear ($I\sim sin$ö). However, in the case of Josephson junction with different orientations between d-wave electrodes and for small values of exchange field Josephson current is $I\sim sin2$ö, with three coexisting states 0, ğ/2 and ğ [5]. For larger exchange field Josephson current varies as sin4ö for angle á = ğ/2 between magnetizations. We found the long range spin-triplet correlations induced on F/F interface. We observe that appearance of ğ/2 state is characteristic for Josephson junction with asymmetric orientations of d-wave electrodes for any value of exchange field and for any angle á. Critical current and transitions between states of junction can be controlled by varying angle between magnetizations and orientations of d-wave electrodes.

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Growth and study of magnetoresistance of the superconductor $LaRu_2P_2$

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We present a study of the magnetoresistance at high magnetic fields of the pnictide superconducting material $LaRu_2P_2$. We have grown single crystals using the solution growth method. This system is similar to iron-based materials, but it superconducts in a stoichiometric phase, which allows to study samples of much higher purity. We have obtained high quality single crystals, with a T_c of 4.16 K and a residual resistivity of 8.6 μΩcm, corresponding to a mean free path of 15 nm. We report measurements of the upper critical field, from which we obtain a value for the coherence length of about 27 nm. Furthermore, we measured the sample to high magnetic fields (22 T) and found signatures of quantum oscillations with low frequency in agreement with band structure calculations.

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Tuning the electronic structure of High Temperature Superconducting films by field induced oxygen diffusion

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A unique feature of high temperature superconductors is that their properties strongly depend on their carrier concentration. In cuprates, a reversible modulation of the carrier density can be produced by means of electric field pulses, inducing a “Resistive Switching (RS) effect” to eventually achieve a metal insulating transition (MIT). The mechanism underlying the RS effect in these materials is still unclear though oxygen vacancies certainly play a key role. Oxygen ex-corporation/incorporation in the system imply a variation of the charge carriers and accordingly a valence change in the transition metal 3d band.

We present studies on the bipolar RS effect in $YBa_2Cu_3O_7$ superconducting thin films evaluated by hysteretic I(V) curves measured on micrometric metal electrodes. Temperature dependent transport and resistance measurements together with micro-Raman experiments were performed to evaluate the local oxygen diffusion through the material in different electrode configurations. In particular, the implication of the intrinsic anisotropic oxygen diffusion in cuprates has been studied experimentally and corroborated with simulation. We demonstrate that non-volatile volume phase transitions can be induced to generate transistor-like devices with free-resistance channels in which the electric field magnitude and direction, temperature, and anisotropic oxygen mobility determine their characteristics.

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Topologically protected degenerate ground states in two-spin systems

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Semiconductor nanowires are one of the most researched materials in the field of quantum electronics. In these nanowires quantum dots (i.e., artificial atoms) can be created with properly designed gate electrodes. In the quantum dots electrons can be trapped, and due to their spin these devices are promising to store quantum information. The object of this research was investigating the ground state of a system

consisting two coupled quantum dots with respect to the outer magnetic field. The microscopic description of this system is complicated because of the strong spin-orbit interactions, spin-dependent tunneling, and anisotropic Zeeman splitting. However according to topological considerations we found out that there is always be such magnetic field where the system's ground state is degenerated and we also verified this statement with measurements on a specimen [1].

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Memristors, Quantum Materials and Quantum Computation

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Recently there is a growing interest in non-volatile memories, and specifically in memristors, which are resistors with history-dependent resistance that provide memory in form of a resistive hysteresis loop [1], [2]. In this direction, in the last few years, there have been suggestions on how quantum materials and quantum computing could be possibly fruitfully coupled with the memristor notion [3] either to create new types of memristors (memristors based on superconducting circuits, quantum dots, etc.) [4], [5] or to provide new ideas on quantum computer simulators. More specifically, in recent works where superconducting circuits based memristors are presented, memristive behavior arises from the quasiparticle-induced tunneling when supercurrents are cancelled. Moreover, quite recently, memristors have been used to represent the state of qubits, contributing with these preliminary steps towards the coupling of quantum computing with the memristor notion. The development of quantum simulators is a crucial step towards general-purpose quantum computers. Quantum simulators using digital circuits could be considered as a really difficult task, mainly because the unit of quantum information, the qubit, has an infinite number of states. On the other hand, analog circuits comprising R, L and C elements have no internal state variables that can be used to reproduce and store qubit states. Therefore, utilizing memristors' analog nature and its memory capability could provide good evidence on possible mapping of qubit states to resistance values of memristors. Both quantum computing and memristor based circuits belong to the unconventional spectrum of computing paradigms which may soon be able to tackle efficiently and reliably computation tasks such as big data processing, design and development of new materials, high-level artificial intelligence and neuromorphic computing.

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Intrinsic and extrinsic effects on the transport properties of nanodevices based on topological insulator Bi_2Se_3

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Topological insulators are novel quantum materials with high interest in nanoelectronic and spintronic applications. They present a bulk band gap like an ordinary insulator, but a large spin-orbit coupling in the material leads to the presence of edge (in 2-D) and surface (in 3-D) conducting states that behave as Dirac massless fermions and are protected by time-reversal symmetry which makes them insensitive to be scattered by impurities [1]. Several topological insulators have been discovered since they were theoretically predicted in 1987. In particular, Bi_2Se_3 has demonstrated these topological properties [2][3]. Our work is focused on the patterning of thin films of this material into the shape of Hall bars with different dimensions by optical lithography, in order to study how their magnetotransport properties depend on the lateral size and thickness of the nanostructure. To do so, we carry out measurements of the magnetoresistance and Hall resistance in a wide range of temperatures down to 2 K and magnetic fields up to 14 T.

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The study of the Second Magnetization Peak in Superconducting Single Crystals

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The nature of the second magnetization peak (SMP) appearing on the dc magnetic hysteresis curves of superconducting single crystals with random pinning is still under debate. There were proposed a large number of models and mechanisms and it is argued at present that the SMP is system dependent. We analyzed the temperature and field dependence of the normalized vortex-creep activation energy in the SMP domain for cuprates and iron-based superconducting single crystals with the external magnetic field H oriented along the crystallographic c axis or perpendicular to it. The sample independent aspects revealed by the relaxation results around the SMP and the determination of the vortex creep exponent using two techniques are the absence of single vortex collective pinning (with a low vortex creep exponent) in the proximity of the field H_{on} for the onset of the SMP, and the sign changing of the creep exponent between H_{on} and the peak field H_p, signaling the presence of a disordered vortex phase above H_p. The observed general behaviour supports strongly the scenario in which the SMP is generated by a pinning-induced disordering of the low-H quasi-ordered vortex solid.

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A high-resolution combined scanning laser and widefield polarizing microscope for cryogenic imaging

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Polarized light microscopy, as a contrast-enhancing technique for optically anisotropic materials, is well suited for the investigation of a wide variety of effects in solid-state physics, as, e.g., birefringence in crystals or the magneto-optical Kerr effect (MOKE). We present a recently developed cryogenic high-resolution optical imaging system that combines a confocal scanning laser microscope (SLM) and a widefield microscope (WPM) with polarization-sensitive detectors. With a high numerical aperture objective, a spatial resolution ~240 nm at a wavelength λ=405 nm for the SLM and ~480 nm at λ=528 nm for the WPM is achieved. Samples are mounted on a ^{4}He continuous flow cryostat providing a temperature range of 4 K – 300 K, in-plane magnetic fields with variable orientation up to 800 mT and out-of-plane fields up to 20 mT [1].

Typical applications of the polarizing microscope are the imaging of the in-plane and out-of-plane magnetization via the longitudinal and polar MOKE, imaging of magnetic flux structures in superconductors covered with a magneto-optical indicator film via the Faraday effect, and imaging of structural features, such as twin-walls in tetragonal $SrTiO_3$ [2]. The SLM furthermore offers the possibility to gain local information on electric transport properties of a sample by detecting the beam-induced voltage change across a current-biased sample.

Another application of the microscope system utilizing the WPM is the investigation of the metal-insulator transition in the strongly correlated oxide V_2O_3. The breakdown of a low-temperature antiferromagnetic insulating phase under the application of a large enough bias current to a paramagnetic metallic phase at around 160 K is of special interest. By measuring the electric properties as well as the spatially resolved optical reflectivity during the breakdown we observed spatially confined metallic filaments. Whether this electrically driven metal-insulator-transition is electric-field-induced or caused by the creation of electro-thermal domains through Joule heating is in focus of recent research.

Altogether, the combination of optical, magnetic, structural, and electric imaging capabilities makes the microscope a viable tool for research in the fields of oxide electronics, spintronics, magnetism, and superconductivity.

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Combined gold and graphene modes in Corbino geometry

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We consider a micromechanical resonator, where two gold beams are coupled to a Corbino shaped monolayer graphene disk. We detect several mechanical resonances of the structure and are able to robustly identify the gold resonances from the graphene modes. The resonances are detected using a frequency mixing technique [1], where the signal is mixed by the Corbino disk thanks to the mechanical nonlinearities of graphene. We create a finite-element model of the resonator structure using COMSOL Multiphysics to identify the mode shapes of the detected resonances, and we find that the simulated frequencies are in agreement with the experiments. Additionally, we solve the time evolution of a driven Corbino disk analytically to further investigate its interactions with the gold beams it is coupled to.

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Quasiparticle interference scattering in the Weyl semimetal WTe_2 at very low temperatures

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The material WTe_2 crystallizes in a layered structure without inversion symmetry. The crystals are of extremely high quality. At zero field, the residual resistance is nearly three orders of magnitude smaller than the room temperature resistance [1]. Interestingly, when applying a magnetic field, the magnetoresistance increases by more than five orders of magnitude [1]. The dependence on the magnetic field is linear and the origin for this linear magnetoresistance is highly debated. The Fermi surface has been studied using ARPES and quantum oscillations [2]. This material is conjectured to be a type-II Weyl semimetal.

Here we use Scanning Tunneling Spectroscopy at very low temperatures to investigate the electronic structure at the surface down to atomic scale. We observe atomic scale images showing the crystalline structure without inversion symmetry. We identify two kinds of defects, interstitials and vacancies. Both provide electronic scattering features which we follow by making precise tunneling conductance maps as a function of the bias voltage. At the vacancies, we identify hole and electron bands, whose, respectively, top and bottom, are very close to the Fermi level. At the interstitials, we observe a complex scattering pattern. For bias voltages of about 60 mV above the Fermi level we observe a highly anisotropic figure-eight-shaped feature in the scattering pattern in reciprocal space. This feature can only be understood by scattering between Fermi arcs resulting from incomplete contours due to topologically non-trivial surface edge states. The observed shape of the scattering pattern is compatible with Fermi arcs joining the surface projection of Weyl points with opposite chirality.

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Generation of Teraherz Oscillations by Thin Superconducting Films in Fluctuation Regime. Theory

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Explicit analytical expressions for the conductivity and fluctuation conductivity above and below critical temperature are derived in the framework of time dependent Ginzburg-Landau theory and Boltzmann equation for fluctuation Cooper pairs. It is confirmed that below critical temperature at small electric fields the differential conductivity becomes negative. At appropriate coupling with a resonator the negative differential conductivity will generate electric oscillations. The maximal frequency of these oscillations is proportional to the critical temperature and for high temperature superconductors the obtained results can stimulate the development of Terahertz generators. The case of gapless superconductivity is briefly discussed.

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Vortex transport in superconducting W-C nanostructures

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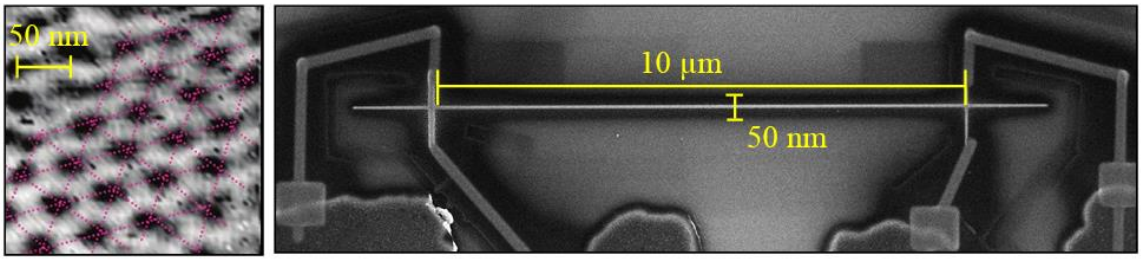
Motion of superconducting vortices within a type II superconductor is usually regarded as an unwanted effect due to the dissipation effects that appear therein. However, their quantized nature makes them potentially useful in quantum information transport.

W-C nanostructures grown by Focused Ion Beam Induced Deposition (FIBID) behave as Type II superconductors [1-3] (figure). In this contribution we report the fabrication of 10 μm-long superconducting W-C nanowires (NWs) grown by FIBID (figure), and the subsequent detection of nonlocal resistances generated solely by vortex motion. By injecting a current at one end of the NW, a Lorentz force is exerted on vortices already present, which push neighboring ones along the long axis of the NW. [4] Vortices passing through the opposite end, fre of current, generate measruable voltages with equivalent resistances as high as 8 Ω. Ginzburg-Landau theory-based numerical simulations support hte experiment interpretation [5], further strengthening the potential applicability of superconducting vortices as quantum information carriers for nanodevices.



Left: hexagonal lattice of superconducting vortices in a W film grown by FIBID [2]. *Right:* W-C NW. Current is injected at one end and voltage is measured at the other.

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Temperature effects in superconducting quantum dots

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A single-level quantum dot connected to superconducting leads is an ideal system for studying the interplay between electronic correlations and the superconducting order. The proximity effect allows the Cooper pairs to leak into the quantum dot, opening a gap in the density of states and the Andreev reflections give rise to a set of discrete subgap (Andreev-Shiba) states. Moreover, the presence of a third, metallic electrode populates the gap with finite density of states and gives control over the Kondo effect.

We use the single-impurity Anderson model coupled to BCS superconducting leads and, optionally, a third metallic lead to study the temperature effects in the system. In order to solve this model, we use the CT-HYB quantum Monte Carlo and the numerical renormalization group (NRG).

The focus is on the behavior of the Josephson current and the zero-pi quantum phase transition. We show the limits of usability of the presented methods and the agreement of our calculations with available experimental results.

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Magnetic penetration depth measurements on the Dirac semimetal $PdTe_2$ and $Sr_xBi_2Se_3$

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The temperature variation of the magnetic penetration depth λ in single crystals of two candidate topological superconductors $PdTe_2$ and $SrxBi_2Se_3$ was studied using the tunnel diode oscillator technique (TDO). TDO allows for the determination of the temperature dependence of λ relative to the value of λ at the lowest achievable temperature T_0 ($\Delta\lambda(T) = \lambda(T) - \lambda(T_0)$). Measuring λ(T) at low temperatures ($T < 0.3T_C$) is a direct probe of the gap symmetry, by which unconventional superconductivity can be identified. Previous work on superconducting Dirac semimetal $PdTe_2$ reporting transport, specific heat and STS studies indicate the presence of Type I BCS behaviour [1-3]. An exponential variation of Δλ(T) below $0.4T_C$ is observed for $PdTe_2$, suggesting $PdTe_2$ is a conventional weak to moderately coupled BCS superconductor with an isotropic gap, indicating that the superconducting and topological features are separated. Fitting the temperature dependence of Δλ(T) shows λ(0) = 500(50) nm. Combined with the calculated BCS coherence length ξ_0 = 1400 nm implies Type I superconductivity. The Type I nature is also supported by the normalized superfluid density curvature, which closely follows a s-wave shape with nonlocal corrections. Rotational symmetry breaking was observed in superconducting SrxBi2Se3, where the origin of the symmetry breaking field remains hitherto unclear [4, 5]. An interesting possibility is the odd parity two dimensional E_u representation of the D_{3d} point group which breaks the threefold symmetry of the lattice and constraints the spin pairing state to a triplet [6,7]. With TDO a power law ($\Delta\lambda(T) \propto T^n$) was inferred at temperatures below $0.3T_C$, with n = 1 and n = 3 for H⊥c and H∥c respectively, indicating the presence of line nodes or 2D point nodes, which is in agreement with the E_u representation, but does not rule out other origins for the superconducting gap symmetry.

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STM at 17T: design and construction

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We describe a Scanning Tunneling Microscope made of non-magnetic Shapal capable of operating at very high magnetic fields. We have reduced the diameter and improved the mechanical stability and wiring arrangements with respect to previous microscopes [1]. The STM is located at the center of a 17 T magnet. The magnet assembly has been modified to make it more rigid and avoid mechanical vibrations induced by the motion of the coil. We present topographic and work function measurements on gold at high magnetic fields, following the methods described in [2]. We also describe and discuss measurements of the conductance through few atoms size bridges. We produce these bridges through repeated indentation, as described in Ref.[3], and show by recording tens of thousands of current vs distance curves, that the conductance through single atoms of gold is exactly at the quantum of conductance at magnetic fields of 17 T. We relate this result to the properties of the bandstructure of gold.

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Indications of Ising spin-orbit coupling in $(LaSe)_{1.14}(NbSe_2)$

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In analogy to the high-T_c copper oxides, $\mathbf{(LaSe)_{1.14}(NbSe_2)}$ and $\mathbf{(LaSe)_{1.14}(NbSe_2)_2}$ are layered superconductors, but substantially simpler with a T_c below 6 K. Our experiments show a large anisotropy of the upper critical field, comparable to the anisotropy of the normal-state resistance. Strikingly, the in-plane upper critical field is much larger than the Pauli field [1], determined solely by the Zeeman coupling, when the orbital motion of the Cooper pairs is negligible. We presume, that this behavior corresponds to the Ising spin-orbit coupling stemming from the layered structure of the compounds. STM study revealed strange surface behavior, despite superconducting transition in transport measurements of bulk sample at 4 K, there is no superconductive gap observed on cleaved surface even at 1.2 K.

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Study of spin – orbit coupling in Graphene/BiTeBr heterostructures

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The research on van der Waals heterostructures assembled from 2D crystals became one of the leading topics in condensed matter physics. By choosing layer properties and their ordercarefully materials with novel properties can be engineered [1].

Here we investigate graphene/BiTeBr heterostructures, where BiTeBr is a material possessing a giant spin – orbit coupling. The calculations suggest that a spin orbit interaction can be induced in graphene by the proximity of BiTeBr. The induced spin orbit interaction can lead to new spintronics functions tuneable by electric gates [2]. To engineer these heterostructures we have produced graphene and BiTeBr flakes with mechanical exfoliation from the bulk crystals. Then the graphene/BiTeBr heterostructures were assembled using van der Waals stacking and nanocircuits for characterizing their behaviour were fabricated using e-beam lithography. We have performed comparative measurements between the heterostructures and simple graphene devices to examine the effects of the BiTeBr on the transport properties of graphene. The basic transport properties are addressed via field-effect measurements, whereas the spin properties are characterized by weak localization measurements.

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Thermal transport in intermetallic compounds based on rare-earth crystals

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Recently discovered features of intermetallic compounds from family RIr_4X_{13} and $RIr_4In_2X_4$ (where R is an alkaline earth metal and X is Ge or Sn) have attracted interest and started intense investigation of crystals of this type. Among the most desiring phenomena were the unconventional superconductivity, hybridization gap, charge density wave state, modulated lattice distortion or enormously big Seebeck coefficient. Depending on their chemical composition they form non-centrosymmetric crystals, which exhibit either metallic or semiconducting behavior.

Here we present the recent results of thermal transport investigations carried out on pure and doped large single crystals taking into account the possible anisotropy of the properties. The measured compounds are as followed $RIr_4In_2X_4$ with europium and strontium as an alkaline earth metal, and X is germanium. For the structure like this one (with atomic cages inside of which some of atoms of the compounds are localized) may consider the influential role that crystal symmetry of the lattice environment plays in the magnetic behavior of an ion, in anisotropy of the semiconducting state or on the nature of superconductivity that may occur in the material's ground state. Cage structures of this nature provide interesting physical properties in their own right due to features that arise from the relatively large interatomic distances, but also due to the consequential possibilities to devise thermoelectric materials of high efficiency. In this concept, an atom that is highly coordinated inside a large cage of neighboring atoms could be expected to act as an effective scatterer of heat-carrying acoustic phonons through off-centre thermal motion ('rattling') resulting in low thermal conductivity of the structure. The results will be presented together with a proposed explanation of the observed macroscopic phenomena at the microscopic level.

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Magnetic Flux Penetration into Finite Length Thin-Walled Niobium Cylinders & Giant Magnetic Flux Jumps

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We report the results of numerical simulation of the distribution of magnetic field in a finite thin-walled superconducting cylinder in an axial magnetic field. We demonstrated that both current density and magnetic field exhibit a strong maximum in the cylinder edges. This triggers a giant flux jump in the hollow cylinder when a slowly increasing external magnetic field reaches a threshold value. Experimentally measured flux jumps were observed in a wide range of external fields, even below H_{c1} of the Nb film [1], [2]. The fields at which the jumps appear are temperature dependent and the field of the first jump increases with temperature. The increase of the field of the first jump with temperature can be explained on the basis of our calculations assuming that the critical current decreases more slowly with temperature than increasing the London penetration depth. We demonstrated that with increasing the wall thickness the singularity of the current density and magnetic field on the edges decreases, which explains the absence of giant jumps in a sample with thick walls in fields below H_{c1} [3].

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NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES

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Flux-flow spin Hall effect in type-II superconductors

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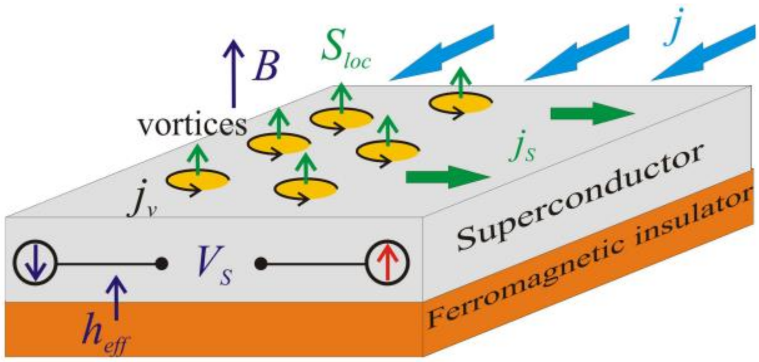
We predict the very large spin Hall effect in type-II superconductors which mechanism is drastically different from the previously known systems. We find that in the flux-flow regime the spin is transported by the spin-polarized Abrikosov vortices moving under the action of the Lorenz force in the direction perpendicular to the applied electric current. Due to the large vortex velocities the spin Hall angle can be of the order of unity in realistic systems based on the high-field superconductors or the recently developed superconductor/ferromagnetic insulator proximity structures. We suggest the high-frequency generator of the pure spin currents stemming from the periodic structure of moving vortex lattices and discuss the inverse flux-flow spin Hall effect when the injected spin current generates longitudinal driving force on vortices and the transverse voltage in result of their motion.



The schematic picture of the effect. The cores of Abrikosov vortices (yellow circles) contain localized normal phase which acquires spin polarization S_{loc} due to the Pauli paramagnetism. Effective spin splitting is given by the Zeeman shift $\mu_B B$ and can be enhanced by the exchange field h_{eff} induced at the interface with ferromagnetic insulator. The interaction of transport j and vortex j_v currents generates the Lorentz force driving vortex motion in the transverse direction with the velocity $v_L \perp j$ resulting in the spin current and edge spin accumulation V_s in the open circuit.

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nanoSQUIDs for Scanning SQUID microscopy

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The miniaturization of SQUID structures down to the sub-micron scale (nanoSQUIDs) is highly promising for their application in high-resolution scanning SQUID microscopy (SSM). Following recent achievements with nanoSQUIDs from conventional metallic superconductors, we are developing nanoSQUIDs for SSM based on the cuprate superconductor $YBa_2Cu_3O_7$ (YBCO) and the superconductor niobium (Nb). After preparation of the SQUID chips, the chips will be turned over and used as a cantilever for SSM. As the resolution of SSM depends critically on distance between the probe and the sample, it is of vital importance to minimize the distance between the SQUID and the edge of the chip. This, however, poses serious challenges in fabrication and positioning of the SQUIDs. Therefore a process for preparing the substrate without harming the properties of the superconductor needs to be developed.

For Nb SQUIDs, for which we use silicon as a substrate, we minimize the distance to the chip edge by dicing the SQUID chip in the shape of a triangle. Here, care must be taken that the SQUID is not damaged by chipping of the substrate.

For the SQUIDs based on grain boundary Josephson junctions in YBCO on a $SrTiO_3$ bicrystal substrate, the chipping does not allow dicing close to the SQUID. This problem can be solved by introducing an antecedent etching-step. We developed an etching process with hydrofluoric acid which avoids preferential etching along the grain-boundary and does thus does not harm the YBCO grain boundary junctions.

Successful fabrication of SQUIDs on a cantilever promises applications for the investigation of magnetic nanoparticles and the development of a 3D-vector SQUID microscope. The use of YBCO offers operation over a wide range of temperature and magnetic field, which can significantly enhance the range of application of nanoSQUIDs for SSM-based nanoscale magnetic sensing and thermometry.

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Development of a scanning SQUID microscope and positioning system for SQUID detection of magnetic nanoparticles

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Since the development of the first Scanning SQUID Microscope (SSM) by Rogers and Bermon [1] in 1983 several approaches to the realization and optimization of SSMs have been made [2]. The core limitation for the resolution of a SSM is the size of the SQUID loop (or pickup loop) and the distance between the SQUID loop and the sample. Successful advancements in miniaturizing SQUIDs to sub-micron dimensions (nanoSQUIDs) [3,4] have opened up the way towards the development of SSMs with sub-micron resolution [5,6].

This work has the goal of building a SSM that makes use of the nanoSQUIDs developed in our research group [7,8]. The SSM setup is combined with force microscopy, based on the use of a mechanically excited quartz tuning fork [9]. To minimize the probe to sample distance specially designed nanoSQUIDs will be attached to this quartz tuning fork. Depending on the kind of nanoSQUID being used the operating temperature will be at about 4K for niobium SQUIDs, or up to about 77K for $YBa_2Cu_3O_7$ (YBCO). The latter case is especially interesting because it offers the investigation of samples over a wide range of temperatures.

Through slight modifications to the SSM setup it should also be possible to examine single magnetic nanoparticles (MNPs). For this purpose, a MNP needs to be attached to a thin tip (e.g. tungsten rod) which can then act as a tip for the force microscope. An underlying SQUID (or SQUID array) then provides information on the magnetic moment of the MNP and possible magnetization reversal mechanisms in sweeping magnetic fields.

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