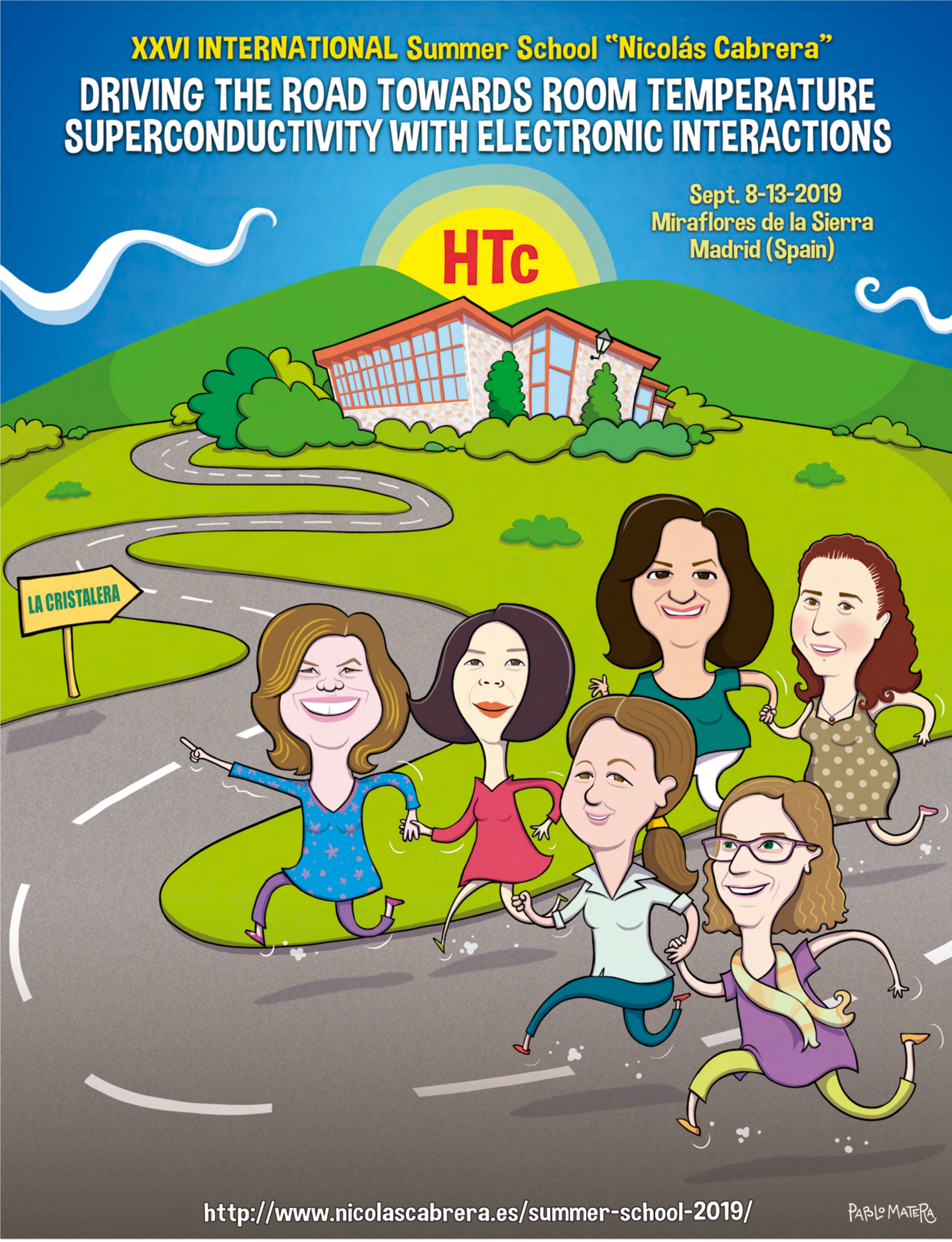

UAM Universidad Autónoma de Madrid

INC

IFIMAC Condensed Matter Physics Center

Fundación BBVA

Contents

Aims and Scope

The challenge to find really high critical temperature (HTc) superconductors was probably first envisioned by a large community of researchers during the late eighties, with the discovery of cuprate superconductivity. After three decades of research, the vision is on the focus again thanks to the discovery of HTc superconductivity in iron-based compounds. HTc superconductivity is found in close proximity to new electronic phases, in particular close to a quantum critical point.

The INC Summer School 2019 is focused on electronic correlations, the vehicle that many want use to drive towards room temperature superconductivity. Charge density waves, antiferromagnetism and, most recently, nematic order, are identified ubiquitously in relation to HTc superconductivity. Electronic correlations driving magnetic order or nematicity and pinning down superconductivity are tightly intertwined. New technologies, such as high magnetic fields, atomic level precision measurements or ultrafast spectroscopies are needed to disentangle the microscopic essence of correlated electron superconductivity from the rich phenomenology of the intertwined phases. The recent discovery of strong electron interactions and superconductivity in bilayer graphene strengthens the motivation and suggests that the goal of finding the materials needed to build useful zero resistance appliances might be closer than we thought of.

The objective of the Summer School is to present a fresh overview about the state of the art in HTc superconductivity by gathering main actors in the field. We will provide a bird's eye view and zoom deep inside the recent advances obtained from experiments and theory. We will discuss new developments in material synthesis, novel experimental probes with high resolution in extreme conditions and powerful theoretical methods. These have been triggered during the last few years to find new clues on electronically driven HTc superconductivity and have made a great impact on other areas in material science.

Organizers

Organizers

• Elena Bascones, ICMM-CSIC • Isabel Guillamón, IFIMAC-UAM • Hermann Suderow, IFIMAC-UAM	• Miriam Alonso, Secretary of the School • Manuela Moreno, Secretary of INC

Contact details

e-mail: school.nicolascabrera@uam.es.

Local organizing committee:

Victor Barrena, UAM

Francisco Martín, UAM

Marta Fernández-Lomana, UAM

Raquel Sanchez, UAM

Edwin Herrera (head of local committee), UAM

Beilun Wu, UAM

David Perconte, UAM

Raquel Fernández-Martín, ICMM-CSIC

Supported by:

Fundación BBVA

Invited Speakers

Annica BLACK-SCHAFFER, Uppsala University, Sweden
Greg S. BOEBINGER, National High Magnetic Field Laboratory, US
Antony CARRINGTON, University of Bristol, UK
Andrés CANO, Institut NEEL, CNRS & UGA, France
Amalia COLDEA, University of Oxford, UK
Andrey CHUBUKOV, University of Minnesota, US
J.C. Seamus DAVIS, University of Oxford, UK
Dmitri K. EFETOV, Institute of Photonic Sciences, Barcelona, Spain
Claudio GIANNETTI, Univesitá Cattolica del Sacro Cuore, Brescia, Italy
Przemyslaw GRZYBOWSKI, ICFO and Adam Mickiewicz University, Poznań, Poland
Francisco GUINEA, IMDEA Nanociencia, Madrid, Spain
Stephen HAYDEN, University of Bristol, UK
Pablo JARILLO-HERRERO, Massachusetts Institute of Technology, US
Bernhard KEIMER, Max Plank Institute for Solid State Research, Stuttgart, Germany
Eun-Ahn KIM, Cornell University, US
Yuji MATSUDA, Kyoto University, Japan
Alexandre POURRET, Université Grenoble, France
Cyril PROUST, Laboratory of Intense Magnetic Fields-Toulouse, France
Teresa PUIG, Institute of Materials Science of Barcelona, Spain
Mohit RANDERIA, The Ohio State University, US
Filip RONNING, Los Alamos National Lab, US
Jörg SCHMALIAN, Karlsruhe Institute of Technology, Germany
Nandini TRIVEDI, The Ohio State University, US
Peter WAHL, University of Saint Andrews, UK
Hai-Hu WEN, Nanjing University, China

Venue and travel information

LA CRISTALERA RESIDENCE

La Cristalera residence (http://www.lacristalera.com/) is located in Miraflores de la Sierra (www.miraflores delasierra.org), a pleasant mountain resort near Madrid.

The residence is equipped with some sport facilities and a swimming pool. Mountain hiking trails for all levels can be easily accessed from the residence.

Internet can be accessed through EduRoam system (www.eduroam.org/) and a wifi network (crisuam), with free access, at the dining room.

TRAVEL INFORMATION

A bus service "Madrid-Barajas Adolfo Suárez Airport T4 ↔ La Cristalera" will be organized for participants arriving Sunday September and departing Friday 13 with the following timetable:
- From the airport to La Cristalera: 18:00.
- From La Cristalera to the airport: 14:30 arriving to the airport at 15:30.

Arrival by plane:

You can reach Miraflores by taxi from the airport but this is an expensive choice (around 90.00 Euro, but please ask before for a price).

The information for the driver is:

> Residencia "La Cristalera"
> Carretera de Miraflores de la Sierra a Rascafría Km.10 (M-611) 28792, Miraflores de la Sierra (Madrid). Tell him to go through "autovía de Colmenar, M-607".

You can also take a taxi from the Airport to Plaza Castilla (30 € fixed fare for Madrid city) and then take a bus (725 line) to Miraflores.

You can find your way from Madrid using the google public transport option, inserting your departure place and “Miraflores de la Sierra, 28792, Madrid” as the arrival place. The journey with public transport may take up to 2 hours, depending on where you depart. The bus line serving Miraflores de la Sierra is the 725 (https://www.crtm.es/tu-transporte-publico/autobuses-interurbanos/lineas/8__725___.aspx?lang=en). You can get out at “Miraflores de la Sierra Centro Social”. Then, there is a 30 minutes walk to the meeting place with approximately 100 meters height difference.

Arrival by train:

Coming from the North, the train station is usually Chamartin. From Chamartin, you can take the Metro (line 1 light blue or line 10: dark blue) to Plaza de Castilla but it is only one station and it is also easy to walk from Chamartin to Pza Castilla. If you arrive at Atocha, you can take the Metro (line 1: light blue, 13 stations) to Plaza Castilla and follow the above-mentioned instructions for the bus.

Arrival by car:

Take the highway M-40. If you come from the south, Portugal, or the Zaragoza Highways, take direction North (N-I). If you come from the Burgos Highway (N-I) take the direction M-607 Tres Cantos- Colmenar Viejo. Go out of the M-40 to the M-607 Highway towards Tres Cantos-Colmenar viejo. When the Highway ends (roughly 30 km) take the direction Miraflores. After 30 km you will reach the village. Once there, follow the signs towards La Cristalera, or Puerto de la Morcuera. One km outside the village you will find the entrance to the residence on your left (but watch out for it since sign is not a big one and may be missed).

GPS location: 40° 49′ 14″ N, 3° 47′ 1″ W

Schematic Program

	Sep 08 Sunday	Sep 09 Monday	Sep 10 Tuesday	Sep 11 Wednesday	Sep 12 Thursday	Sep 13 Friday
08:50		Opening				
09:00		Materials, mechanisms and non-equilibrium Matsuda	Nematicity and superconduct. Chubukov	Correlations and super. in twisted bilayer graphene Boebinger	Pair density wave, pseudogap and fluctuations in cuprates Kim	Correlations in superconduct. heavy fermions and Applications Wahl
09:00		Chubukov	Schmalian	Jarillo-Herrero	Davis	Ronning
10:10		Randeria	Matsuda	Efetov	Proust	Pourret
11:20		Coffee Break				
11:50		Giannetti	Coldea	Guinea	Trivedi	Puig
13:00		Lunch and time for discussion			Grzybowski	Closing
13:35		Lunch and time for discussion				
15:00		Normal state properties Davis	Superc. gap in IBS and Odd paring Schmalian	EXCURSION AND CONFERENCE DINNER	Charge and spin in cuprates and Topological superconduct. Proust	
15:00		Carrington	Wahl		Keimer	
16:10		Boebinger	Wen		Hayden	
17:20		Coffee Break	Coffee Break		Coffee Break	
17:50	Welcome reception	Cano	Black Schaffer		Kim	
18:25		Flash and poster session 1				
19:00			Flash and poster session 2		Flash and poster session 3	
20:30	Dinner				Barbecue Dinner	

Detailed Program

Monday, 09 Sep 2019

8:50	**Opening**	
9:00-13:00	***Materials, mechanisms and non-equilibrium*** **Chair: Matsuda**	
09:00-10:10	***Superconductivity from repulsion***	**Chubukov**
10:10-11:20	***Upper bounds on the superconducting transition temperature: Applications to twisted-bilayer graphene and ultra-cold Fermi gases***	**Randeria**
11:20-11:50	**Coffee Break**	
11:50-13:00	***Ultrafast optical spectroscopy of strongly correlated materials and high-temperature superconductors: a non-equilibrium approach***	**Giannetti**
13:00-15:00	**Lunch and time for discussion**	
15:00-18h25	***Normal state properties*** **Chair: Davis**	
15:00-16:10	***Normal state properties of cuprate high T_C Superconductors***	**Carrington**
16:10-17:20	***Using high magnetic fields to reveal thermodynamic evidence of critical behaviour near optimum doping in high-temperature superconductivity***	**Boebinger**
17:20-17:50	**Coffee Break**	
17:50-18:25	***Superconductivity in the novel Fe-based silicide LaFeSiH***	**Cano**
18:25-20:00	**Flash and poster session 1**	
20:30	**Dinner**	

Tuesday, 10 Sep 2019

9:00-13:00	***Nematicity and superconductivity*** **Chair: Chubukov**	
09:00-10:10	***Nematic superconductivity in doped topological insulators***	**Schmalian**
10:10-11:20	***Rotational symmetry breaking in cuprate and iron-based superconductors***	**Matsuda**
11:20-11:50	**Coffee Break**	
11:50-13:00	***Experimental probes to investigate the electronic structure of iron-based superconductors***	**Coldea**
13:00-15:00	**Lunch and time for discussion**	
15:00-19:00	***Superconducting gap in IBS and Odd paring*** **Chair: Schmalian**	
15:00-16:10	***Imaging and control of magnetic phases in quantum materials using spin-polarized scanning tunneling microscopy***	**Wahl**
16:10-17:20	***Vortex bound states in conventional and topological superconductors***	**Wen**
17:20-17:50	**Coffee Break**	
17:50-19:00	***Mechanisms and materials for odd-frequency superconductivity***	**Black-Schaffer**
19:00-20:30	**Flash and poster session 2**	
20:30	**Dinner**	

Wednesday, 11 Sep 2019

9:00-11:20	***Correlations and superconductivity in twisted bilayer graphene*** **Chair: Boebinger**	
09:00-10:10	***Magic angle graphene: A new platform for strongly correlated physics***	**Jarillo-Herrero**
10:10-11:20	***Superconductors, orbital magnets, and correlated states in magic angle bilayer graphene***	**Efetov**
11:20-11:50	**Coffee Break**	
11:50-13:00	***Electronic properties of twisted graphene layers: bands, interactions and superconductivity***	**Guinea**
13:35-15:00	**Lunch and time for discussion**	
15:00 23:30	**Excursion and Conference Dinner**	

Thursday, 12 Sep 2019

9:00-13:35	***Pair density wave and pseudogap and fluctuations in cuprates*** **Chair: Kim**	
09:00-10:10	***Discovery and exploration of the cuprate pair density wave state***	**Davis**
10:10-11:20	***The remarkable underlying ground states of cuprates***	**Proust**
11:20-11:50	**Coffee Break**	
11:50-13:00	***Superconductor-Insulator transition driven by disorder and magnetic field: the emergence of novel insulating phases***	**Trivedi**
13:00-13:35	***The origin of the nano-scale separation in cuprates***	**Grzybowski**
15:00-19:00	**Lunch and time for discussion**	
15:00-19:00	***Charge and spin in cuprates and Topological superconductors*** **Chair: Proust**	
15:00-16:10	***Charge order and dynamics in cuprate superconductors***	**Keimer**
16:10-17:20	***Spin fluctuations in cuprate superconductors***	**Hayden**
17:20-17:50	**Coffee Break**	
17:50-19:00	***Let there be topological superconductors***	**Kim**
19:00-20:30	**Flash and poster session 3**	
20:30	**Barbecue Dinner**	

Friday, 13 Sep 2019

9:00-11:20	***Correlations in superconducting heavy fermions and Applications*** **Chair: Wahl**	
09:00-10:10	***Heavy fermion superconductivity***	**Ronning**
10:10-11:20	***Introduction to p-wave superconductors: from ferromagnetic to paramagnetic materials***	**Pourret**
11:20-11:50	**Coffee Break**	
11:50-13:00	***Superconducting materials and their applications***	**Puig**
13:00-13:10	**Closing**	
13:10-14:30	**Lunch and time for discussion**	

Abstracts of Lecturers

Mon01| *Materials, mechanisms and non-equilibrium*

SUPERCONDUCTIVITY FROM REPULSION

Andrey V. CHUBUKOV [1]

[1] *Department of Physics, University of Minnesota, Minneapolis, MN 55455, USA*

In my talk, I review recent and not so recent works aiming to understand whether a nominally repulsive Coulomb interaction can by itself give rise to a superconductivity. I discuss a generic scenario of the pairing by electron-electron interaction, put forward by Kohn and Luttinger back in 1965, and modern studies of the electronic mechanisms of superconductivity in the lattice systems which model cuprates, Fe-based superconductors, and even doped graphene. I show that the pairing in all three classes of materials can be viewed as a lattice version of Kohn-Luttinger physics, despite that the pairing symmetries are different. I discuss under what conditions the pairing occurs and rationalize the need to do renormalization-group studies, using Fe-based systems as an example. I also discuss the interplay between superconductivity, magnetism, and orbital order.

E-mail: **achubuko@umn.edu**

***Mon02**| Materials, mechanisms and non-equilibrium*

UPPER BOUNDS ON THE SUPERCONDUCTING TRANSITION TEMPERATURE: APPLICATIONS TO TWISTED-BILAYER GRAPHENE AND ULTRA-COLD FERMI GASES

Mohit RANDERIA[1]

[1] *Department of Physics, The Ohio State University, Columbus, Ohio 43210, EEUU*

Understanding the material parameters that control the superconducting transition temperature T_c is a problem of fundamental importance. We use sum rules to derive a rigorous upper bound on the superfluid phase stiffness D_s valid in any dimension. This in turn leads to an upper bound on T_c in two dimensional (2D) systems, which holds irrespective of mechanism, strength of pairing interaction, or order-parameter symmetry. While this bound is of general validity, it is particularly useful and leads to stringent constraints for the strongly correlated regime of low-density and narrow-band systems, where conventional the BCS-Eliashberg approach fails. For a simple parabolic band, we find that k_BT_c can never exceed $E_F/8$ in 2D. We show that this bound is close to being saturated in 2D ultracold Fermi gases in the strongly interacting regime of the BCS-BEC crossover. Applying our multi-band bound to magic-angle twisted bilayer graphene (MA-TBG), we find that the available electronic structure results already constrain the maximum possible T_c to be close to the experimentally observed value. Finally, I will discuss the theoretical challenges in deriving rigorous upper bounds on T_c in three dimensions (3D) and the experimental evidence for or against such a 3D bound.

E-mail: **randeria.1@osu.edu**

***Mon03**| Materials, mechanisms and non-equilibrium*

ULTRAFAST OPTICAL SPECTROSCOPY OF STRONGLY CORRELATED MATERIALS AND HIGH-TEMPERATURE SUPERCONDUCTORS: A NON-EQUILIBRIUM APPROACH

Claudio GIANNETTI [1]

[1] *Department of Mathematics and Physics, Università Cattolica del Sacro Cuore, Brescia, Italy*

Interdisciplinary Laboratories for Advanced Materials Physics (ILAMP), Università Cattolica del Sacro Cuore, Brescia, Italy

Non-equilibrium techniques are emerging as a unique tool to investigate in real time the electronic interactions in correlated materials and the coupling of electrons to bosonic degrees of freedom. The possibility of obtaining simultaneously spectroscopic and temporal information from ultrafast techniques has led to insights that are complementary to (and in several cases beyond) those attainable by studying the matter at equilibrium.

In this talk we will provide an overview of the recent advances in the field. We will discuss the possibility to investigate non-equilibrium electronic, optical, structural and magnetic properties of correlated materials and to unveil the energy relaxation processes in unconventional superconductors, with particular focus on superconducting copper oxides. We will also address the possibility to induce and control novel transient electronic phases with no counterpart at equilibrium.

E-mail: **claudio.giannetti@unicatt.it**

NORMAL STATE PROPERTIES OF CUPRATE HIGH T_c SUPERCONDUCTORS

Antony CARRINGTON[1]

[1] *HH Wills Physics Laboratory, University of Bristol*

The aim will be to summarise our understanding of the normal state properties of cuprate high T_c superconductors and how these inform the discussion about the origin of superconductivity in these materials. The focus will be on bulk experimental probes rather than spectroscopic methods. We will start by reviewing the phase diagram and briefly describe the phenomenology of the pseudo-gap and charge density wave phases. Electronic structure as calculated using density functional theory will be presented and how this is modified by Mott-Hubbard correlations described. How the temperature dependence of the transport properties (resistivity, Hall effect and thermopower) and the specific heat are used to construct the phase diagram and determine the nature of the electronic structure will be reviewed. We will then move to describing Boltzmann transport theory, particularly in high magnetic fields, and we will outline to what extent this explains the evolution of the transport properties across the phase diagram. Finally, we will cover the very high field limit where quantum oscillations are observed and describe what these tell us about the evolution of the normal state across the phase diagram.

1. Phase diagram with brief review of pseudogap and CDW phases
2. Electronic structure – DFT and Mott-Hubbard
3. Resistivity, R(T)
4. Hall Effect R_H(T) and magnetoresistance R(T,B)
5. Specific heat and thermopower
6. Boltzmann theory of R(T,B) and RH(T,B). Low and high field limits. Jones/Zener and Shockley tube integral formulations
7. Quantum Oscillations in underdoped and overdoped regime

E-mail: **A.Carrington@bristol.ac.uk**

Mon05 | *Normal state properties*

USING HIGH MAGNETIC FIELDS TO REVEAL THERMODYNAMIC EVIDENCE OF CRITICAL BEHAVIOR NEAR OPTIMUM DOPING IN HIGH-TEMPERATURE SUPERCONDUCTIVITY

Gregory BOEBINGER[1]

[1] *Professor of Physics, Florida State University and University of Florida and Director, U.S. National High Magnetic Field Laboratory*

We measure the electronic specific heat in a series of Ba122 high-temperature superconductors. High magnetic fields are used to suppress the superconducting state, providing a direct experimental determination of the density of electronic states that take part in superconductivity in these samples. We find that this density of states is greatly increased as one approaches optimum doping, evidencing enhanced electronic correlations in more strongly superconducting samples. Indeed, the data extrapolate to imply a divergence precisely at optimum doping.

E-mail: **gsb@magnet.fsu.edu**

SUPERCONDUCTIVITY IN THE NOVEL Fe-BASED SILICIDE LaFeSiH

Andrés CANO[1]

[1] *Institut NEEL, CNRS & UGA, Grenoble, France*

The so-called Fe-based superconductors have proven to be a very rich family of high-temperature unconventional superconductors in terms of both physics and materials [1]. Remarkably, the most interesting superconducting properties of these systems seem to be invariably obtained when the Fe atom is bonded to the toxic pnictogen As or the scarce chalcogenide Se. At present, the fundamental reasons behind such a chemical limitation are not well understood [2].

In this talk, I will introduce the novel Fe-based silicide LaFeSiH and discuss its superconducting properties [3]. This system surpasses the above chemical limitation displaying superconductivity with Tc ~ 10 K at ambient pressure, already in its parent phase. From the electronic-band-structure point of view, LaFeSiH displays essentially the same features than the reference material LaFeAsO at the expense of a more 3D character that reduces its nesting properties. This is still compatible with single-stripe atiferromagnetic order, although with an increased tendency towards ferromagnetism. Superconductivity in LaFeSiH cannot be explained due to electron-phonon coupling and hence emerges from an unconventional mechanism. In fact, magnetic penetration depth measurements in LaFeSiH reveal a nodal superconducting gap compatible with d-wave symmetry.

References

[1] See e.g. H. Alloul and A. Cano, Special Issue on Iron-based superconductors, C. R. Phys. **17**, 1 (2016), and the references therein.

[2] D. Guterding, H. O. Jeschke, I. I. Mazin, J. K. Glasbrenner, E. Bascones, and R. Valentí, Phys. Rev. Lett. **118**, 017204 (2017); P. Villar Arribi, F. Bernardini, L. de'Medici, P. Toulemonde, S. Tencé, and A. Cano, Magnetic competition in iron-based germanide and silicide superconductors, arXiv:1810.10306.

[3] F. Bernardini, G. Garbarino, A. Sulpice, M. Núñez-Regueiro, E. Gaudin, B. Chevalier, M.-A. Méasson, A. Cano, and S. Tencé, Iron-based superconductivity extended to the novel silicide LaFeSiH, Phys. Rev. B **97**, 100504(R) (2018).

[4] L. Hung and T. Yildirim, First-principles study of magnetism, lattice dynamics, and superconductivity in LaFeSiHx, Phys. Rev. B **97**, 224501 (2018).

E-mail: **andres.cano@neel.cnrs.fr**

Tue01 | Nematicity and superconductivity

NEMATIC SUPERCONDUCTIVITY IN DOPED TOPOLOGICAL INSULATORS

Jörg SCHMALIAN [1]

[1] *Institute for Theory of Condensed Matter and Institute for Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany*

If the topological insulator Bi2Se3 is doped with electrons, superconductivity with $T_c \approx 3-4K$ emerges for a low density of carriers ($n \approx 10^{20} cm^{-3}$) and with a small ratio of the superconducting coherence length and Fermi wavelength: $\xi/\lambda_F \approx 2 \cdots 4$. These values make fluctuations of the superconducting order parameter increasingly important, to the extend that the T_c-value is surprisingly large. Strong spin-orbit interaction led to the proposal of an odd-parity pairing state. This begs the question of the nature of the transition in an unconventional superconductor with strong pairing fluctuations. We show that for a multi-component order parameter, these fluctuations give rise to a nematic phase at $T_{nem} > T_c$. Below T_c several experiments demonstrated a rotational symmetry breaking where the Cooper pair wave function is locked to the lattice. Our theory shows that this rotational symmetry breaking, as vestige of the superconducting state, already occurs above T_c. The nematic phase is characterized by vanishing off-diagonal long-range order, yet with anisotropic superconducting fluctuations. It can be identified through direction-dependent para-conductivity, lattice softening, and an enhanced Raman response in the E_g symmetry channel. In addition, nematic order partially avoids the usual fluctuation suppression of T_c.

References

[1] M. Hecker and J. Schmalian, npj Quantum Materials **3**, 26 (2018).

E-mail: **joerg.schmalian@kit.edu**

ROTATIONAL SYMMETRY BREAKING IN CUPRATE AND IRON-BASED SUPERCONDUCTORS

Yuji MATSUDA[1]

[1] *Department of Physics, Kyoto University, Japan*

Electronic nematicity that spontaneously breaks the rotational symmetry of the underlying crystal lattice has been a growing issue in high-temperature superconductivity of iron pnictides/chalcogenides and cuprates. Here we discuss the nematicity in these two classes of superconductors.

A long-standing controversial issue in the quest to understand the superconductivity in cuprates is the nature of the enigmatic pseudogap region of the phase diagram. Especially important is whether the pseudogap state is a distinct thermodynamic phase characterized by broken symmetries below the onset temperature T_{pg}. We measured torque-magnetometry measurements of anisotropic susceptibility [1] within the ab planes in orthorhombic YBCO[2] and tetragonal Hg1201[3] with exceptionally high precision. Two-fold susceptibility anisotropy emerges spontaneously at T_{pg}, providing direct evidence of the broken rotational symmetry. These firmly establish that the nematic phase transition is universal in high-T_c cuprates. Furthermore, in Hg1201, the development of the nematicity is suppressed below the CDW order, implying that the nematicity competes with CDW.

A fundamental issue concerning iron-based superconductivity is the roles of electronic nematicity and magnetism in realizing high transition temperature [1]. To address this issue, FeSe is a key material, as it exhibits a unique phase diagram involving non-magnetic nematic ordered phases. $FeSe_{1-x}S_x$, in which the nematicity can be tuned by isoelectronic sulfur substitution, offers a fascinating opportunity to clarify the direct relationship between the nematicity and superconductivity [4]. Here we discuss how the normal state and superconducting properties change at the critical concentration of sulfur where the nematicity disappears, i.e., nematic critical point. We discuss a dramatic change in the superconducting gap structure [5], a possible BCS-BEC crossover [6] and non-Fermi liquid behavior at the critical point [7].

References

[1] S. Kasahara et al. Nature **486**, 382 (2012).
[2] Y. Sato et al. Nature Phys. **13**, 1074 (2017).
[3] H. Murayama et al. Nature Commun. to be published.
[4] K. Matsuura et al. Nature commun. **8**, 1143 (2017).
[5] Y. Sato et al. Proc. Natl. Acad. Sci. USA **115**, 1227 (2018).
[6] S. Kasahara et al. Proc. Natl. Acad. Sci. USA **111**, 16309 (2014).
[7] S. Licciardello et al. Nature **567**, 213 (2019).

E-mail: **matsuda@scphys.kyoto-u.ac.jp**

Tue03| *Nematicity and superconductivity*

EXPERIMENTAL PROBES TO INVESTIGATE THE ELECTRONIC STRUCTURE OF IRON-BASED SUPERCONDUCTORS

Amalia COLDEA[1]

[1] *Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom*

In this talk I will present an overview of a few key experiments to investigate the electronic behaviour of a class of iron based-superconductors (iron-chalcogenides) using angle resolved photoemission, quantum oscillations and magnetotransport studies.

E-mail: **Amalia.Coldea@physics.ox.ac.uk**

***Tue04**| Superconducting gap in IBS and Odd paring*

IMAGING AND CONTROL OF MAGNETIC PHASES IN QUANTUM MATERIALS USING SPIN-POLARIZED SCANNING TUNNELING MICROSCOPY

Peter WAHL[1]

[1]*School of Physics and Astronomy, University of St Andrews, UK*

Quantum materials host many properties, which are highly desirable for technological applications, yet our lack of understanding of their physics often prevents them from being exploited. A delicate balance between different competing interactions results in close proximity of emergent orders such as magnetic order and superconductivity. Understanding the interactions which govern these phases is believed to be key to unravelling their enigmatic properties and making them amenable for applications.

In my talk, I will introduce spin-polarized scanning tunnelling microscopy as a tool to characterize the emergent properties of quantum materials, as well as to locally manipulate them. I will discuss this exemplarily for $Fe_{1+\delta}Te$, a material that is antiferromagnetically ordered and becomes superconducting by replacing Se for Te (fig. 1) [1]. I will show how we can control the magnetic order through manipulation of the surface composition [2].

I will highlight the opportunities of atomic scale imaging and spectroscopy for establishing a better understanding of the physics of quantum materials, which will be at the basis of exploring their emergent properties for applications.

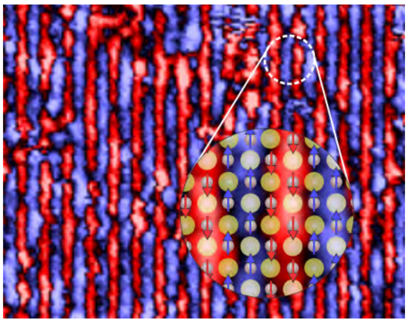

Figure 1: Atomic scale image of the magnetic order in the parent compound $Fe_{1+\delta}Te$ of the iron chalcogenide superconductors. Red and Blue indicate areas where the magnetization points in opposite directions.

References

[1] M. Enayat, et al., Real Space Imaging of the Atomic-Scale Magnetic Structure of Fe1+yTe, Science **345**, 653 (2014).

[2] C. Trainer, et al., Manipulating surface magnetic order in iron telluride, Sci. Adv. **5**, eaav3478 (2019).

E-mail: **gpw2@st-andrews.ac.uk**

***Tue05**| Superconducting gap in IBS and Odd paring*

VORTEX BOUND STATES IN CONVENTIONAL AND TOPOLOGICAL SUPERCONDUCTORS

Hai-Hu WEN[1]

[1] *Physics Department, Nanjing University, China*

In type-II superconductors, magnetic flux with a flux quanta $\Phi_0 = h/2e = 2.07\times10^{-15}$ Wb will be formed when applied magnetic field is higher than the lower critical one H_{c1}. The single vortex can be regarded as a normal core region with electrons satisfying the Bogoliubov dispersion. Surrounding this normal core there is a supercurrent with Cooper pairs as the charge carriers. Due to the spatial confinement to the quasiparticles, bound states with eigenstate energies of $E = \mu\Delta^2 / E_F$ (μ=±1/2, 3/2, 5/2,...)[1,2] exist within the vortex core. In conventional superconductors, due to $E_F >> \Delta$, the separation between these eigenstate energy levers is very small, which makes it difficult to be observed. What turns out is a central bound state peak which locates at zero bias energy and is formed by the accumulation of many bound states with different levels. When moving away from the vortex center, this central peak will split into two and gradually moves to the gap edge. By measuring the spatial evolution of tunnelling spectra on the surface of $FeTe_{0.55}Se_{0.45}$, we observed the long sought discrete Caroli-de Gennes-Matricon bound states[3] within some vortex cores. By analyzing the energies of the lowest level and the interval between the energy levels, we found that the iron based superconductor $FeTe_{0.55}Se_{0.45}$ has the shallow band with the Fermi energy of about 5-20 meV, indicating the possibility of a crossover from BEC-BCS. Furthermore we have measured the vortex core bound states on many other vortices in different areas and/or different samples, and found that, in some vortices there is a strong bound state peak locating at zero energy. With the rather symmetric shape at the gap edge, we would conclude that it may correspond to the Majorana mode[4]. The influence of magnetic field, temperature and local proportion ratio of Te/Se on the zero energy mode will also be reported.

To explore the possible topological superconductivity in materials with the basic Bi_2Te_3 structure, we depot the thin film on the $FeTe_{0.55}Se_{0.45}$ substrate and get the proximity induced superconductivity. By using the quasiparticle interference technique, we demonstrate clear evidence of twofold symmetry of the superconducting gap. The gap minimum is along one of the main crystalline axis following the so-called Δ_{4y} notation. This is also accompanied by the elongated vortex shape. Within the vortex core, along the stretched direction, a zero energy peak appears and stays until going out of the vortex. Our results reveal the direct evidence of superconductivity with two-fold symmetry in Bi_2Te_3 thin film[5] .

References

[1] C. Caroli, P. G. de Gennes, and & J. Matricon, J. Phys. Lett. **9**, 307–309 (1964).
[2] N. Hayashi, T. Isoshima, M. Ichioka, & K. Machida, Phys. Rev. Lett. **80**, 2921 (1998).
[3] M. Y. Chen, X. Y. Chen, H. Yang, H.-H. Wen et al. Nat. Commun. **9**, 970 (2018).
[4] X. Y. Chen, M. Y. Chen, H. Yang, H.-H. Wen et al. to be published.

E-mail: **hhwen@nju.edu.cn**

Tue06| Superconducting gap in IBS and Odd paring

MECHANISMS AND MATERIALS FOR ODD-FREQUENCY SUPERCONDUCTIVITY

Annica BLACK SCHÄFER[1]

[1] *Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden*

Odd-frequency superconductivity is a very unique superconducting state that is odd in time or, equivalently, frequency, which is opposite to the ordinary behavior of superconductivity. It has been realized to be the key to understand the surprising physics of superconductor-ferromagnet (SF) structures and has also enabled the emerging field of superconducting spintronics. More recent discoveries have also identified odd-frequency superconductivity in a range of known superconductors, ranging from doped topological insulators to multiband superconductors such as Sr_2RuO_4 and UPt_3. In this talk I will give a conceptual introduction to odd-frequency superconductivity followed by a review of systems and materials where odd-frequency superconductivity is important for our understanding of the superconducting state.

E-mail: **annica.black-schaffer@physics.uu.se**

MAGIC ANGLE GRAPHENE: A NEW PLATFORM FOR STRONGLY CORRELATED PHYSICS

Pablo JARILLO-HERRERO [1]

[1] *Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA*

The understanding of strongly-correlated quantum matter has challenged physicists for decades. Such difficulties have stimulated new research paradigms, such as ultra-cold atom lattices for simulating quantum materials. In this talk I will present a new platform to investigate strongly correlated physics, based on graphene moiré superlattices. In particular, I will show that when two graphene sheets are twisted by an angle close to the theoretically predicted 'magic angle', the resulting flat band structure near the Dirac point gives rise to a strongly-correlated electronic system. These flat bands exhibit half-filling insulating phases at zero magnetic field, which we show to be a correlated insulator arising from electrons localized in the moiré superlattice. Moreover, upon doping, we find electrically tunable superconductivity in this system, with many characteristics similar to high-temperature cuprate superconductivity. These unique properties of magic-angle twisted bilayer graphene open up a new playground for exotic many-body quantum phases in a 2D platform made of pure carbon and without magnetic field. The easy accessibility of the flat bands, the electrical tunability, and the bandwidth tunability though twist angle may pave the way towards more exotic correlated systems, such as quantum spin liquids or correlated topological insulators.

E-mail: **pjarillo@mit.edu**

Wed02| Correlations and superconductivity in twisted bilayer graphene

SUPERCONDUCTORS, ORBITAL MAGNETS, AND CORRELATED STATES IN MAGIC ANGLE BILAYER GRAPHENE

Dmitri k. EFETOV[1], X. LU, P. STEPANOV, W. YANG, M. XIE, M. Ali AAMIR, I. DAS, C. URGELL, K. WATANABE, T. TANIGUCHI, G. ZHANG, A. BACHTOLD, A. H. MACDONALD

[1] *ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860, Castelldefels, Barcelona, Spain*

Superconductivity often occurs close to broken-symmetry parent states and is especially common in doped magnetic insulators. When twisted close to a magic relative orientation angle near 1 degree, bilayer graphene has flat moire superlattice minibands that have emerged as a rich and highly tunable source of strong correlation physics, notably the appearance of superconductivity close to interaction-induced insulating states. Here we report on the fabrication of bilayer graphene devices with exceptionally uniform twist angles. We show that the reduction in twist angle disorder reveals insulating states at all integer occupancies of the four-fold spin/valley degenerate flat conduction and valence bands, i.e. at moire band filling factors nu = 0, +(-) 1, +(-) 2, +(-) 3, and superconductivity below critical temperatures as high as 3 K close to - 2 filling. We also observe three new superconducting domes at much lower temperatures close to the nu = 0 and nu = +(-) 1 insulating states. Interestingly, at nu = +(-) 1 we find states with non-zero Chern numbers. For nu = - 1 the insulating state exhibits a sharp hysteretic resistance enhancement when a perpendicular magnetic field above 3.6 tesla is applied, consistent with a field driven phase transition. Our study shows that symmetry-broken states, interaction driven insulators, and superconducting domes are common across the entire moire flat bands, including near charge neutrality.

E-mail: **Dmitri.Efetov@icfo.eu**

Wed03| *Correlations and superconductivity in twisted bilayer graphene*

ELECTRONIC PROPERTIES OF TWISTED GRAPHENE LAYERS: BANDS, INTERACTIONS AND SUPERCONDUCTIVITY

Francisco GUINEA[1,2]

[1] *IMDEA Nanoscience, Madrid, Spain*

[2] *DIPC, San Sebastián, Spain*

Twisted graphene bilayers define tunable Moiré structures with unique properties, including superconductivity and other broken symmetry phases. The electronic bands show unusual topological features, and very narrow bandwidths. The main features of these bands, as well as the nature and role of the leading interactions are discussed. Emphasis is made on the interplay between electrostatic interactions and superconductivity.

E-mail: **paco.guinea@imdea.org**

***Thu01**|Pair density wave, pseudogap and fluctuations in cuprates*

DISCOVERY AND EXPLORATION OF THE CUPRATE PAIR DENSITY WAVE STATE

J.C. Séamus DAVIS[1,2,3]

[1] *Institute Clarendon Laboratory, University of Oxford, Oxford, OX1 3PU, UK*
[2] *Department of Physics, University College Cork, Cork T12R5C, IE*
[3] *LASSP, Department of Physics, Cornell University, Ithaca NY, USA*

Cooper-pairs, if they have finite center-of-mass momentum Q_P, can form a remarkable state in which the density of pairs modulates periodically in space at wavevector Q_P. Intense theoretical interest has recently emerged in whether such a 'pair density wave' (PDW) state could, due to strong electron-electron interactions, be another principal state in the phase diagram of underdoped cuprates. The most common model invoked is an eight unit-cell ($8a_0$) periodic modulation of the electron-pair condensate.

To search for a cuprate PDW at zero field, we developed a nanometer-resolution scanned Josephson tunneling microscopy (SJTM) to image Cooper-pair tunneling from a d-wave superconducting STM tip at millikelvin temperatures to the Cooper-pair condensate of underdoped $Bi_2Sr_2CaCu_2O_8$. The resulting images of the Cooper-pair condensate show clear pair-density modulations oriented along the Cu-O bond directions with a $4a_0$ period in modulating Josephson current [1].

Application of high magnetic fields in cuprates generates an extraordinary density wave state which could also be a PDW. To search for evidence of such a PDW state at high fields, we visualize the modulations in the density of electronic states N(r) within the halo surrounding vortex cores. This revealed multiple signatures of a field-induced PDW, including two sets of N(r) modulations occurring at wavevectors Q_P and $2Q_P$, the amplitude of the latter decaying twice as rapidly as the former. This is in detailed agreement with theory for a field-induced primary PDW; that generates secondary CDWs [2].

Finally, using a new approach at zero field for $Bi_2Sr_2CaCu_2O_{8+\delta}$, we discover strong energy-gap modulations $\Delta(r)$ expected of a PDW, that have wavevectors $Q_P=2\pi/a_0(1/8,0)$; $2\pi/a_0(0,1/8)$. Simultaneous imaging of the local-density-of-states reveals electronic modulations with at wavevectors Q_P and $2Q_P$, as anticipated when the PDW coexists with superconductivity. Finally, by visualizing the topological defects in these density waves at 2Q, we discover them to be concentrated in areas where the PDW spatial phase changes by π as predicted by the theory of half-vortices in a PDW state. [3]

Overall, these provide compelling evidence, from multiple signatures, of a PDW state coexisting with superconductivity in a canonical cuprate.

References

[1] Nature **532**, 343 (2016)
[2] Science **364**, 976 (2019)
[3] Z. Du et al, submitted Nature (2019)

E-mail: **jcseamusdavis@gmail.com**

***Thu02**| Pair density wave, pseudogap and fluctuations in cuprates*

THE REMARKABLE UNDERLYING GROUND STATES OF CUPRATES

Cyril PROUST [1]

[1] *Laboratoire National des Champs Magnétiques Intenses - Toulouse / Grenoble, France*

Cuprates exhibit exceptionally strong superconductivity. To understand why, it is essential to elucidate the nature of the electronic interactions that cause pairing. Superconductivity occurs on the backdrop of several underlying electronic phases, including a doped Mott insulator at low doping, a strange metal at high doping, and an enigmatic pseudogap phase in between -- inside which a phase of charge-density-wave order appears. Here, we aim to survey the ground state properties of cuprates once superconductivity has been removed by the application of a large magnetic field, where experimental signatures and theoretical statements become sharper.

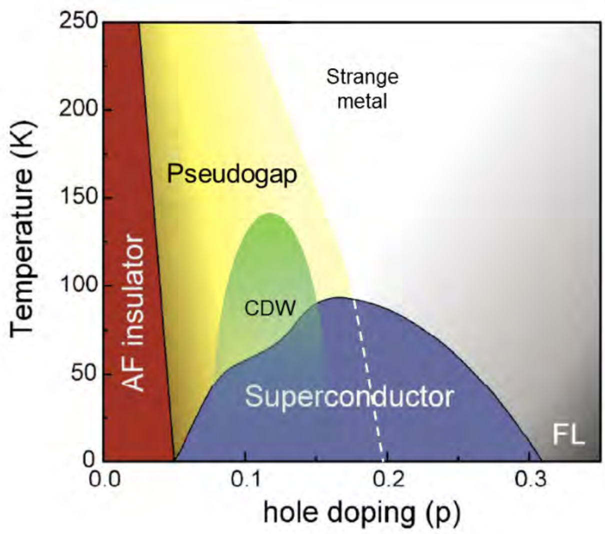

Figure 1: Generic temperature–doping phase diagram of high temperature superconductors. Various states are revealed: superconductivity, an antiferromagnetic Mott insulator at low doping, the pseudogap phase below a temperature T^* ending at a critical point p^*, a charge density wave (CDW) phase and a strange metal phase just above p^*. At high doping, a Fermi

E-mail: **cyril.proust@lncmi.cnrs.fr**

Thu03| Pair density wave, pseudogap and fluctuations in cuprates

SUPERCONDUCTOR-INSULATOR TRANSITION DRIVEN BY DISORDER AND MAGNETIC FIELD: THE EMERGENCE OF NOVEL INSULATING PHASES

Nandini TRIVEDI [1]

[1] *The Ohio State University*

I will discuss the breakdown of the BCS paradigm in three cases: (a) The transformation of a band insulator without a Fermi surface to a superconductor upon tuning the bandwidth and interactions in a clean system [1]. (b) The transition driven by disorder from a superconductor to a novel insulator pairs with a vanishing two-particle gap at the transition from the insulating side, but a finite single particle gap across the transition [2]. (c) The transition of a vortex lattice with insulating cores in a disordered superconductor in a magnetic field to an insulator rather than the expected superconductor-metal transition arising from overlapping Abrikosov vortices [3].

References

[1] Y.-L. Loh, M. Randeria, N. Trivedi, C.-C. Chang, R. T. Scalettar, "Superconductor – Insulator Transition and Fermi-Bose Crossovers", Phys. Rev. X **6**, 021029 (2016).

[2] (a) K. Bouadim, Y.-L. Loh, M. Randeria and N. Trivedi, "Single and two-particle energy gaps across the disorder-driven superconductor-insulator transition," Nature Physics **7** 884 (2011); (b) A. Ghosal, M. Randeria, and N. Trivedi, "Role of Spatial Amplitude Fluctuations in Highly Disordered s-Wave Superconductors", Phys. Rev. Lett. **81**, 3940 (1998); "Inhomogeneous Pairing in Highly Disordered s-wave Superconductors", Phys. Rev. B **65** 014501 (2002).

[3] Anushree Datta, Anurag Banerjee,Nandini Trivedi, and Amit Ghosal, "New paradigm for a disordered superconductor in a magnetic field", preprint.

E-mail: **trivedi.15@osu.edu**

***Thu04**| Pair density wave, pseudogap and fluctuations in cuprates*

THE ORIGIN OF THE NANO-SCALE SEPARATION IN CUPRATES

Przemyslaw GRYBOWSKI[1,2]

[1] *ICFO-Institut de Ciències Fotòniques, Av. Carl Friedrich Gauss 3, 08860, Barcelona, Spain*

[2] *Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614, Poznań, Poland*

The pseudogap phenomenology is one of the enigmas of the physics of High Tc superconductors. Recent experimental progress has allowed the identification of high resolution details of this phase both in momentum and real space in many members of the cuprate family, *viz.* characteristic highly anisotropic Fermi arc spectra and organization of charge modulations into nano-scale domains and intraunit cell discrete rotational symmetry breaking in the CuO_2 plane. Here, we present a theory which lead to these features as a result of the interplay between electronic and non-linear electron-phonon interactions within a model of fluctuating Cu-O-Cu bonds. Remarkably, while nanoscale segregation is usually attributed to doping induced disorder in cuprates, we find that at a fundamental level, disorder is not necessary for this phenomenon.

Moreover, we find, that magnetic (non-magnetic) vacancies act favourably (destructively) towards the prevalence of the pseudogap phase in accordance with experimental results.

E-mail: **p.r.grzybowski@gmail.com**

Thu05| Charge and spin in cuprates and Topological superconductors

CHARGE ORDER AND DYNAMICS IN CUPRATE SUPERCONDUCTORS

Bernhard KEIMER [1]

[1] *Max Planck Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany*

We will review charge ordering phenomena and their interplay with superconductivity in copper-oxide superconductors, with a focus on recent results obtained by resonant elastic and inelastic x-ray scattering. We will also discuss recent advances in the theoretical description of these phenomena, as well as analogies to other material systems where both superconductivity and charge order have been observed.

E-mail: **b.keimer@fkf.mpg.de**

SPIN FLUCTUATIONS IN CUPRATE SUPERCONDUCTORS

Stephen HAYDEN [1]

[1] *H H Wills Physics Laboratory University of Bristol BS6 6BN, UK*

We will review studies collective spin fluctuations in cuprate superconductors and their interplay with superconductivity. I focus on inelastic neutron scattering (INS) and resonant inelastic x-ray spectroscopy (RIXS). Studies have show that the collective magnetic excitations are anomalous in the antiferromagnetic parent compounds. Spin fluctuations have been observed across the phase diagram and are believed mediate unconventional superconductivity.

E-mail: **s.hayden@bristol.ac.uk**

Thu07| *Charge and spin in cuprates and Topological superconductors*

LET THERE BE TOPOLOGICAL SUPERCONDUCTORS

Eun-Ah KIM[1]

[1] *Laboratory of Atomic and Solid State Physics, Cornell University, USA*

In this lecture, I will review the criteria for a superconductor to be topological and discuss theoretical proposals and candidate systems.

E-mail: **eun-ah.kim@cornell.edu**

HEAVY FERMION SUPERCONDUCTIVITY

Filip RONNING [1]

[1] *Los Alamos National Laboratory, US*

The discovery of superconductivity in $CeCu_2Si_2$ in 1979 revealed that magnetism need not compete with superconductivity. Since then heavy fermion materials consisting of Ce, Pr, Yb, U, Np or Pu have been shown to be ideal model systems to explore the interplay between magnetism and superconductivity, which is present in many classes of unconventional superconductors. Despite low absolute values for their transition temperatures, heavy fermion superconductors are attractive materials to study for multiple reasons: i) Because of the small energy scales present in heavy fermions, they are highly tunable with small amounts of pressure. ii) They are typically stoichiometric, and hence have very low levels of disorder. iii) Tc relative to their Fermi energy is still large, and hence they can be thought of as high temperature superconductors. iv) The presence of strong spin orbit coupling makes them tantalizing candidates for topological superconductivity. I will provide a brief overview of the physics of f-electron heavy fermion materials and give a survey of heavy fermion superconductivity more broadly.

E-mail: **fronning@lanl.gov**

Fri02| Correlations in superconducting heavy fermions and Applications

INTRODUCTION TO P-WAVE SUPERCONDUCTORS: FROM FERROMAGNETIC TO PARAMAGNETIC MATERIALS

Alexandre POURRET [1]

[1] *University Grenoble Alpes, France*
CEA, IRIG, PHELIQS

In this lecture, I will give an overview of the physics of p-wave superconductors. After a short introduction, I will present the different thermodynamic and transport properties of the three ferromagnetic superconductors URhGe [1], UCoGe [2] and UGe_2 [3]. One of the most fascinating consequence of the interplay between ferromagnetism and superconductivity in these materials is the strong anisotropy of $H_{C2}(T)$ [4], leading for URhGe and UCoGe to a reinforcement of the superconducting state when a magnetic field is applied along the hard magnetization axis. The unconventional shape of $H_{C2}(T)$ can be described assuming a field-induced enhancement of the pairing strength in the strong coupling limit. In a second part, I will discuss the Fermi surface properties, more precisely the different Fermi surface instabilities (as Lifshitz transitions) observed in these systems underlying the strong interplay existing between Fermi surface reconstructions and magnetic fluctuations at the ferromagnetic to paramagnetic order transition. Finally, I will present recent results on the new discovered (november 2018) paramagnetic superconductor UTe_2 (T_{sc}=1.5K) [5] [6], which appears to be the first p-wave paramagnetic superconductor exhibiting reentrant superconductivity induced by a magnetic field [7].

References

[1] D. Aoki, A. Huxley, E. Ressouche, D. Braithwaite, J. Flouquet, J. P. Brison, E. Lhotel, and C. Paulsen, Nature **413**, 613 (2001).

[2] N. Huy, A. Gasparini, D. de Nijs, Y. Huang, J. Klaasse, T. Gortenmulder, A. de Visser, A. Hamann, T. Görlach, and H. Löhneysen, Phys. Rev. Lett. **99**, 067006 (2007).

[3] S. S. Saxena, P. Agarwal, K. Ahilan, F. M. Grosche, R. K. W. Haselwimmer, M. J. Steiner, E. Pugh, I. R. Walker, S. R. Julian, P. Monthoux, G. G. Lonzarich, A. Huxley, I. Sheikin, D. Braithwaite, and J. Flouquet, Nature **406**, 587 (2000).

[4] D. Aoki, K. Ishida, and J. Flouquet, J. Phys. Soc. Jpn. **88**, 022001 (2019).

[5] S. Ran, C. Eckberg, Q.-P. Ding, Y. Furukawa, T. Metz, S. R. Saha, I.-L. Liu, M. Zic, H. Kim, J. Paglione, and N. P. Butch, arxiv:1811.11808 (2018).

[6] D. Aoki, A. Nakamura, F. Honda, D. Li, Y. Homma, Y. Shimizu, Y. J. Sato, G. Knebel, J.-P. Brison, A. Pourret, D. Braithwaite, G. Lapertot, Q. Niu, M. Vališka, H. Harima, and J. Flouquet, J. Phys. Soc. Jpn. **88**, 043702 (2019).

[7] G. Knebel, W. Knafo, A. Pourret, Q. Niu, M. Vališka, D. Braithwaite, G. Lapertot, M. Nardone, A. Zitouni, S. Mishra, I. Sheikin, G. Seyfahrt, J.-P. Brison, D. Aoki, and J. Flouquet, J. Phys. Soc. Jpn **88**, 063707 (2019).

E-mail: **alexandre.pourret@cea.fr**

SUPERCONDUCTING MATERIALS AND THEIR APPLICATIONS

Teresa PUIG[1]

[1] *ICMAB-CSIC, Campus UAB, 08193 Bellaterra, Spain*

Superconductivity is a quantum phenomenon discovered more than 100 years ago with important implications in our lives even though we do not usually realise it. This exotic phenomenon is able to detect the smallest magnetic fields and generate the largest magnetic fields in the world. In the first case, SQUIDs (superconducting quantum interference devices) were developed as the most sensitive magnetic field detectors and nowadays a large area of superconducting RSFQ logics and q-bits is steady progressing in the field of quantum computing. In the second case, high field magnets have been extensibly developed making possible high energy accelerators and magnetic resonance (NMR and MRI). Since the discovery of high temperature superconductors (HTS), energy applications were envisaged thanks to the liquid nitrogen operating temperature. However, the nature of the HTS materials, being highly anisotropic and ceramic, strongly slowed down their real application implementation. Thanks to one of the ever largest constant efforts in material science during the last 20 years, nowadays these HTS materials are industrially produced as flexible long length conductors and a large number of different device prototypes have been demonstrated. Recently, the scientific community also realized that some of these HTS materials are the highest field conductors available at helium temperatures, thus opening new opportunities also in the area of ultrahigh magnetic fields for high energy accelerators, magnetic resonance and fusion. Presently, one of the main hindrances for their marketability is their cost and therefore strong efforts are devoted to decrease it. In this presentation, I will revise the most relevant superconducting materials for applications, the present situation, how they are produced, their physical properties and requirements. I will mostly focus on high current applications and the new opportunities of HTS materials operating at different temperatures in different sectors (energy, medicine, accelerators).

E-mail: **teresa@icmab.es**

Abstracts of Posters

P01 | Poster Session

METAL-INSULATOR TRANSITIONS IN DISORDERED CORRELATED SYSTEMS AWAY FROM HALF-FILLING

Nathan Giovanni ANDRADE[1], M. CIVELLI, & M. C. O. AGUIAR THOR [1]

[1]*Laboratoire de Physique des Solides - Université Paris-Sud, France*

In this work we study strongly correlated electron systems in the presence of disorder. The interplay between interaction and disorder can be studied by considering the Anderson-Hubbard model, which considers a hopping term, electronic interaction when two electrons are in one site, different values of the electron local energy and a chemical potential term through which we change the doping. To solve this model we use the Dynamical Mean-Field theory (DMFT) methodology; within this method, the lattice with its many degrees of freedom is mapped onto a single-impurity problem, which is coupled to a non-interacting electronic bath that is self-consistently determined. Together with DMFT we use Typical-Medium Theory (TMT), which considers the typical spectral function, calculated by taking the geometric average. The typical spectral function carries information about the extended states of the system; its value at the Fermi level becomes zero in the Anderson insulating phase. We also compute the average spectral function, which describes both localized and extended states of the system. Our results show that there are three phases in the system in the doped case: a metal, a Mott insulator (MI), and an Anderson-Mott insulator (AMI). Within AMI, we observe a region where the average density of states around the Fermi level presents a power-law, V-shaped behavior (V-AMI). At half-filling, AMI exists when the disorder is larger than the interaction and there are doubly occupied sites, sites with only one electron per site, and empty sites. In the doped case, AMI phase exists for large interaction and intermediate disorder; in this case there are sites with double occupation and sites that are single occupied. V-AMI region appears for larger disorder, when some of the sites become empty. By changing the interaction, disorder, and doping, we explore for which sets of parameters the V-AMI is observed.

E-mail: **nathangiat@gmail.com**

P02|*Poster Session*

QUASIPARTICLE INTERFERENCE AND VORTEX LATTICE IMAGING IN $BaFe_2(As_{1-x}P_x)_2$

Víctor BARRENA[1], B. WU[1], P. WALMSLEY[2], I. FISHER[2], H. SUDEROW[1] & I. GUILLAMÓN[1]

[1] *Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[2] *Geballe Laboratory for Advanced Materials and Department of Applied Physics, Stanford University, California, USA.*

The isoelectronic substitution of As by P induces high TC superconductivity in $BaFe_2(As_{1-x}P_x)_2$. In the parent compound, $BaFe_2As_2$ (x=0), an antiferromagnetic (AFM) order appears through a second order phase transition at low temperatures. As increasing x, the AFM transition temperature decreases and superconductivity arises with maximum critical Tc for x_c = 0.3, close to the point where the AFM order is suppressed at zero temperature. Specific heat, quantum oscillations and superfluid density measurements have shown evidence for the divergence of the effective mass when approaching x_c, suggesting the presence of a quantum critical point (QCP) [1,2]. An anomalous behavior of the critical fields in the proximity to x_c has been also found. In particular, the lower critical field H_{c1} increases close x_c, suggesting an enhancement of the vortex core energy close to the QCP, which might in turn lead to a modified vortex core size [3].

Here we study single crystals of $BaFe_2(As_{1-x}P_x)_2$ using Scanning Tunneling Microscopy and Spectroscopy (STM/STS) at low temperatures. We show results in samples with x=0.44 (T_c=27 K) and with x_c=0.3 (T_c=30 K). We achieve atomic resolution and perform Quasiparticle Interference (QPI) imaging to study the electronic properties at local scale. The superconducting density of states shows the presence of a V-shaped superconducting gap, consistent with nodal superconductivity. We have imaged the vortex lattice as a function of the magnetic field for both compositions and tracked the changes in the vortex core size when moving across the phase diagram.

E-mail: **victor.barrena@uam.es**

P03 | Poster Session

DEVELOPMENT OF SUPERCONDUCTING LUMPED ELEMENT RESONATORS FOR MOLECULAR SPIN QUANTUM PROCESSORS

Marina CALERO DE ORY[1], I. GIMENO[2], M. T. MAGAZ[1], E. BURZURÍ[1], D.GRANADOS[1], F. L. VITALLA[2], A. GÓMEZ [3]

[1] *IMDEA Nanociencia, Campus de Cantoblanco, 28049 Madrid, Spain*

[2]*Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC-Universidad de Zaragoza, 50009, Spain.*

[3] *Centro de Astrobiología CSIC-INTA, 28850 Torrejón de Ardoz, Spain*

Molecular nanomagnets strongly coupled to superconducting coplanar waveguide resonators have been proposed as an implementation for large-scale quantum computation. The crucial advantage of this proposal is the use of molecules as spin qubits, with multiple addressable quantum spin states, which brings the opportunity of a scalable architecture [1].

In this work, we propose to couple the molecular nanomagnets to Lump-Element superconducting Resonators (LERs). Each LER consists of a series inductance-capacitance circuit coupled in parallel to a single transmission line [2]. Contrary to coplanar wave resonators, LERs allow large freedom on the geometry design, which enables to control key parameters such as the quality factor and the induced magnetic field. These parameters are essential to tailor the interaction between qubits and photons, and therefore, determine the coupling and coherence between them. In addition, LERs are intrinsically multiplexable on-chip, which allows the simultaneous read-out of several qubits at different frequencies [3].

In order to optimize the coupling between Niobium LERs and single molecules magnets, different designs are studied. Simulations and low-temperature characterization are used to tailor the resonators properties such as resonance frequency, quality factor and induced magnetic field. In addition, the influence of temperature, incident microwave power and magnetic field on these parameters is presented.

References

[1] M. Jenkins et al., Dalton Tran. **45**, 16682 (2016).
[2] S. Doyle et al., J. Low Temp. Phys. 151, 530-536 (2008).
[3] A. Tkalcec et al., Phys. Rev. B, **90**, 075112 (2014).

E-mail: **marina.calero@imdea.org**

***P04**|Poster Session*

TWISTS AND THE ELECTRONIC STRUCTURE OF GRAPHITIC MATERIALS

Tommaso CEA[1]

[1]*IMDEA Nanociencia, Madrid, Spain*

We analyze the effect of twists on the electronic structure of configurations of infinite stacks of graphene layers. We focus on three different cases: an infinite stack where each layer is rotated with respect to the previous one by a fixed angle, two pieces of semi-infinite graphite rotated with respect to each other, and finally a single layer of graphene rotated with respect to a graphite surface. In all three cases we find a rich structure, with sharp resonances and flat bands for small twist angles. The method used can be easily generalized to more complex arrangements and stacking sequences.

E-mail: **tommaso.cea@imdea.org**

P05|*Poster Session*

GROWTH AND STUDY OF MAGNETORESISTANCE OF THE SUPERCONDUCTOR $LARu_2P_2$

Marta FERNÁNDEZ-LOMANA[1], V. BARRENA, S. DELGADO, R. ALVAREZ, H. SUDEROW & I. GUILLAMON

[1] *Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Facultad de Ciencias Universidad Autónoma de Madrid, 28049 Madrid, Spain.*

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 8.6μΩcm, 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 27nm. 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.

E-mail: **marta.fernandez-lomana@uam.es**

P06|Poster Session

SPIN-ORBITAL INTERPLAY IN THE MECHANISM OF SUPERCONDUCTIVITY OF IRON SUPERCONDUCTORS

Raquel FERNÁNDEZ-MARTÍN[1], L. FANFARILLO[2], M.J. CALDERÓN[1], & B. VALENZUELA[1]

[1]*Instituto de Ciencia de Materiales de Madrid, ICMM-CSIC, Cantoblanco, E-28049 Madrid, Spain*

What is the mechanism of superconductivity in unconventional superconductors is one of the most exciting question in physics nowadays. In many of these unconventional superconductors there is a phase diagram where a magnetic order is found either coexistent or nearby the superconducting phase. As a consequence, spin fluctuations have arising as a strong candidate for the pairing of Cooper pairs [1].

Iron superconductors are an example of this unconventional superconductivity. They are high Tc superconductors and multiorbital systems. They present a strong interplay between the spin and the orbital degrees of freedom. An example is the nematic phase which origin has been one of the most controversial topics in this field.

Our group has proposed a low-energy effective model for iron-based superconductors characterized by the presence of orbital-selective spin fluctuations (OSSF) [2,3]. The model has been used to explain puzzle experiments in the nematic and in the superconducting phase [2,3,4,5]. In this work we study the possibility of OSSF as mechanism of superconductivity in iron superconductors. We calculate the pairing vertex mediated by the OSSF for the FeSe and the 122 families in the tetragonal and nematic phases. We compute the spin-fluctuation susceptibility via the random-phase approximation (RPA) and compare the results with standard multiorbital RPA for iron superconductors and with neutron scattering experiments [7]. Finally, we compute the gap equation for the FeSe and the 122 families within this OSSF scenario.

References

[1] D. J. Scalapino, Rev. Mod. Phys. **84**,1383.

[2] L. Fanfarillo, et al, Phys. Rev. B **91**,214515.

[3] L. Fanfarillo, et al, Phys. Rev. B **97**,121109(R).

[4] R. Fernández, et al, Phys. Rev. B **94**,155138.

[6] L. Fanfarillo, et al, npj Quantum Materials **3**(1),56.

[7] A. Kreisel, et al, Phys. Rev. B **98**,214518.

E-mail: **raquelfm.92@gmail.com**

P07 | *Poster Session*

DISSIPATIONLESS CURRENTS IN WEYL SEMIMETALS AND THE TORSIONAL ANOMALY

Yago FERREIROS[1], Y. KEDEM[2], E. J. BERGHOLTZ[2], J. H. BARDARSON[3]

[1] *IMDEA nanociencia, Ciudad Universitaria de Cantoblanco, 28049, Madrid, Spain*

[2] *Department of Physics, Stockholm University, Albanova University Center, 106 91, Stockholm, Sweden*

[3] *Department of Physics, Stockholm University, KTH Roy al Institute of Technology, 106 91, Stockholm, Sweden*

Weyl semimetals are gapless three-dimensional materials which low energy excitations are Weyl fermions, always coming in pairs of opposite, left and right, chirality. If the number of left- and right-handed quasiparticles is different, the material amazingly presents a dissipationless current in the direction of an applied magnetic field, in what is called the chiral magnetic effect. To achieve an imbalance of left- and right-handed carriers, the chiral anomaly comes into fore. In its more conventional form, the chiral anomaly is the process in which right-handed fermions are converted into left-handed fermions (or vice versa) when non orthogonal electric and magnetic fields are applied simultaneously. This result in a different number of left- and right-handed carriers, and through the chiral magnetic effect a positive magnetoconductivity is realized [1].

We will show that a less known version of the chiral anomaly, which instead of electromagnetic fields requires non-vanishing torsion of the space in which the Weyl fermions move [2,3], can be activated in a Weyl semimetal. The required torsional fields that will generate the chiral invalance can be modelled by applying strain, specifically by the combined effect of applying uniaxial strain plus sending sound waves through the material [4]. If on top of that a magnetic field is applied, due to the chiral magnetic effect an alternating current in the direction of the field will appear [4].

References

[1] C.-L. Zhang et al., Nat. Commun. **7**, 10735 (2016).

[2] H. T. Nieh and M. L. Yan, Journal of Mathematical Physics **23**, 373 (1982).

[3] Osvaldo Chandia and Jorge Zanelli, Phys. Rev. D **55**, 7580 (1997).

[4] Yago Ferreiros, Y. Kedem, E. J. Bergholtz, Jens H. Bardarson, Phys. Rev. Let. **122**, 056601 (2019).

E-mail: **yagoferreiros@gmail.com**

P08|*Poster Session*

LATTICE THERMAL CONDUCTIVITY OF $SrTiO_3$. AN AB INITIO STUDY

Adolfo O. FUMEGA[1], Y. FU, D. J. SINGH, V. PARDO

[1]*Universidade de Santiago de Compostela, Spain*

Due to its transport properties, SrTiO3 is one of the most used semiconductors for thermoelectric applications. It is then of high interest to study its properties in detail. However, despite the big amount of previous works on SrTiO3, one of its key properties, lattice thermal conductivity, remains not completely understood.

In this work, we will analyze the effect of different structural parameters (unit cell volume, octahedral rotation angle, strain, etc) on SrTiO3 lattice thermal conductivity. We will use an ab initio perspective including third-order-force constants that will allow us to control each parameter in an independent way. That way, it is possible to study separately their influence on the lattice thermal conductivity. Our conclusions will provide a route to tune lattice thermal conductivity of SrTiO3 and related compounds. These will also help experimentalists to have a better understanding on the thermal conductivity of perovskite-based oxides and their nanostructures in general.

E-mail: **adolfoterofumega@gmail.com**

P09|*Poster Session*

THERMOGRAVIMETRIC STUDY OF THE OXYGEN CONCENTRATION IN YBa2Cu3O7-D SUPERCONDUCTOR POWDER

Lorenzo GALLO[1], L.ZINNI[1], J. A. MALARRIA[1, 2] & R. F. LUCCAS[2]

[1]*Facultad de Ciencias Exactas, Ingeniería y Agrimensura - UNR, Av. Pellegrini 250, S2000BTP Rosario, Argentina.*

[2] *Institute of Physics Rosario - CONICET - UNR, Bv. 27 de Febrero 210bis, S2000EZP Rosario, Argentina.*

Superconducting properties of the $YBa_2Cu_3O_{7-d}$ (YBCO) cuprate largely depend on its oxygen concentration d. Additionally, a modification in the oxygen concentration implies a change in the mass of the material. Therefore, a variation in the mass of the YBCO can be directly associated with a variation on its superconducting properties. Temperature conditions involved in the growth process of this material make this mechanism an interesting option for an in-situ analysis of final product obtained in a line production.

In this work we report on results on the evolution of mass of YBCO superconductor powder under oxygenation conditions, as a function of time and for different values of temperature in the range of 290 °C - 790 °C. Experiments were performed at room pressure using a thermogravimetric balance under controlled atmospheric conditions for an optimal oxygenation/deoxygenation of samples. Results show the best independent-of-time behaviour around 345 °C for oxygenation of YBCO, with excellent conditions of oxygenation in a fast-absorption mode around 690 °C. Finally, evidence of the tetragonal-orthorhombic structural transition is discussed.

E-mail: **loren.ther@hotmail.com**

P10 | *Poster Session*

TRANSPORT PROPERTIES OF Na_xCoO_2 SINGLE CRYSTALS IN HIGH-MAGNETIC FIELDS

Ildar F. GILMUTDINOV [1], S. BENHABIB[1], D. VIGNOLLES[1], C. PROUST[1], R. SCHÖNEMANN[2], I.R. MUKHAMEDSHIN[3], L. BALICAS[2] & H. ALLOUL[3]

[1] *Laboratoire National des Champs Magnétiques Intenses, Toulouse, France*
[2]*National High Magnetic Field Laboratory, Tallahassee, USA*
[3]*Laboratoire de Physique des Solides, Orsay, France*

Rich variety of physical properties have been observed in the sodium cobaltates Na_xCoO_2**:** ordered magnetic states, large thermoelectric effect, superconductivity *etc*. These effects occur due to complex band structure and strong interplay between Na atomic ordering and the electronic density on the Co sites [1]. However Fermi surface peculiarities of the sodium cobaltates is still under debate. Pockets on the Fermi surface should exist according to the theoretical predictions, but only single hole like surface was detected by angle-resolved photoemission studies. Both approaches have pros and cons and independent experimental methods like the Shubnikov–de Haas oscillations could resolve a dispute.

We have synthesized high quality single crystals of sodium cobaltates with x = 0.5-0.8 using optical floating zone technique and electrochemical treatment [2]. In this poster we report the results of investigation of electrical transport of sodium cobaltates crystals with different sodium content at very low temperatures and very high magnetic fields. As example some of our experimental results for a $Na_{0.77}CoO_2$ compound are shown in fig.1.

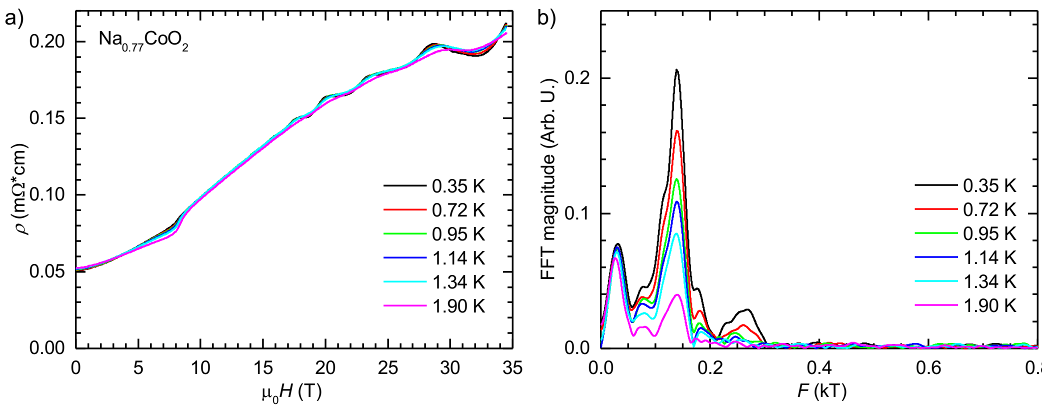

Fig.1 a) Resistivity ρ as a function of field for a $Na_{0.77}CoO_2$ single crystal. b) Amplitude of the fast Fourier transform (FFT) for several values of temperature. Two main frequencies are detected: F_1 = 31 T and F_2 = 140 T.

References

[1] Y.V. Lysogorskiy, S.A. Krivenko, I.R. Mukhamedshin, O.V. Nedopekin, D.A. Tayurskii, Phys. Rev. B, **2016**, 94, 205138.

[2] I.F. Gilmutdinov, I.R. Mukhamedshin, F. Rullier-Albenque, H. Alloul, J. Phys. Chem. Solids, **2018**, 121, 145-150.

E-mail: **Ildar.Gilmutdinov@gmail.com**

P11 | Poster Session

TOWARDS SUPERCONDUCTING SPINTRONICS BASED ON INTERFACIAL SPIN ORBIT COUPLING AND SYMMETRY FILTERING

César GONZÁLEZ-RUANO [1], P. HÖGL, I. MARTINEZ [1], J. P. CASCALES , C. TIUSAN, Y. LU, M. HEHN, A. MATOS-ABIAGUE, J. FABIAN, I. ŽUTIĆ & FARKHAD G. ALIEV

[1] *Universidad Autónoma de Madrid, Spain*

Realizing exotic states and emerging low-dissipation applications in superconducting spintronics focuses on overcoming competition between ferromagnetism and superconductivity through long-range triplet (LRT) proximity effects. The common expectation is that LRT requires complex ferromagnetic multilayers, relying on noncollinear/spiral magnetization or half-metals. Unfortuantely, these approaches are not compatible with commerical spintronic applications based on ferromagnets, such as a Fe or Co which with MgO tunnel barrier ensure record values of room-temperature magnetoresistance (MR). To overcome these limitations, we propose a new platform for superconducting spintronics based on interfacial spin-orbit coupling (SOC) and symmetry-filtering in all-epitaxial Fe/MgO/V junctions. Remarkably, as supported by detailed theoretical calculations, we experimentally demonstrate that the resulting transport phenomena, consistent with LRT, are strongly influenced by SOC, even when its role in the normal state is negligible. Below the superconducting temperature of Vanadium, Fe/MgO/V junction has a thousand-fold increase in tunneling anisotropic MR [1]. Unique features in our epitaxial junctions arise from the spin reorientation non-volatile transition below 80 K [2]. Such transition allows creation and control of different remanent magnetization states even at zero applied magnetic field and opens unexplored opportunities for superconducting spintronics.

E-mail: **cesar.gonzalez-ruano@uam.es**

***P12**|Poster Session*

STUDY OF 2D TMDCS-BASED MOSFETS FOR THEIR APPLICATION IN QUANTUM TECHNOLOGIES

Celia GONZÁLEZ SÁNCHEZ[1], J.CUADRA VÉLIZ[1], E. J.H. LEE[1]

[1] *Universidad Autónoma de Madrid, Department of Condensed Matter Physics, Campus de Cantoblanco, Madrid, Spain.*

Bidimensional materials have been a field with intense research activity since graphene was discovered in 2004, due to its unique properties [1]. Within the recent work in this field, it is the exploration of new types of 2D crystals as well as the so-called van der Waals heterostructures (complex structures formed by atomic planes in a certain sequence). This work is the result of the analysis of properties of 2D TMDCs-based (Transition metal dichalcogenide monolayers) MOSFETs. Within this type of materials, both MoS2 and WSe2 are a promising candidate for a new generation of devices [2, 3]. The MoS2 samples lead to the realization of h-BN encapsulated devices with graphite contacts with μ ~500 cm2 /Vs y Ion/Ioff ~ 104, values which are really close to those found in the literature [4, 5] and optimal for the efficiency of this kind of transistors. In the same way, it was possible to observe the ambipolar behaviour of WSe2-based transistors [6], in addition to the voltage ranges for the holes and electrons dominated transport. The study of different geometries for the gates in both cases, together with the low temperature measurements, could be interesting for future applications in nanoelectronics and quantum technologies.

References

[1] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov, Science **306**, 666 (2004).
[2] B. Radisavljevic, A. Radenovic, J. Brivio, V. Giacometti and A. Kis, Nature Nanotechnology **6**, 147-150 (2011)
[3] H.-J. Chuang, X. Tan, N. J. Ghimire, M. M. Perera, B. Chamlagain, M. M.-C. Cheng, J. Yan, D. Mandrus, D. Tománek and Z. Zhou, Nano Letters **14**, 3594-3601 (2014).
[4] W. Bao, X. Cai, D. Kim, K. Sridhara and M. S. Fuhrer, Applied Physics Letters **102** (2013).
[5] Y. Du, L. Yang, J. Zhang, H. Liu, K. Majumdar, P. D. Kirsch y P. D. Ye, IEEE Electron Device Letters **35**, 599-601 (2014).
[6] Z. Wang, Q. Li, Y. Chen, B. Cui, Y. Li, F. Besenbacher and M. Dong, NPG Asia Materials **10**, 703-712, (2018).

E-mail: **celia.gonzalezsanchez@estudiante.uam.es**

VESTIGIAL NEMATIC ORDER AND SUPERCONDUCTIVITY IN THE DOPED TOPOLOGICAL INSULATOR CuxBi2Se3

Mathias HECKER[1]

[1] *Karlsruhe Institute of Technology, Germany*

If the topological insulator Bi2Se3 is doped with electrons, superconductivity with Tc = 3–4 K emerges for a low density of carriers (n = 1020 cm−3) and with a small ratio of the superconducting coherence length and Fermi wave length: ξ/λ F = 2…4. These values make fluctuations of the superconducting order parameter increasingly important. Below Tc several experiments demonstrated a rotational symmetry breaking which is mostly consistent with a multidimensional superconducting order parameter. First, we show theoretically that a two-dimensional order parameter, together with the strong fluctuations, leads to a preformed, first-order nematic phase transition where superconducting fluctuations break a rotational symmetry before the U(1) symmetry is broken. Second, together with the experimental group of R. Lortz from Hong Kong University (HKUST), we present thermodynamic measurements on Nb doped Bi2Se3 which are in good agreement with a vestigial nematic theory where Tnem~3.8 K and Tc ~3.25 K.

E-mail: **matthias.hecker@kit.edu**

P14|*Poster Session*

STM AT VERY HIGH MAGNETIC FIELDS

Marta FERNÁNDEZ-LOMANA[1], Beilun WU, F. MARTIN,
H. SUDEROW & I. GUILLAMON

[1]*ILaboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Facultad de Ciencias Universidad Autónoma de Madrid, 28049 Madrid, Spain.*

A STM has been successfully installing a dilution refrigerator. The set-up has a simplified vibration control system and has been successfully used to measure single atom point contacts of gold at more than 20 T. We will describe the in-situ sample breaking mechanism and a few peculiarities of the cabling, including a new high frequency filter and its characterization.

E-mail: **marta.fernandez-lomana@uam.es**

E-mail: **beilun.wu@uam.es**

TILTED MAGNETIC FIELDS AND SCANNING PROBE MICROSCOPIES TO MANIPULATE VORTICES

Edwin Herrera[1], J. GALVIS[2], A. CORREA[3], S. VIEIRA1, C. MUNUERA[2], F. MONPEAN2, M. GARCÍA-HERNANDEZ[2], I. GUILLAMÓN[1], H. SUDEROW[1]

[1] *Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Facultad de Ciencias Universidad Autónoma de Madrid, 28049 Madrid, Spain.*

2. Facultad de Ciencias e Ingeniería. Universidad Central. Bogotá. Colombia.

[3]*Unidad Asociada de Bajas Temperaturas y Altos Campos Magnéticos, UAM, CSIC, Cantoblanco, E-28049 Madrid, Spain*

Here, by using scanning tunneling microscopy and magnetic force microscopy inside of a homemade three-axis magnet coil, we study vortices in tilted magnetic fields on three-layered superconductors with very different electronic properties. In β-Bi2Pd we find that vortices under tilted magnetic fields, exit the sample perpendicular to the surface, even when the magnetic field is parallel to the surface. Thus, vortices are bent beneath the surface [1]. Tilted magnetic fields in 2H-NbSe2 produce patterns of stripes due to in-plane vortices. The stripe pattern changes with the in-plane direction of the magnetic field. Our data show that vortices exit at an angle with the surface and that the sixfold gap anisotropy is present over the whole Fermi surface [2]. By tilting the magnetic field in Bi2Sr2CaCu2O8, we trigger Abrikosov vortex motion in between Josephson vortices, and find that Josephson vortices in different layers can be brought on top of each other [3].

Our measurements suggest that vortices can be manipulated in tilted magnetic fields much more easily that in the usual perpendicular magnetic field configuration. This can be used to design methods to entangle vortices.

References

[1] E. Herrera, et. al., Subsurface bending and reorientation of tilted vortex lattices in bulk isotropic superconductors due to Coulomb-like repulsion at the surface. Physical Review B, **96**, 184502 (2017).

[2] Galvis,et. al., Tilted vortex cores and superconducting gap anisotropy in 2H-NbSe2. Communications Physics **1**, 30 (2018).

[3] A. Correa, et. al., Attractive interaction between superconducting vortices in tilted magnetic fields. Communications Physics **2**, 31 (2019)

E-mail: **edwin.herrera@uam.com**

P16|*Poster Session*

PSEUDOGAP PHASE OF CUPRATES FROM ELECTRON-PHONON AND COULOMB INTERACTIONS

Sergi JULIÀ-FARRÉ[1], A. DAUPHIN[1], R. W. CHHAJLANY[2], P. T. GROCHOWSKI[3], S. WALL[1], M. LEWENSTEIN[1, 4] & P. R. GRZYBOWSKI[1]

[1] *ICFO-Institut de Ciències Fotòniques, Av. Carl Friedrich Gauss 3, 08860 Barcelona, Spain*

[2] *Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland*

[3] *Center for Theoretical Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, 02-668 Warsaw, Poland*

[4] *ICREA-Institució Catalana de Recerca i Estudis Avançats, Lluis Companys 23, Barcelona, Spain*

The pseudogap phenomenology is one of the enigmas of the physics of High Tc superconductors. Recent experimental progress has allowed the identification of high resolution details of this phase both in momentum and real space in many members of the cuprate family, *viz.* characteristic highly anisotropic Fermi arc spectra and organization of charge modulations into nano-scale domains and intraunit cell discrete rotational (C_4) symmetry breaking in the CuO_2 plane. Here, we present a theory which lead to these features as a result of the interplay between electronic and non-linear electron-bond phonons interactions. We revisit the model of fluctuating Cu-O-Cu bonds, known as the fluctuating bond model (FBM) [Newns and Tsuei, Nat. Phys. (2007)] and show that: (i) the originally presented uniform pseudogap phase of the FBM Hamiltonian is internally unstable towards macroscopic charge separation (ii) it is therefore necessary to include the effect of Coulomb interactions and consider pseudogap states resulting from the interplay of bond-phonon instabilities and electronic correlations. In our work, we perform unrestricted mean-field studies of the FBM with reduced density fluctuations due to Coulomb interactions at the experimentally relevant regimes of fillings and temperatures. We obtain non-uniform pseudogap states exhibiting domains with C_4 symmetry breaking in real space and Fermi arcs in the reconstructed Fermi surface.

E-mail: **sergi.julia@icfo.eu**

P17|Poster Session

EXTENDED HUBBARD MODEL WITH NEAREST NEIGHBOR EXCHANGE INTERACTION

Edin KAPETANOVIĆ [1]

[1] *Institut für Theoretische Physik, Universität Bremen, Germany*

We study an extended Hubbard model (EHM) taking into account nearest neighbor direct Coulomb and exchange interactions. Whereas the simple EHM (without exchange interaction) can be mapped on a simple Hubbard model with renormalized on-site interaction $\tilde{U}$, the EHM with ferromagnetic exchange (i.e. the extended Hubbard-Heisenberg model) at half filling, allows for both, ferro- and antiferromagnetic phases, which is not captured by a simple Hubbard model. For the case of intermediate coupling strengths, which cannot be addressed by perturbation theory or similar approaches, we apply a variational scheme by mapping the EHM with exchange on an effective Hubbard model within an effective magnetic field. In the aforementioned parameter regime we find a partly magnetized phase where the kinetic energy is still significant. In contrast to the known limiting cases, a first order magnetic transition to the fully magnetized state occurs. Further study of these phenomena may provide insight on exotic magnetic phases within correlated materials. For performing the variation we rely on exact numerical solutions of the effective Hubbard model on finite clusters using determinant quantum Monte Carlo.

E-mail: **ekapetan@itp.uni-bremen.de**

***P18**|Poster Session*

WEAK- TO STRONG-COUPLING CROSSOVER & GROUND STATE DEGENERACY IN TWISTED BILAYER GRAPHENE

Markus KLUG[1]

[1] *Karlsruhe Institute of Technology, Germany*

The observation of unconventional superconductivity in twisted bilayer graphene (TBG) at small twisting angles attracted great interest in the recent year, though the underlying mechanism remains still unknown. Instead, understanding the nature of the insulating phases neighbouring the superconducting pocket on the electron- and hole-doped side might shed light on the origin of superconductivity in TBG. In this work, we use an effective electron model, which is valid in the small twist-angle / low-temperature regime, to discuss possible ground states and their degeneracies for various filling factors. Results are obtained in the weak- and strong-coupling regime and related to experiments.

E-mail: **markus.klug@kit.edu**

P19 | *Poster Session*

ULTRAFAST LASER-INDUCED ELECTRON DYNAMICS AND TOPOLOGY IN TWO-DIMENSIONAL NANOMATERIALS

Hamed KOOCHAKI-KELARDEH [1]

[1] *Max Planck Institute (MPI-PKS), Germany*

We address the ultrafast and strong field quantum phenomena in nanocrystals induced by ultrashort and intense laser pulses. The proposal consists of three subprojects. Firstly, we provide the theoretical description of an ultrashort laser pulse interacting with nanoscale solids and determine the optical and transport properties of nanostructures and controllability criteria by the ultrafast optical pulse. An emphasis is being made on the novel two dimensional (2D) crystalline structures. To attain our goal, we develop a computational method to describe electron dynamics in crystalline solids and extremely nonlinear electron dynamics induced by strong fields. Such an intense and ultrashort laser pulse, which is at the heart of attosecond science, is a key for further development of nanotechnology and material science. Secondly, we study the topological aspects of nanocrystals. Such a topological nature plays a key role in the emergence of unique phenomena such as the anomalous and quantum Hall effects, topological insulating and superconducting phases at room temperature. Thirdly, we unravel elementary processes behind ultrafast phenomena and address the fundamental concepts in strong many-particle phenomena such as carrier-carrier, carrier-phonon, and carrier-photon interactions. Such many-body processes play a key role in the design of future nanoelectronic devices such as photo-emitting, amplifying, and detecting devices.

E-mail: **hkelardeh@pks.mpg.de**

***P20**|Poster Session*

UNCONVENTIONAL SUPERCONDUCTIVITY AND QUANTUM CRITICALITY IN NON-CENTROSYMMETRIC HEAVY FERMIONS

Javier LANDAETA[1]

[1] *Max Plank Institute for Chemical Physics of Solids, Germany*

The interplay of superconductivity and magnetism is one of the most important issues in condensed matter physics. Being these two phenomena mutually exclusive in a large class of alloys and elements, it is striking that superconductivity appears nearby a magnetic quantum critical point (QCP) in a wide range of strongly correlated electron systems (SCES), such as high-Tc cuprates, organics, iron pnictides/chalcogenides, and heavy fermions. It is widely believed that in these compounds the magnetic QCP cause unconventional behaviors. In order to explore this physics, I present here a study of the non-centrosymmetric heavy-fermion superconductors CeIrSi3 and CeRhSi3 carried out using a newly developed system for high-resolution magnetic penetration-depth measurements under pressure. Superconductivity in CeIrSi3 shows a change from an excitation spectrum with a line-nodal gap to one which is entirely gapful when pressure is close but not yet at the QCP. In contrast, CeRhSi3 does not possess an obvious pressure-tuned magnetic QCP and the superconducting phase remains for all accessible pressures with a nodal gap. Combining both results suggests that in these compounds unconventional superconducting behaviors are rather connected with the coexisting antiferromagnetic order. This study provides a new viewpoint on the interplay of superconductivity, magnetism, and quantum criticality in heavy fermions and maybe in other SCES.

E-mail: **Javier.Landaeta@cpfs.mpg.de**

P21|Poster Session

ELECTRONIC INTERFERENCE AND SCATTERING THROUGH THE MAGNETIC TRANSITIONS OF RH-DOPED CeRu2Si2 AT VERY LOW TEMPERATURES

Francisco MARTÍN[1], E. HERRERA[1, 2], I. GUILLAMÓN[1, 3] & H. SUDEROW [1,3], D. AOKI[4,5], J. FLOUQUET[4]

[1] *Laboratorio de Bajas Temperaturas y Altos Campos Magnéticos, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain*

[2] *Departamento de Ciencias Naturales, Facultad de Ingeniería y Ciencias Básicas, Universidad Central, Bogotá, Colombia*

[3] *Unidad Asociada de Bajas Temperaturas y Altos Campos Magnéticos, UAM/CSIC, Cantoblanco, E-28049 Madrid, Spain*

[4]*Université Grenoble Alpes, CEA, INAC-PHELIQS, F-38000 Grenoble, France*

[5]*Department of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan*

$Ce(Ru_{0.92}Rh_{0.08})_2Si_2$ is a heavy fermion system with a magnetic field induced quantum critical transition between an antiferromagnetic (AF) and a polarized paramagnetic phase (PPM) at H_C = 2.8 T. At higher magnetic fields, the paramagnetic moments polarize into a magnetic field induced ferromagnetic phase (FM) at H_m = 5.8 T [1]. To understand the critical behavior of electrons at the transition, we have measured the bandstructure and the spatial dependence of the electronic properties using very low temperature Scanning Tunneling Microscopy and Spectroscopy. We show large topographic images with atomic resolution, in which we identify the Rh distributed randomly. We study electronic scattering as a function of the magnetic field when crossing through the quantum phase transition and in the high field polarized phase.

In addition, we have moved a dilution refrigerator cryostat with a 17 T magnet to new premises. We briefly describe the experimental arrangement in the new premises and show first tunneling spectroscopy experiments in superconducting aluminum. We also use new electronics build at the UAM (segainvex) and show the efforts to improve filtering of the cryostat and reduce the temperature of the experiments to state of the art values.

References

[1] D. Aoki t al., J. Phys. Soc. Jpn. **81**, 034711 (2012) Work supported by Spanish MINECO, ERC Starting Grant and CIG Marie Curie program.

E-mail: **francisco.martin@uam.es**

***P22**|Poster Session*

ORDER/DISORDER OF ANION AND CATION IN SUPERCONDUCTING MOLYBDO-CUPRATES $MO_{0.3}CU_{0.7}Sr_2RECu_2O_Y$ (RE = Pr, Nd, Gd, Tm AND Yb)

Xabier MARTÍNEZ DE IRUJO-LABALDE[1], S.A. LÓPEZ-PAZ, E. URONES-GARROTE, A S. GARCÍA-MARTÍN & M.A. ALARIO-FRANCO[1]

[1] *Departamento de Química Inorgánica, Universidad Complutense de Madrid, Avda. Complutense s/n 28040, Madrid (Spain)*

The richness of the phase diagram of the High Temperature Superconducting Cuprates (HTSC) continues to attract the attention of the scientific community. In the so-called underdoped region, some key problems are still under debate because different electronic phases and orderings emerge and compete. On the contrary, at higher doping levels, the dome-like dependence of the critical temperature T_C with hole concentration in the CuO_2 planes, has been widely accepted[1].

Recent results, including our own, on the family of *molybdo-cuprates* with general formula $Mo_{0.3}Cu_{0.7}Sr_2RECu_2O_y$ (RE = Pr, Nd, Gd, Tm and Yb) are, however, questioning the doping dependence of T_C. For the compounds containing smaller RE (= Tm and Yb), while the optimal level doping obtained by ozone oxidation leads to a T_C = 35 K[2], high-pressure oxidation allows T_C to be increased up to 83 K and entering in the overdoped regime[3]. Moreover, the compounds containing bigger RE (= Pr and Nd) do not show superconductivity upon any oxidation treatment suggesting, moreover, a marked dependence of the superconducting properties with the structural ordering in this system.

Here, we aim to stress the strong influence of the crystal structure in the electronic properties as reflected in the unusual phase diagram of this family. To that end, we have oxidized $Mo_{0.3}Cu_{0.7}Sr_2RECu_2O_y$ (RE = Pr, Nd, Gd, Tm and Yb) by different techniques. The evolution of T_C has been determined by magnetization and electric resistivity measurements. In order to evaluate the oxidation state of Cu and, subsequently, the hole concentration, we have performed EELS spectroscopy and BVS analysis. The structural characterization has been done in detail by X-Ray Diffraction (XRD), Neutron Diffraction (ND) as well as Atomic Resolution Electron Microscopy (ARM).

The obtained results will be presented and discussed.

References

[1] Rybicki, D.; Jurkutat, M.; Reichardt, S.; Kapusta, C.; Haase, J. Nat. Commun. 2016, 7 (1), 11413

[2] Martínez de Irujo-Labalde, X.; Urones-Garrote, E.; García-Martín, S.; Alario-Franco, M. Á. Inorg. Chem. 2018, 57 (19), 12038–12049.

[3] Gauzzi, A.; Klein, Y.; Nisula, M.; Karppinen, M.; Biswas, P. K.; Saadaoui, H.; Morenzoni, E.; Manuel, P.; Khalyavin, D.; Marezio, M.; et al. Phys. Rev. B 2016, 94 (18), 180509.

E-mail: **xabimart@ucm.es**

***P23**|Poster Session*

HIGH PRESSURE MAGNETIC MEASUREMENTS OF MULTIBAND SUPERCONDUCTOR 2H-NbSe2

Israel OSMOND[1], S. FRIEDEMANN[1], O. MOULDING[1] & T. MURAMATSU[1]

[1] *H.H. Wills Physics Laboratory, University of Bristol, United Kingdom*

With superconductivity often found in the vicinity of ordered states such as charge density waves (CDW) and antiferromagnetism, the ability to tune materials through these states serves as a vital tool in exploring the interplay of these phases with superconductivity. For characterizing a given superconductor, magnetic measurements provide a non-invasive method of measuring critical temperatures and fields, and thus deducing key parameters of the superconducting state, such as the coherence length and London penetration depth.

High pressures serve as an avenue to continuously and systematically tune across many of these phases in a single high purity sample. As such, the application of pressure provides a method to both access novel structures not available at ambient pressure, and to explore the competition between phases such as the CDW and superconducting order. This work develops current pressure cell technology compatible with commercial SQUID magnetometers, in both piston cylinder and gemstone anvil type cells.

Previous research into 2H-NbSe2 has shown superconductivity that is enhanced under pressure, while CDW order is suppressed around 5 GPa. Here, we use the aforementioned pressure cells for magnetic susceptibility measurements, mapping the behaviour of both Tc(P) and the evolution of critical fields in 2H-NbSe2 with temperature and pressure. Tc(P) is seen to vary for different pressure media and is discussed within scenarios relating to both quantum critical enhancement of superconductivity, along with alternative theories.

With previous evidence of multiband superconductivity, the critical fields are analysed within a two-band model, with models of superfluid density used to probe Fermi-sheet dependent superconducting gaps.

E-mail: **io17399@bristol.ac.uk**

***P24**|Poster Session*

STRONG ANTISYMMETRIC SPIN–ORBIT COUPLING AND SUPERCONDUCTING PROPERTIES: THE CASE OF NONCENTROSYMMETRIC LaPtSi

Sabrina PALAZZESE[1]

[1] *Institute for Scientific Research/INFN, Padova, Italia*

In this work we aim to analyze the effect of a strong antisymmetric spin–orbit coupling (ASOC) on the superconductivity of noncentrosymmetric LaPtSi. We study the energy gap structure of polycrystalline LaPtSi by using magnetic penetration depth measurements down to 0.02T c. We observed a dirty s-wave behavior, which provides compelling evidence that the spin-singlet component of the mixed pairing state is highly dominant. This is consistent with previous results in the sense that the mere presence of a strong ASOC does not lead to unconventional behaviors. Our result also downplays LaPtSi as a good candidate for realizing time-reversal invariant topological superconductivity.

E-mail: **spalazzese@gmail.com**

FLAT BANDS IN GRAPHENE STACKS

Pierre A. PANTALEÓN[1], T. CEA[1], R. BROWN[2], N. R. WALET[2] & F. GUINEA[1, 3]

[1] *IMdea Nanoscience, Faraday 9, 28015 Madrid, Spain.*

[2] *Department of Physics and Astronomy, University of Manchester, Manchester, M13 9PY, UK*

[3] *Donostia International Physics Center DIPC, Paseo Manuel de Lardizabal 4, 2018 Donostia-San Sebastián, Spain*

The emergence of flat bands in moiré superlattices leads to an enhancement of interaction effects, and thus to highly correlated phases at low temperatures [1]. In particular, for graphene placed over hexagonal boron nitride (hBN), a periodic variation of the interlayer interaction in form of moiré pattern appears due to the lattice mismatch. Here, the resulting periodic perturbation acts over the graphene charge carriers and leads to multiple minibands and the generation of flat bands.

In this work, we theoretically investigate the emergence and tunability of flat bands in moiré superlattices arising from the interaction of monolayer, bilayer and trilayer graphene with a hBN substrate, as well as the case of twisted bi-bilayer graphene. Using a low-energy electronic model [2], and taking into account the effects of substrate-induced strain [3], we find that the induced flat bands are highly sensitive to the substrate parameters and external electric fields [4-5]. Therefore their shape, bandwidth and topology all become tunable. In addition, using a self-consistent description of the interactions in the Hartree approximation as in Ref. [6], our results reveals that the band structure and their topological invariants depend sensitively on the band filling.

References

[1] Yuan Cao, et al, Nature **556**, pages 80–84 (2018)

[2] J. R. Wallbank et al, Phys. Rev. B **87**, 245408 (2013)

[3] Pablo San-Jose et al, Phys. Rev. B **90**, 115152 (2014)

[4] Ya-Hui Zhang et al, Phys. Rev. B **99**, 075127 (2019)

[5] Bheema Lingam Chittari et al, Phys. Rev. Lett. **122**, 016401 (2019)

[6] Tommaso Cea et al, arXiv:1906.10570.

E-mail: **ppantaleon@uabc.edu.mx**

P26|*Poster Session*

STUDY OF TWO-DIMENSIONAL SUPERCONDUCTORS BY ELECTRONIC TRANSPORT MEASUREMENTS

David PERCONTE[1], D. CALDEVILLA[1], R. SANCHEZ[1], R. ALVAREZ[1], I. GUILLAMON[1] & H. SUDEROW[1]

[1] *Laboratorio de Bajas Temperaturas y Altos Campos Magnéticos, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain*

While high temperature superconductors are promising for applications[1], the underlying physics is very complicated[2,3] and not yet fully understood. Two dimensional superconductors are in principle simpler and can be thought as toy model for this problem. For example, it has recently been shown that bilayer graphene can intrinsically host superconductivity if the angle between the two layers is appropriately tuned[4]. The phase diagram of bilayer graphene is resembling those of high Tc superconductors.
We analyse in this work the superconducting transition of 2H-NbSe2 and observe a new feature of the superconducting transition consisting of a reactance at low frequencies. We will discuss the dependence of the reactance with temperature, magnetic field and coupling to the thermal bath. Our work shows that heat exchange results in a reactive electronic behaviour whenever a sharp change in the resistance with temperature is accompanied by a non-linear I-V curve, as probably occurs in bilayer graphene and many other devices of 2D materials. The reactance is intimately related to heat transport and might serve to analyse quantum coherence and dissipation in devices.
Our goal on the long term is to study ultra-thin layered superconductors both by electronic transport measurement and by scanning tunnelling microscopy.

References

[1] Pawlowski, E. R., Kermorvant, J., Crété, D., Lemaître, Y., Marcilhac, B., Ulysse, C., ... & Lesueur, J. (2018). Static and radio frequency magnetic response of high T c superconducting quantum interference filters made by ion irradiation. Superconductor Science and Technology, 31(9), 095005.

[2] Parker, C. V., Aynajian, P., da Silva Neto, E. H., Pushp, A., Ono, S., Wen, J., ... & Yazdani, A. (2010). Fluctuating stripes at the onset of the pseudogap in the high-T c superconductor Bi 2 Sr 2 CaCu 2 O 8+ x. Nature, 468(7324), 677.

[3] Kirtley, J. R., Tsuei, C. C., Verwijs, C. J. M., Harkema, S., & Hilgenkamp, H. (2006). Angle-resolved phase-sensitive determination of the in-plane gap symmetry in YBa 2 Cu 3 O 7− δ. *Nature Physics*, 2(3), 190.

[4] Cao, Y., Fatemi, V., Fang, S., Watanabe, K., Taniguchi, T., Kaxiras, E., & Jarillo-Herrero, P. (2018). Unconventional superconductivity in magic-angle graphene superlattices. Nature, 556(7699), 43.

E-mail: **perconte-duplain@uam.es**

OPTICALLY-CONTROLLED ORBITRONICS ON A TRIANGULAR LATTICE

Võ Tiến PHONG[1], Z. ADDISON, S. AHN, H. MIN, R. AGARWAL & E. J. MELE

[1]*Department of Physics and Astronomy, University of Pennsylvania, USA*

Orbital polarization is an internal attribute of an electronic Bloch state in a crystal that, in addition to spin, can endow band structure with nontrivial geometry and manifest itself in unique responses to applied fields. Here we identify this physics in a generic model for an orbital multiplet propagating on a two dimensional triangular lattice. The theory features nontrivial fully orbitally-derived quantum geometry applicable to materials containing only light elements and without support from a nonprimitive space group. We obtain line-node degeneracies protected by a perpendicular mirror symmetry and two types of point degeneracies protected by PT symmetry. Crucially, and in contrast to the well-studied problem on the honeycomb lattice, here point degeneracies with opposite winding numbers are generically offset in energy which allows the activation of anomalous transport responses using readily-implemented spatially-uniform local potentials. We demonstrate this by calculations of an anomalous Hall conductance (AHC) coherently controlled by a circularly-polarized optical field and a related anomalous orbital Hall conductance (AOHC) activated by layer buckling. The model provides a prototypical demonstration of orbitally-induced topological responses in crystals with applications in many lattice structures.

E-mail: **vophong.travel@gmail.com**

***P28**|Poster Session*

INTERNAL SCREENING AND DIELECTRIC ENGINEERING IN MAGIC-ANGLE TWISTED BILAYER GRAPHENE

Jose PIZARRO[1]

[1] *University of Bremen, Germany*

Twisted bilayer graphene (TBG) has appeared as a tunable testing ground to investigate the conspiracy of electronic interactions, band structure, and lattice degrees of freedom to yield exotic quantum many-body ground states in a two-dimensional semiconductor framework. While the impact of external parameters such as doping or magnetic field can be conveniently modified and analyzed, the lack of open accessiblity of the quasi-2D electron gas combined with its intricate internal properties pose a challenging task to characterize the quintessential nature of the different insulating and superconducting states found in transport experiments. We analyze the possible role of the dielectric environment for TBG on the internal electronic interaction profile, which could be conveniently adjusted in experiment, e.g. by varying the capping layer composition and thickness. We find that this allows to significantly modify the internal interaction strength. In doing so, we propose the experimental tailoring of the dielectric environment as a promising pursuit to provide further evidence for resolving the hidden nature of quantum many-body states in TBG.

E-mail: **jpizarro@uni-bremen.de**

P29*|Poster Session*

EFFECT OF THE ALIGNMENT OF THE SUPERCONDUCTING NODAL DIRECTION WITH THE SAMPLE EDGE IN THE ORIENTATION OF VORTEX NANOCRYSTALS

Joaquin PUIG [1]

[1] *Instituto Balseiro, Bariloche, Argentina*

We have studied the orientation of compact planes in vortex nanocrystals with roughly 100 vortices when nucleated in micrometric cuboids of the high-Tc $Bi_2Sr_2CaCu_2O_{8+y}$ superconductor. The cuboids are engineered such that they have their edges either parallel to the nodal or antinodal direction of the d-wave superconducting order parameter of this material. By applying magnetic decoration we obtain snapshots of the field-cooled vortex nanocrystals nucleated at different fields and observe differences in the orientation of the vortex compact planes for both types of samples. While in antinodal cuboids a given family of compact planes is always aligned with the sample edge, in nodal cuboids no family of compact planes is in register of the sample edge. We also study the interaction force between all vortices of the nanocrystal and found a larger the dispersion in the spatial distribution of this magnitude for vortex nanocrystals nucleated in nodal cuboids. We suggest this is associated to the orientation of the vortex structure for both types of samples.

E-mail: **joquinpuig1907@gmail.com**

P30|Poster Session

SPIN FLUCTUATIONS AND HIGH TEMPERATURE SUPERCONDUCTIVITY IN THE CUPRATE $Bi_2Sr_2CaCu_2O_{8+\delta}$

Francisco RESTREPO [1]

[1] *University of Illinois, Chicago, EEUU*

We use ARPES data on the High T_C compound Bi2212 to construct the spin response function at different temperatures. In theories where High T_C Superconductivity is mediated by spin fluctuations, the effective pairing interaction is proportional to this response function. Hence, we test the spin fluctuation scenario by solving the (strong coupling) Bethe-Salpeter Equation (BSE) using the ARPES-derived susceptibilities as the pairing interaction. We identify a hitherto overlooked artifact coming from the "symmetrization" procedure commonly employed to extend ARPES data to all frequencies and suggest a way to mitigate its effects. This artifact shows up most clearly in the pairing bubble as an anomalously strong response at q=(0,0) and has important consequences for the solution of the BSE; in particular, a spin response function predominantly peaked near (0,0) leads to a suppression of T_C. By correcting for this artifact via a suitable choice of the effective antiferromagnetic exchange parameter, the BSE was solved and the eigenvalue λ was seen to approach unity in the superconducting state (albeit at a temperature below T_C) at near optimal doping. This result lends support to the notion that Spin Fluctuations may mediate superconductivity.

E-mail: **frestr2@uic.edu**

P31|*Poster Session*

HYBRID FERMI-BOSE DRESSING OF EXCITONS LEADING TO CHARGED BIEXCITON FORMATION IN TRANSITION METAL DICHALCOGENIDES

Hector SAINZ [1]

[1] *ETH Zurich, Switzerland*

An exciton in the K valley of a Transition Metal Dichalcogenide monolayer interacts simultaneously with a condensate of excitons in the K' valley and with a Fermi Sea of electrons. We run numerical simulations to study this impurity problem in which the exciton in K can be dressed by electron-hole pairs out of the Fermi Sea, by Bogoliubov excitations out of the condensate in K', and also by both dressing clouds. We observe how at low E$_{F}$ and low condensate number these phenomena give rise to spectral resonances which correspond to trion, biexciton and charged biexciton formation.

E-mail: **hector.scsc@gmail.com**

P32|Poster Session

CHARGE DENSITY WAVE AND VORTEX LATTICE OF $NbSe_2$ WITH A NEW HIGH MAGNETIC FIELD MICROSCOPE

Raquel SÁNCHEZ[1] , F. MARTÍN [1], H. SUDEROW [1] & I. GUILLAMÓN [1]

1 Laboratorio de Bajas Temperaturas y Altos Campos Magnéticos, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain

We describe a Scanning Tunneling Microscope made of non-magnetic Shapal capable of operating at very high magnetic fields. We have considerably reduced the diameter and improved the mechanical stability and wiring arrangements with respect to previous microscopes [1]. We discuss the principle of motion of an inertial motor and show how it is implemented in our device. The STM is located at the center of a 17T magnet. We have characterized the vortex lattice of the superconducting material NbSe2. We also have measured the atomic lattice and the charge density wave of this material at magnetic fields up to 14T. We discuss the tunneling spectroscopy and possible influence of the magnetic field in the density of states.

References

[1] H. Suderow et al., Review of Scientific Instruments **82**, 033711 (2013)

E-mail: **raquel.sanchezb@uam.es**

ELIASHBERG THEORY OF SUPERCONDUCTIVITY IN MONOLAYER FESE ON $SrTiO_3$

Fabian SCHRODI [1], ALEX APERIS, & PETER M. OPPENEER

[1] *Department for Physics and Astronomy, Uppsala University, Sweden*

Superconductivity in bulk iron selenide appears at a critical temperature Tc = 8 K [1]. Surprisingly, when FeSe is thinned down to the thickness of just one monolayer FeSe on an $SrTiO_3$ (STO) substrate the critical temperature increases to values of 60 – 100 K [2-4]. This astonishing increase of the superconducting transition temperature has given rise to much debate on the responsible pairing mechanism.

The superconducting state in iron-based superconductors is customarily associated with spin fluctuations. However, for FeSe/STO the situation is markedly different. The existence of an interfacial electron-phonon coupling has been identified for FeSe on STO [5], yet it is generally considered that the estimated low value of the electron-phonon coupling constant (λ ~0.4) is insufficient to explain the high Tc unless another dominant electronic pairing mechanism, as spin fluctuations is operative. In spite of extensive research on this subject, no consensus has been reached yet.

Here we investigate the superconductivity in FeSe/STO employing a materials' specific framework, the multiband, full bandwidth, and anisotropic Eliashberg theory as implemented in the Uppsala Superconductivity code (UppSC) [6]. Using this Eliashberg-theory framework we discuss the superconductivity in FeSe/STO and compare various calculated quantities with recent experimental results [7].

References

[1] F.-C. Hsu et al., Proc. Natl. Acad. Sci. USA **105**, 14262 (2008).
[2] D. Liu et al., Nature Commun. **3**, 931 (2012).
[3] S. He et al., Nature Mater. **12**, 605 (2013).
[4] S. Tan et al., Nature Mater. **12**, 634 (2013).
[5] J. J. Lee et al., Nature (London) **515**, 245 (2014).
[6] A. Aperis and P. M. Oppeneer, Phys. Rev. B **97**, 060501(R) (2018).
[7] F. Schrodi, A. Aperis and P. M. Oppeneer, Phys. Rev. B **98**, 094509 (2018).

E-mail: **fabian.schrodi@physics.uu.se**

***P34**|Poster Session*

MAJORANA BOUND STATE LOCALIZATION AND ENERGY OSCILLATIONS FOR MAGNETIC IMPURITY CHAINS ON CONVENTIONAL SUPERCONDUCTORS

Andreas THEILER[1], K. BJÖRNSON[2], A. M. BLACK-SCHAFFER[1]

[1] *1Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden*

2Niels Bohr Institute, University of Copenhagen, Juliane Maries Veg 30, DK-2100 Copenhagen, Denmark

We study a chain of magnetic impurities on top of a conventional s-wave superconductor with spin-orbit coupling, calculating the superconducting order parameter fully self-consistent by utilizing the Chebychev expansion method.

In the topological regime, we find the lowest energy state at zero energy past the phase transition and identify it as a topological edge Majorana bound state (MBS). With increasing magnetic impurity strength, energy oscillations in the lowest energy state are observed. We link these oscillations to a strong hybridization between the MBSs and in-gap Yu-Shiba-Rusinov (YSR) states. This provides an intuitive real space picture explaining both energy oscillations as function of the magnetic impurity strength and oscillations in the wave function of the lowest energy state.

By treating the MBS as a topological boundary mode that only depends on the effective mass gap, we are able to calculate a fully parameter-free functional form of its localization. We show that the localization decreases with magnetic impurity strength, opposite to the behaviour of the superconducting coherence length and show that the direct MBS overlap is negligible.

References

A. Theiler, K. Björnson and A. M. Black-Schaffer, arXiv:1808.10061v3

E-mail: **andreas.theiler@physics.uu.se**

***P35**|Poster Session*

NONLINEAR ELECTROMAGNETIC WAVES IN A GRAPHENE SUPERLATTICE

F. Martin-Vergara, F. Rus & Francisco **R. VILLATORO**[1]

[1] *Escuela de Ingenierías Industriales, Universidad de Málaga 29071 Málaga, Spain*

A graphene superlattice is a graphene sheet deposited on a superlattice made by several periodically alternating layers of SiO2 and h-BN. The propagation of electromagnetic waves in this device is described by a nonlinear wave equation for the vector potential, a perturbed sine-Gordon equation whose nonlinearity depends on a shape parameter [1]. Being a non-integrable equation, the interaction between kink and antikink solutions can be calculated by using numerical methods [2,3]. The radiation resulting from the kink-antikink interaction is numerically explored and characterized.

References

[1] Francisca Martin-Vergara, Francisco Rus, Francisco R. Villatoro, "Solitary Waves on Graphene Superlattices," in Nonlinear Systems, Vol. 2, edited by Juan F. R. Archilla et al., Springer (2018), pp. 85-110. DOI: 10.1007/978-3-319-72218-4_4

[2] Francisca Martin-Vergara, Francisco Rus, Francisco R. Villatoro, "Padé numerical schemes for the sine-Gordon equation," Applied Mathematics and Computation **358**: 232-243 (2019). DOI: 10.1016/j.amc.2019.04.042

[3] Francisca Martin-Vergara, Francisco Rus, Francisco R. Villatoro, "Padé schemes with Richardson extrapolation for the sine-Gordon equation," Communications in Nonlinear Science and Numerical Simulation, Manuscript submitted for publication. (2019).

E-mail: **frvillatoro@uma.es**

P36 | Poster Session

NANOCALORIMETRIC EVIDENCE FOR NEMATIC SUPERCONDUCTIVITY IN THE DOPED TOPOLOGICAL INSULATOR $Sr_{0.1}Bi_2Se_3$

Kristin WILLA[1,2], R. WILLA[1,2], K. W. SONG[1], G. D. GU[3], J. A. SCHNEELOCH[3,4], R. ZHONG[3,5], A. E. KOSHELEV[1], W.-K. KWOK[1], U. WELP,[1]

[1] Materials Science Division, Argonne National Laboratory, Lemont, Illinois 60439, USA
[2] Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany
[3] Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, Upton, New York 11793, USA
[4] Department of Physics and Astronomy, Stony Brook University, Stony Brook, New York 11794, USA
[5] Department of Materials Science and Engineering, Stony Brook University, Stony Brook, New York 11794, USA

Spontaneous rotational-symmetry breaking in the superconducting state of doped Bi_2Se_3 has attracted significant attention as an indicator for topological superconductivity. In this paper, high-resolution calorimetry of the single-crystal $Sr_{0.1}Bi_2Se_3$ provides unequivocal evidence of a twofold rotational symmetry in the superconducting gap by a bulk thermodynamic probe, a fingerprint of nematic superconductivity. The extremely small specific heat anomaly resolved with our high-sensitivity technique is consistent with the material's low carrier concentration proving bulk superconductivity. The large basal-plane anisotropy of Hc2 is attributed to a nematic phase of a two-component topological gap structure η = (η1, η2) and caused by a symmetry-breaking energy term. A quantitative analysis of our data excludes more conventional sources of this twofold anisotropy and provides an estimate for the symmetry-breaking strength.

E-mail: **kristin.willa@kit.edu**

P37|*Poster Session*

ANGULAR DEPENDENCE OF MAGNETORESISTANCE UP TO 22T IN TOPOLOGICAL MATERIALS

Beilun WU[1], V. BARRENA[1], M. FERNANDEZ-LOMANA[1], H. SUDEROW [1,2], I. GUILLAMON[1,2]

[1] *Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Facultad de Ciencias, Universidad Autónoma de Madrid, 28049 Madrid, Spain*

2 Unidad Asociada de Bajas Temperaturas y Altos Campos Magnéticos, UAM, CSIC, Cantoblanco, E-28049 Madrid, Spain

Recently, several compounds have been discovered to show an extremely large magnetoresistance that does not saturate at very high magnetic fields. This is at odds of what we know about the resistance under magnetic fields and is often found in semi-metals that have features in the band structure likely holding excitations that are topologically non-trivial, such as Dirac or Weyl fermions. Here we report extremely large, non-saturating magnetoresistance measurements up to 22T on hexagonal semimetallic $PtBi_2$. We carefully study the magnetoresistance as a function of the angle between the magnetic field and the crystalline axis. There is no saturation for all angles and we observe a change from a positively curved to a negatively curved magnetoresistance as a function of the angle. At the angle where the behavior changes, the magnetoresistance is exactly linear with magnetic field. We find Shubnikov-de Haas oscillations for all angles and use these to characterize the Fermi surface of this compound. Our data connect features of the topology of the electronic properties with the linear magnetoresistance and are a further step forward to understand this phenomenon. Finally we will also discuss on some recent angular-dependent magnetoresistance data on the topological insulator Ru2Sn3 and the topological superconductor Au_2Pb.

E-mail: **beilun.wu@uam.es**

List of Participants

Nathan Giovani ANDRADE	*Laboratoire de Physique des Solides - Université Paris-Sud*	**nathangiat@gmail.com**
Victor BARRENA	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**victor.barrena@uam.es**
Leni BASCONES	*ICMM-CSIC*	**Leni.bascones@icmm.csic.es**
Annica BLACK-SCHAFFER	*Uppsala University*	**annica.black-schaffer@physics.uu.se**
Gregory BOEBINGER	*Florida State University, University of Florida and Director and U.S. National High Magnetic Field Laboratory*	**richerson@magnet.fsu.edu**
Marina CALERO DE ORY	*IMDEA Nanociencia*	**marina.calero@imdea.org**
Andrés CANO	*Institut NEEL, CNRS & UGA, Grenoble*	**andres.cano@neel.cnrs.fr**
Antony CARRINGTON	*University of Bristol*	**A.Carrington@bristol.ac.uk**
Tommaso CEA	*IMDEA Nanociencia*	**tommaso.cea@imdea.org**
A.V. CHUBUKOV	*University of Minnesota*	**achubuko@umn.edu**
Amalia COLDEA	*University of Oxford*	**Amalia.Coldea@physics.ox.ac.uk**
Séamus DAVIS	*University of Oxford, University College Cork and Cornell University*	**jcseamusdavis@gmail.com**
Dmitri EFETOV	*ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology*	**Dmitri.Efetov@icfo.eu**
Raquel FERNÁNDEZ-MARTIN	*ICMM*	**raquelfm.92@gmail.com**
Marta FERNANDEZ-LOMANA	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**marta.fernandez-lomana@uam.es**
Yago FERREIROS	*IMDEA Nanociencia*	**yagoferreiros@gmail.com**
Lorenzo GALLO	*Universidad Nacional de Rosario*	**loren.ther@hotmail.com**
Claudio GIANNETTI	*Università Cattolica del Sacro Cuore*	**claudio.giannetti@unicatt.it**
Ildar GILMUTDINOV	*Laboratoire National des Champs Magnétiques Intenses, Toulouse*	**ildar.gilmutdinov@gmail.com**
Cesar GONZÁLEZ	*Universidad Autónoma de Madrid*	**cesar.gonzalez-ruano@uam.es**
Celia GONZÁLEZ	*Universidad Autónoma de Madrid*	**celia.gonzalezsanchez@estudiante.uam.es**
Przemyslaw GRYBOWSKI	*ICFO-Institut de Ciències Fotòniques Barcelona and Adam Mickiewicz University*	**p.r.grzybowski@gmail.com**

Isabel GUILLAMON	*Laboratorio Bajas Temperaturas, Universidad Autónoma de Madrid*	**Isabel.guillamon@uam.es**
Francisco GUINEA	*IMDEA Nanoscience and DIPC of San Sebastián*	**paco.guinea@gmail.com**
Stephen HAYDEN	*University of Bristol*	**s.hayden@bristol.ac.uk**
Matthias HECKER	*Karlsruhe Institute of Technology*	**matthias.hecker@kit.edu**
Edwin HERRERA	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**edwinherrera24@gmail.com**
Pablo JARILLO-HERRERO	*Massachusetts Institute of Technology*	**pjarillo@mit.edu**
Alejandro JIMENO POZO	*IMDEA Nanociencia*	**alejandrojimenopozo@gmail.com**
Sergi JULIÀ-FARRÉ	*ICFO*	**sergi.julia@icfo.eu**
Edin KAPETANOVIC	*Institut für Theoretische Physik, Universität Bremen*	**ekapetan@itp.uni-bremen.de**
Bernhard KEIMER	*Max Planck Institute for Solid State Research*	**b.keimer@fkf.mpg.de**
Eun-Ahn KIM	*Cornell University*	**eun-ah.kim@cornell.edu**
Markus KLUG	*Karlsruhe Institute of Technology*	**markus.klug@kit.edu**
Hamed KOOCHAKI	*Max Planck Institute (MPI-PKS)*	**hkelardeh@pks.mpg.de**
Javier LANDAETA	*Max Plank Institute for Chemical Physics of Solids*	**Javier.Landaeta@cpfs.mpg.de**
Francisco MARTIN	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**francisco.martin@uam.es**
Miriam MARTINEZ	*University of Oviedo*	**miriamart97@gmail.com**
Xavier MARTINEZ DE IRUJO	*Universidad Complutense de Madrid*	**xabimart@ucm.es**
Yuji MATSUDA	*Kyoto University*	**matsuda@scphys.kyoto-u.ac.jp**
Israel OSMOND	*University of Bristol*	**io17399@bristol.ac.uk**
Adolfo O. FUMEGA	*Universidade de Santiago de Comostela.*	**adolfoterofumega@gmail.com**
Sabrina PALAZZESE	*Venezuelan Institute for Scientific Research/INFN (en Padova-Italia)*	**spalazzese@gmail.com**
Pierre Anthony PANTALEON	*IMDEA Nanociencia*	**ppantaleon@uabc.edu.mx**
David PERCONTE	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**david.perconte-duplain@uam.es**
Vo Tiên PHONG	*University of Pensylvania*	**vophong@sas.upenn.edu**
José PIZARRO	*University of Bremen*	**jpizarro@uni-bremen.de**
Alexandre POURRET	*University Grenoble Alpes*	**alexandre.pourret@cea.fr**
Cyril PROUST	*Laboratoire National des Champs Magnétiques Intenses - Toulouse / Grenoble*	**cyril.proust@lncmi.cnrs.fr**

Teresa PUIG	*ICMAB-CSIC, Universidad Autónoma de Barcelona*	**teresa@icmab.es**
Joaquin PUIG	*Instituto Balseiro*	**joaquinpuig1907@gmail.com**
Carlos José RAMOS	*Universidad de Valencia*	**carlos.ramos.marimon@gmail.com**
Mohit RANDERIA	*The Ohio State University*	**randeria.1@osu.edu**
Francisco RESTREPO	*University of Illinois at Chicago*	**frestr2@uic.edu**
Filip RONNING	*Los Alamos National Laboratory*	**fronning@lanl.gov**
Hector SAINZ CRUZ	*ETH Zurich*	**hector.scsc@gmail.com**
Raquel SANCHEZ	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**raquel.sanchezb@uam.es**
Jörg SCHMALIAN	*Karlsruhe Institute of Technology*	**joerg.schmalian@kit.edu**
Fabian SCHRODI	*Department for Physics and Astronomy*	**fabian.schrodi@physics.uu.se**
Hermann SUDEROW	*Laboratorio de bajas temperaturas, Universidad Autónoma de Madrid*	**Hermann.suderow@uam.es**
Andreas THEILER	*Uppsala University*	**andreas.theiler@physics.uu.se**
Nadini TRIVEDI	*The Ohio State University*	**trivedi.15@osu.edu**
Francisco VILLATORO	*Universidad de Málaga*	**frvillatoro@uma.es**
Peter WAHL	*University of St Andrews*	**gpw2@st-andrews.ac.uk, wahl@st-andrews.ac.uk**
Jonatan WARDH	*Department of physics, Gothenburg University*	**jonatan.wardh@physics.gu.se**
Hai Hu WEN	*Nanjing University*	**hhwen@nju.edu.cn**
Kristin WILLA	*Karlsruhe Institut of Technology*	**kristin.willa@kit.edu**
Beilun WU	*Lab bajas temperaturas, Universidad Autónoma de Madrid*	**beilun.wu@uam.es**