VORTEX 2021

18th International Conference on Vortices in Superconductors (online)

27th May to 3rd June, 2021

IIT Kanpur
Diamond Jubilee

https://www.iitk.ac.in/vortex2021/

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Logo designed by Aabhinav Basak,
Design Program, IIT Kanpur

g) Abstract of Poster Presenters

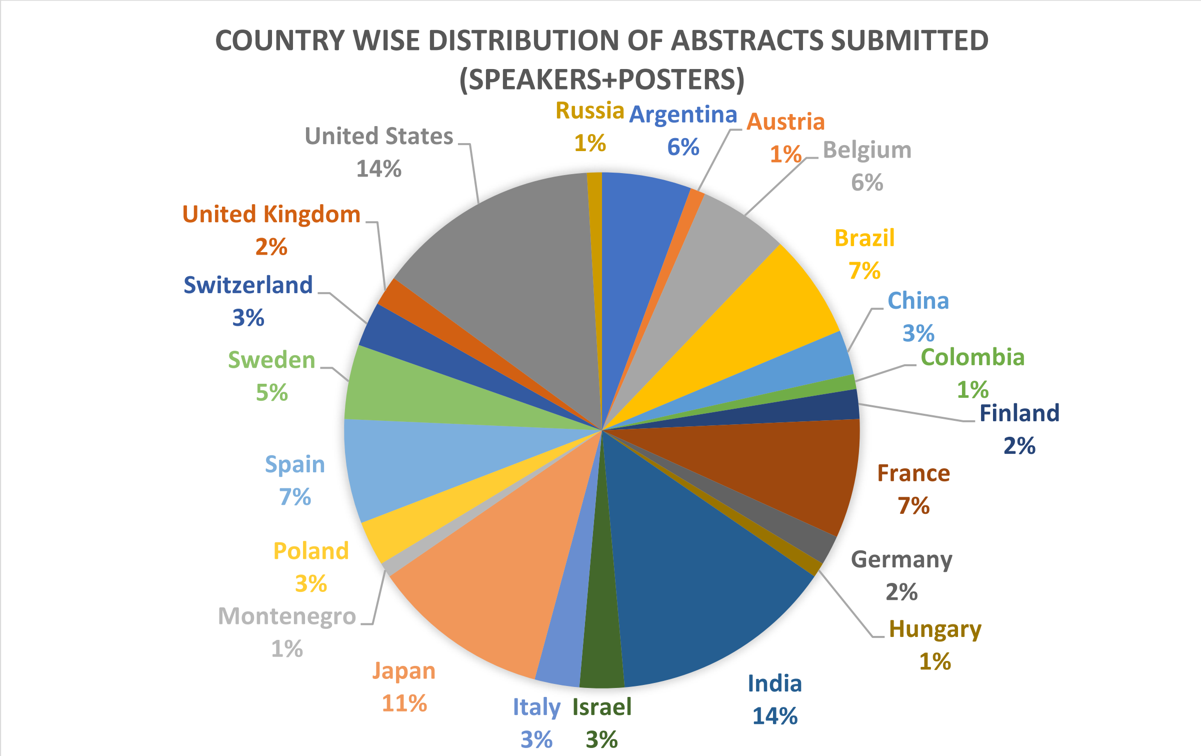
The 18th International Vortex Workshop 2021 (Vortex 2021)

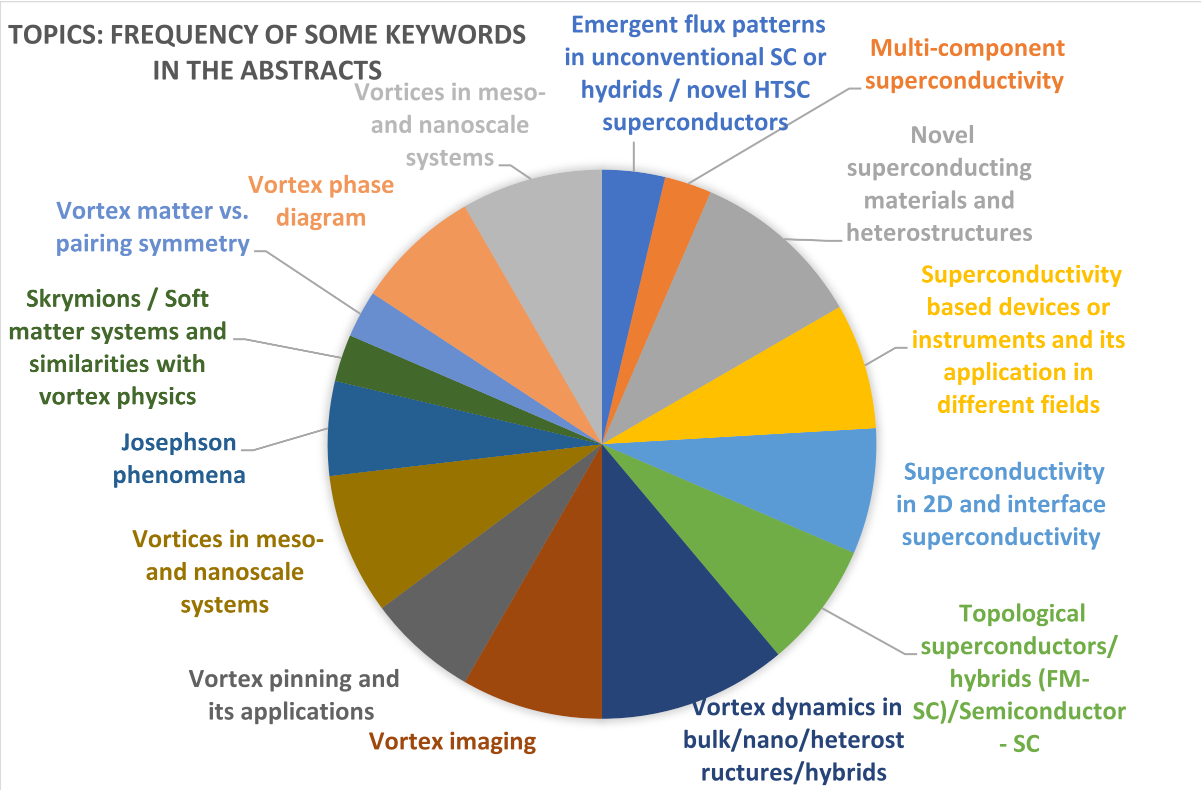
In recent times, rapid advances in the development of superconductor based Quantum Computing Chip, the discovery of near room temperature superconductivity at high pressure, superconductivity in twisted bilayer 2D materials, have caused an excitement in the field of superconductivity. Exciting new results driving the revival of interest in superconductivity span new studies in, iron pnictide superconductors, two-dimensional superconductors, strongly correlated heavy fermion materials, interactions between skrymions and vortices, and finding efficient ways of pinning vortices in superconductors. In order to discuss and capture some of these exciting advances in the field we are organizing the 18th International Online Workshop (Vortex-2021-online) on Vortex Matter in Superconductors, which is to be held online from May 27th to June 4th, 2021. This is a prestigious international event. This workshop continues the tradition of International Conference on Vortex Matter in Superconductors, which began in 1994, Palaiseau France. Its purpose is to promote international collaboration and exchange of ideas in the fascinating field of physics of vortices in superconductors.

Following the successful bid in Antwerp in May 2019 for holding the Vortex workshop in India in 2021, the international vortex conference returns to India after a gap of 15 years. While originally the Vortex 2021 was planned to be held as a physical meeting in New Delhi, India, however, as a fall out of the devastating pandemic, the International Scientific Committee decided to hold Vortex2021 as a fully online conference. This meeting is being jointly organized by Indian Institute of Technology Kanpur (IIT Kanpur), Kanpur and Tata Institute of Fundamental Research (TIFR), Mumbai. The Vortex 2021 commemorates the, Diamond Jubilee (60 years) of Indian Institute of Technology Kanpur (IITK), Kanpur and Platinum Jubilee (75 years) of Tata Institute of Fundamental Research (TIFR), Mumbai.

At the time of compiling this abstract we have received more than 100 abstracts from invited speakers and poster presenters. The number of invited speakers and poster presenters are almost equal. The abstracts we have received are from almost all corners of the globe and they span a wide spectrum of themes, thereby showing that vortex state studies and its connections to diverse aspects of superconductivity and its application, continues to be a flourishing area of research.

Satyajit Banerjee,
Department of Physics, IIT Kanpur
May, 2021





The above are also the topics of the conference

List of VORTEX conferences held to date (Website of VORTEX 2021 : www.iitk.ac.in/vortex2021/**)**
1994 Palaiseau, France, June 26th – July 1st
1995 Lake Forest, IL,USA, June 22nd – 28th
1996 Shoresh, Israel, June 23rd – 30th

1997 Monte Verita, Switzerland, June 17th – 23rd
1998 Hachimantai, Japan, June 18th – 24th
1999 Stanford University, CA, USA, June 19th-25th
2000 Lunteren, the Netherlands, August 28th – September 1st
2001 Bariloche, Argentina, November 27th – December 2nd
2003 Ile d'Oleron, France, June 23rd – 27th
2005 Mumbai, India, January 9th – 14th
2006 Wroclaw, Poland, July 3rd – 8th
2009 Lake Yamanaka, Japan, September 12th – 16th
2011 Chicago, USA, July 31st – August 5th
2013 Nanjing, China, May 21st – 28th
2015 El Escorial, Spain, May 10th – 15th
2017 Natal, Brazil, May 28th – June 3rd
2019 Antwerp, Belgium, May 20-25, 2019
2021 India (online), May 27 – June3, 2021

Committees:

Satyajit Banerjee, Indian Institute of Technology Kanpur, India (Convenor)
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Atsutaka Maeda, University of Tokyo, Japan
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Dimitri Roditchev, ESPCI Paris, France
Hermann Suderow, Universidad Autónoma de Madrid, Spain
José Luis Vicent, Universidad Complutense de Madrid, Spain
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The website of the conference is www.iitk.ac.in/vortex2021/ and conference email ID is: vortex2021online@gmail.com

The conference pays homage to the lives lost worldwide due to the pandemic. It also salutes the human spirit and its scientific endeavours to help humankind out of the pandemic.

Time (Indian Standard Time, IST)	Thursday 27th May, 2021	Friday 28th May 2021,	Saturday 29th May, 2021	Sunday, 30th May, 2021	Monday 31st May, 2021	Tuesday 1st June, 2021	Wednesday, 2nd June 2021	Thursday 3th June 2021
16:00 - 16:50	Inauguration address (16:25 - 16:55)	Poster session	Poster session		Poster session	Poster session	Poster session	Closing address (16:40 - 16:55)
16:50 - 16:55		Break	Break		Break	Break	Break	
	Vortex imaging/Pairing symmetry and Vortices	Soft matter systems, skrymions-connections with vortex physics	Superconductivity / Vortices in 2D systems, HTSC and interfaces		Novel superconducting devices / Structures/ applications	Vortex imaging/Pairing symmetry/Vortices in New systems	Vortex Pinning/ Vortex Dynamics/ Fluctuations/ Applications	Vortex phase diagram, Multi-component superconductivity, Vortex matter vs. pairing symmetry
17:00 - 17:30	Tetsuo Hanaguri	Ajay Sood	Koichiro Ienaga		Yosi Yeshurun	Hai Hu Wen	Atsutaka Maeda	Yoshihiro Iwasa
17:30 - 18:00	Hermann Suderow	Pietro Tierno	Hemant K. Kundu		R. Vijayaraghavan	Beena Kalisky	Tsuyoshi Tamegai	Shigeru Kasahara
18:00 - 18:30	Dimitri Roditchev	Christos Panagopoulos	Alexander Buzdin	Break	Alejandro Silhanek	Yanina Fasano	Wilson Ortiz	Ravi Prakash Singh
18:30 - 19:00	Simon Bending	Charles Reichhardt	Mandar M Deshmukh		Javier Villegas	Surajit Dutta	Lara Benfatto	Leonardo Civale
19:00 - 19:30	Break	Break	Break		Break	Break	Sarod Concert : Indian Classical Instrumental Music program (19:00 - 19:45)	Break
	Multigap superconductors, disorder: effect on order parameter symmetry/ phase diagrams/pinning/ applications	Driving Vortices in bulk/nano/heterostructures/hybrids	Topological superconductors/ hybrids (FM-SC)		Josephson Junctions / THz / Applications	Superconductivity in 2D materials/HTSC and interfaces		Statics and dynamics of Vortices in extreme confinement/Nanostructures/hybrids
19:30 - 20:00	Marcin Konczykowski	Oleksandr Dobrovolskiy	Tomasz Cichorek		Joris Van de Vondel	Philip Kim	Superconductivity and 2D Quantum Materials-Synergy	Milorad Milosevic
20:00 - 20:30	Vadim Geshkenbein	Ankit Kumar	Irina V. Grigorieva		Vladimir Krasnov	Floriana Lombardi	Pablo Jarillo - Herrero	Vladimir M. Fomin
20:30 - 21:00	David Larbalestier	Ulrich Welp	Alexei E. Koshelev		N. Peter Armitage	Goutam Sheet	Dmitri Efetov	Mauro M Doria
21:00 - 21:30	Morten Ring Eskildsen	Alex Gurevich	Valerii Vinokur		Valentine Novosad	Maria Iavarone	Sameer Grover	Boldizar Janko
21:30 - 22:00	Ruslan Prozorov	Poster session	Poster session		Vasily Stolyarov	Poster session	Anindya Das	Closing comments an End of Conference
22:00 - 22:30					Poster session		Poster session	

Each talk (Total: 27 mins = 22 mins talk + 5 mins discussions)

The times given in the time table are in Indian Standard time (IST)

Each day has 4 hours of invited talk divided into two sessions of two hours

Two poster sessions of 50 minutes each, on 5 days of the conference before and after the talk. All posters will be on display on all days

Conference talk timings for different countries:

Tokyo: 20:30 to 01:00 (IST + 3 hours 30 minutes)
Beijing : 19:30 - 00:00 (IST + 2 hours 30 mins)
India, IST: 17:00 to 21:30
UK : 12:30 to 17:00 (IST - 4 hour 30 minutes)
Brussels: 13:30 to 18:00 (IST - 3 hours 30 mins)
Paris: 13:30 to 18:00 (IST - 3 hours 30 mins)
Sweden: 13:30 to 18:00 (IST - 3 hours 30 mins)
Buenos Aires: 8:30 to 13:00 (IST - 8 hours 30 mins)
Rio de Janerio: 8:30 to 13:00 (IST - 8 hours 30 mins)
New York: 7:30 to 12:00 (IST - 9 hours 30 mins)
Indianapolis:7:30 to 12:00 (IST - 9 hours 30 mins)
Massachusetts:7:30 to 12:00 (IST - 9 hours 30 mins)
Chicago : 6:30 to 11:00 (IST - 10 hours 30 mins.)
Los Angeles/California: 4:30 to 9:00 (IST - 12 hours 30 mins)
New Mexico: 5:30 - 10:00 (IST - 11 hours 30 mins)

Detailed Program

(All times below are India Time)

Time conversion for some time zones indicated at the end of the table*. Please convert the times shown in Indian time to your time.

Day 1: 27th May, 2021, Thursday	
16:25 - 16:55	Inauguration
	Inaugural remarks
	Address by Director IIT Kanpur, Prof. Abhay Karandikar
	Session: Vortex imaging/Pairing symmetry and Vortices Chair: Gianni Blatter , ETH Zurich, Switzerland Co-Chair: Gorky Shaw, KIIT Orissa, India
17:00 - 17:30	Tetsuo Hanaguri, RIKEN, Japan Title: High-field superconducting phase in FeSe investigated by spectroscopic-imaging scanning tunneling microscopy
17:30 - 18:00	Hermann Suderow, IFIMAC, Universidad Autónoma de Madrid, Spain Title: Scanning tunnelling microscopy of bound states in superconductors
18:00 - 18:30	Dimitri Roditchev, Sorbonne University, France Title: Crossover from ferromagnetic superconductor to superconducting ferromagnet in p-doped $EuFe_2(AsP)_2$
18:30 - 19:00	Simon Bending, University of Bath, United Kingdom Title: Imaging the Suppression of Superconductivity by Correlated Magnetic Fluctuations in $RbEuFe_4As_4$
19:00 - 19:30	Break
	Session: Multigap superconductors, disorder: effect on order parameter symmetry/ phase diagrams/pinning/ applications Chair: T. V. Ramakrishnan, IISc Bangalore Co-Chair: Deepshikha Jaiswal Nagar, IISER Thiruvanathapuram, India
19:30 - 20:00	Marcin Konczykowski, Laboratoire des Solides Irradies, Institut Polytechnique de Paris, France Title: Tuning of Composition - Temperature Phase Diagram of Iron-Based Superconductors by Disorder
20:00 - 20:30	Vadim Geshkenbein, Affiliation Institut for Theoretical Physics ETH Zu¨rich, Switzerland Title: Creep effects on the Campbell response in type II superconductors
20:30 - 21:00	David Larbalestier, National High Magnetic Field Laboratory, Florida State University, USA Title: Mysteries of Vortex Pinning in Nb47wt.%Ti

21:00 - 21:30	Morten Ring Eskildsen, University of Notre Dame, Notre Dame, USA Title: Localized and reversible ordering and disordering of the vortex lattice in UPt_3
21:30 - 22:00	Ruslan Prozorov, Ames Laboratory, Iowa State University, USA Title: Temperature-dependent anisotropy of London penetration depth in single- and two-band superconductors
Day 2: 28th May, 2021, Friday	
16:00 – 16:50	Poster Session
	Session: Soft matter systems, skrymions - connections with vortex physics Chair: Arghya Taraphdar, IIT Kharagpur, India.
17:00 - 17:30	Ajay Sood, Indian Institute of Science, Bangalore, India Title: New Paradigms in Driven Soft Matter: Instabilities, Rheo-chaos, Memory encoding and retrieval
17:30 - 18:00	Pietro Tierno, Universitat de Barcelona, Spain Title: Collective dynamics of driven colloids on ordered and disordered magnetic landscapes
18:00 – 18:30	Christos Panagopoulos, Nanyang Technological University, Singapore Title: Coupling Topological Solitons in Hybrid Quantum Materials
18:30 - 19:00	Charles Reichhardt, Los Alamos National Laboratory, New Mexico, USA Title: Vortex and skyrmion dynamics on moire superlattices
19:00 - 19:30	Break
	Driving Vortices in bulk/nano/heterostructures/hybrids Chair: Subroto Mukerjee, IISc Bangalore, India
19:30 - 20:00	Oleksandr Dobrovolskiy, University of Vienna, Austria Title: Microwave stimulation of superconductivity in the vortex state
20:00 - 20:30	Ankit Kumar, Indian Institute of Technology, Kanpur, India Title: Imaging the drive current effect on the low-field vortex melting phenomenon in a $Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor
20:30 - 21:00	Ulrich Welp, Argonne National Laboratory, Argonne, USA Title: Superconductivity and Magnetism in $RbEuFe_4As_4$
21:00 - 21:30	Alex Gurevich, Old Dominion University, Norfolk, USA Title: Nonlinear dynamics of a vortex driven by a strong ac Meissner current
21:30 - 22:30	Poster session

Day 3: 29th May, 2021, Saturday	
16:00 – 16:50	Poster Session
	Session: Superconductivity / Vortices in 2D systems, HTSC and interfaces Chair: Hermann Suderow, IFIMAC, Universidad Autónoma de Madrid Spain Co-Chair: Ajay Thakur, IIT Patna, India
17:00 - 17:30	Koichiro Ienaga, Tokyo Institute of Technology, Japan Title: Quantum criticality in the field-induced metallic state of disordered superconducting thin films probed by thermoelectric effects
17:30 - 18:00	Hemant K. Kundu, Indian Institute of Science, Bangalore, India Title: Effect of Dimensionality on vortex dimensionality in type II sc.
18:00 - 18:30	Alexander Buzdin, Université de Bordeaux and CNRS, France Title: Spontaneous currents and vortex generation via the spin-orbit mechanism at S/F interfaces
18:30 - 19:00	Mandar M Deshmukh, TIFR, Mumbai, India Title: Tuning and modification of superconductivity in a 2d high TC superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$
19:00 - 19:30	Break
	Session: Topological superconductors/ hybrids (FM-SC) Chair: Prof. C. V. Tomy, IIT Bombay, India. Co-Chair: Surjeet Singh, IISER Pune, India
19:30 - 20:00	Tomasz Cichorek, Institute of Low Temperature and Structure Research, Poland Title: Destruction of a sign-changing order parameter by artificial atomic defects in multiband superconductor $PrOs_4Sb_{12}$
20:00 - 20:30	Irina V. Grigorieva, University of Manchester, UK Title: Magnetization signature of topological surface states in a non-symmorphic superconductor
20:30 - 21:00	Alexei E. Koshelev, Argonne National Laboratory, Illinois, USA Title: Influence of correlated magnetic fluctuations on parameters of magnetic superconductors
21:00 - 21:30	Valerii Vinokur, Terra Quantum AG, Switzerland Title: Topological nature of high temperature superconductivity
21:30 - 22:30	Poster session
Day 4, 30th May, 2021, Sunday **No Sessions on this Day – Full day BREAK**	

Day 5 31st May, 2021, Monday	
16:00 – 16:50	Poster Session
	Session: Novel superconducting devices / Structures/ applications Chair: Wilson Ortiz, Universidade Federal de Sao Carlos, Brazil Co-Chair: Pallavi Kushwaha, NPL New Delhi, India
17:00 - 17:30	Yosi Yeshurun, Bar-Ilan University, Israel Title: DNA-assembled superconducting nanoscale architectures
17:30 - 18:00	R. Vijayaraghavan, Tata Institute of Fundamental Research, Mumbai, India Title: Long-range connectivity in superconducting qubits using a ring resonator
18:00 - 18:30	Alejandro Silhanek, Université de Liège, Belgium Title: Direct Visualization of Current-Stimulated Oxygen Migration in $YBa_2Cu_3O_{7-\delta}$ Thin Films
18:30 - 19:00	Javier Villegas, Université Paris-Saclay, Palaiseau, France Title: Revisiting photodoping, photoconductivity and photo - superconductivity in the cuprates
19:00 - 19:30	Break
	Session: Josephson Junctions / THz / Applications Chair: Milorad Milosovic, University of Antwerp, Belgium Co-Chair: Prof. Neeraj Khare, IIT Delhi, New Delhi, India
19:30 - 20:00	Joris Van de Vondel, KU Leuven, Belgium Title: Giant fractional Shapiro steps in anisotropic Josephson junction arrays
20:00 - 20:30	Vladimir Krasnov, Stockholm University, Sweden Title: Vortex-based Electronics
20:30 - 21:00	N. Peter Armitage, The Johns Hopkins University, Baltimore, USA Title: Nonlinear THz electrodynamics of unconventional and disordered superconductors
21:00 - 21:30	Valentine Novosad, Argonne National Laboratory, Lemont, USA Title: Superconducting sensors: From basic physics to large scale science experiments
21:30 – 22:00	Vasily Stolyarov, Moscow Institute of Physics and Technology, Dolgoprudny, Russia Title: Low dissipative Josephson vortex dynamics
22:00 - 22:30	Poster session

Day 6 1st June 2021, Tuesday	
16:00 – 16:50	Poster Session
	Session: Vortex imaging/Pairing symmetry/Vortices in New systems Chair: Vladimir Krasnov, Stockholm University, Sweden
17:00 - 17:30	Hai Hu Wen, Nanjing University, China Title: Vortex and its bound states in a layered superconductor $KCa_2Fe_4As_4F_2$
17:30 - 18:00	Beena Kalisky, Bar-Ilan University, Ramat-Gan, Israel Title: Imaging the magnetic landscape in chiral superconductor candidate 4Hb-TaS_2
18:00 - 18:30	Yanina Fasano, Centro Atómico Bariloche, Argentina Title: Non-gaussian tail in the force distribution: A hallmark of correlated disorder in the host media of elastic objects
18:30 - 19:00	Surajit Dutta, TIFR, Mumbai, India Title: Observation of two-dimensional melting and zero-point fluctuation of vortices in a very weakly pinned a-MoGe thin film
19:00 - 19:30	Break
	Session: Superconductivity in 2D materials/HTSC and interfaces Chair: Marcin Konczykowski, Institut Polytechnique de Paris, France Co-Chair: Pallavi Kushwaha, NPL, New Delhi India
19:30 - 20:00	Philip Kim, Harvard University, Cambridge, USA Title: Toward realization of novel superconductivity based on twisted van der Waals Josephson junction in cuprates
20:00 - 20:30	Floriana Lombardi, Chalmers University of Technology, Sweden Title: Reshaping the phase diagram of HTSC by nm thin films and nanodevices
20:30 - 21:00	Goutam Sheet, Indian Institute of Science Education and Research, Mohali, India Title: Tip-induced superconductivity
21:00 - 21:30	Maria Iavarone, Temple University, Philadelphia, USA Title: Proximity induced superconductivity in monolayer MoS_2
21:30 - 22:30	Poster session
Day 7 2nd June 2021, Wednesday	
16:00 – 16:50	Poster Session
	Session: Vortex Pinning/ Vortex Dynamics/ Fluctuations/ Applications Chair: Mauro Doria, Universida de Federal do Rio de Janeiro, Brazil Co-Chair: Prof. Anjan Gupta, IIT Kanpur, India
17:00 - 17:30	Atsutaka Maeda, University of Tokyo, Japan

	Title: Large Hall angle in the flux flow of high-*Tc* cuprate superconductors measured by microwave Hall effect
17:30 - 18:00	Tsuyoshi Tamegai, The University of Tokyo, Japan Title: Impacts of defects on the peak effect in NbSe2
18:00 - 18:30	Wilson Ortiz, Universidade Federal de São Carlos, Brazil Title: Recording magnetic flux in the mixed state of superconducting thin films
18:30 - 19:00	Lara Benfatto, University of Rome, Rome, Italy Title: Dynamical signatures of a fragile glass transition in thin superconducting films
19:00 - 20:00	Sarod Concert: Indian Classical Instrumental Music program (19:00 - 19:45) Shri. Debanjan Bhattacharjee www.DebanjanBhattacharjee.com
	Session: Superconductivity and 2D Quantum Materials-Synergy Chair: Arindam Ghosh, IISc Bangalore, India
20:00 - 20:30	Pablo Jarillo – Herrero, MIT, Cambridge, USA Title: Moiré Magic 3.0
20:30 – 21:00	Dmitri Efetov, ICFO, Barcelona, Spain Title: Competing phases of correlated Chern insulators in Superconducting Twisted Bilayer Graphene
21:00 - 21:30	Sameer Grover, Weizmann Institute of Science, Rehovot, Israel Title: SQUID-on-tip imaging of topological currents in magic-angle graphene
21:30 - 22:00	Anindya Das, Indian Institute of Science, Bangalore, India Title: Dynamics of Andreev edge state at the interface of quantum Hall and superconductor
22:00 - 22:30	Poster Session
Day 8 3rd June, 2021, Thursday	
16:25 - 16:40	Address by Director TIFR, Prof. S. Ramakrishnan
	Session: Vortex phase diagram, Multi-component superconductivity and connections with Vortex matter vs. pairing symmetry Chair : Atsutaka Maeda, University of Tokyo, Japan
17:00 - 17:30	Yoshihiro Iwasa, University of Tokyo, Japan Title: Two-dimensional BCS-BEC crossover
17:30 - 18:00	Shigeru Kasahara, Research Institute for Interdisciplinary Science, Okayama University, Japan Title: Fulde-Ferrell-Larkin-Ovchinnikov States in the BCS-BEC-Crossover Superconductor FeSe

18:00 - 18:30	Ravi Prakash Singh, Indian Institute of Science Education and Research, Bhopal, India Title: Time Reversal Symmetry Breaking in Noncentrosymmetric Superconductors
18:30 - 19:00	Leonardo Civale, Los Alamos National Laboratory, USA Title: Using vortex dynamics tools to explore magnetic configurations in non-superconducting materials
19:00 - 19:30	Break
	Session: Statics and dynamics of Vortices in extreme confinement/Nanostrcutures/hybrids Chair: Arun K. Grover, India Co-Char: Ravi Prakash Singh, IISER, Bhopal, India
19:30 - 20:00	Milorad Milosevic, University of Antwerp, Belgium Title: Advances in multiscale simulations of fluxonic devices
20:00 - 20:30	Vladimir M. Fomin, Institute for Integrative Nanosciences, Dresden, Germany Title: Topological effects in advanced superconductor nanoarchitectures
20:30 - 21:00	Mauro M Doria, Universidade Federal do Rio de Janeiro, Brazil Title: An unstable giant vortex in the mesoscopic type I superconductor - The spike state
21:00 - 21:30	Boldizar Janko, University of Notre Dame, Indiana, USA Title: Superconducting Vortex Matter Under Extreme Confinement: The Effect of Anisotropic Interaction
	Closing Remarks
-----x---------x---------x-- Conference Ends --x---------x---------x-----	

*Conference time for your time zone

Tokyo: 20:30 to 01:00   (IST + 3 hours 30 minutes)
Beijing : 19:30 - 00:00 (IST + 2 hours 30 mins)
India, IST: 17:00 to 21:30
UK : 12:30 to 17:00 (IST - 4 hour 30 minutes)
Brussels: 13:30 to 18:00 (IST - 3 hours 30 mins)
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Massachusetts:7:30 to 12:00 (IST - 9 hours 30 mins)
Chicago : 6:30 to 11:00 (IST - 10 hours 30 mins.)
Los Angeles/California: 4:30 to 9:00 (IST - 12 hours 30 mins)
New Mexico: 5:30 - 10:00 (IST - 11 hours 30 mins)

Please note the timings indicated are Indian times (see the last page of this document for more information on time zone convertor resources*). The poster sessions are indicated in the main program. Apart from the sessions indicated for you, you can be present at other times too. All poster's will be available for viewing and discussion all throughout the conference period.

Name of Poster Presenter	Poster Title	Affiliation (detailed postal address)	Country	Session in which to be present
Aleix Barrera Català	TAILORED SPIN-TEXTURES IN HYBRID SUPERCONDUCTING-FERROMAGNETIC STRUCTURES	Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de la UAB 08193 Bellaterra, Spain	Spain	May 31, 2021 16:00 to 16:50 Poster - Hall - 2
Alex Khanukov	Imaging the destruction of superconductivity in MoSi rings	Bar Ilan University Department of Physics, Bar-Ilan University, Ramat-Gan 5290002, Israel	Israel	May 28, 2021 21:30 to 22:30 Poster Hall - 4
Allan Leishman	TOPOLOGICAL BARRIER FOR SKYRMION LATTICE FORMATION IN MnSi	225 Nieuwland Science Hall University of Notre Dame Notre Dame, IN 46556	USA	June 1, 2021 21:30 to 22:30 Poster - Hall - 1
Arushi	Unconventional superconducting properties of a new Re-rich non-centrosymmetric α-Mn superconductor, Re5.5Ta	Crystal Growth Lab, AB3, Indian Institute of Science Education and Research, Bhopal, India-462066	India	June 1, 2021 16:00 to 16:50 Poster - Hall - 1
Balazs Ujfalussy	Magnetic adatoms on conventional superconductor surfaces	Wigner Research Centre for Physics, POB 49 H-1056 Budapes, Hunrary	Hungary	May 28, 2021 21:30 to 22:30 Poster Hall - 4

Biplab Bag	Scaling of I-V curves and identification of non-equilibrium phase transitions at two unique depinning thresholds in 2H-NbS2 single crystals	Post-Doctoral fellow, CG35, Department of Condensed Matter Physics and Material Sciences, Tata Institute of Fundamental Research, Mumbai, Maharashtra-400005, India	India	June 1, 2021 21:30 to 22:30 Poster - Hall - 1
Carmine Attanasio	NbRe nitride films for potential application as superconducting nanowire single photon detector	Dipartimento di Fisica “E.R. Caianiello”, Università degli Studi di Salerno, I-84084 Fisciano (Sa), Italy	Italy	May 28, 2021 21:30 to 22:30 Poster – Hall- 1
Daniele Torsello	Interplay between magnetism and superconductivity in EuFe2(As1−xPx)2 single crystals	Department of Applied Science and Technology, Politecnico di Torino, Corso Duca degli Abruzzi 24, I-10129 Torino, Italy	Italy	May 29, 2021 16:00 to 16:60 Poster Hall - 1
Davi A. D. Chaves	Decreasing the flux front penetration depth in a Nb thin film under inhomogeneous magnetic field	Federal Univerisity of São Carlos, PO Box 676, 13565-095, São Carlos, SP, Brazil.	Brazil	May 29, 2021 21:30 to 22:30 Poster Hall - 2
Edgar J. Patiño	CAN COOPER-PAIRS TUNNEL AS BOSONIC PARTICLES? THEORY AND RESULTS	Departamento de Física, Superconductivity and Nanodevices Laboratory, Universidad de los Andes, Carrera 1 No. 18A-12, A.A. 4976-12340, Bogotá, Colombia	Colombia	May 29, 2021 21:30 to 22:30 Poster Hall - 4

Elijah Anertey Abbey	MAGNETIC FLUX AVALANCHES IN NANOSCALE WEDGE-SHAPED SUPERCONDUCTING THIN FILMS	Departamento de Física, Universidade Federal de São Carlos, 13565-905 São Carlos, SP, Brasil. Grupo de Supercondutividade e Magnetismo Rodovia Washington Luiz, km 235 CEP: 13565-905 Caixa Postal: 676 São Carlos - SP Brazil.	Brazil	June 1, 2021 21:30 to 22:30 Poster Hall - 1
Eylon Persky	Imaging the magnetic landscape of chiral superconductor candidate 4Hb-TaS2	Bar Ilan University Department of Physics, Bar-Ilan University, Ramat-Gan 5290002, Israel	Israel	May 28, 2021 21:30 to 22:30 Poster Hall - 3
Filippo Gaggioli	Effects of creep on the linear ac magnetic response in type II superconductors	1Institut für Theoretische Physik, ETH Zürich, CH-8093 Zürich, Switzerland	Switzerland	June 1, 2021 16:00 to 16:50 Poster Hall - 3
Gabriela Pasquini	Interplay between nematicity and superconductivity in strained pnictides superconductors	Departamento de Física, FCEyN, Universidad de Buenos Aires; IFIBA, CONICET; Buenos Aires 1428, Argentina.	Argentina	May 28, 2021 21:30 to 22:30 Poster Hall - 3
Gonzalo Agustín Rumi	Two-step ac screening and non-local effects in the vortex lattice on BSCCO samples	Laboratorio de Bajas Temperaturas, Centro Atómico Bariloche, CNEA & Instituto Balseiro, Bariloche CP 8400, Argentina	Argentina	May 28, 2021 21:30 to 22:30 Poster Hall - 2
Govindarajan P	Symmetry reorientation transition in the vortex lattice and flux jumps in single crystals of V3Si superconductor	IISER Thiruvananthapuram, Maruthamala P.O., Vithura, Thiruvananthapuram - 695551, India	India	May 28, 2021 16:00 to 16:50 Poster Hall - 2

Heleen Dausy	The impact of kinetic inductance on the critical current oscillations of nanobridge SQUIDs	Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium	Belgium	May 31, 2021 16:00 to 16:50 Poster Hall - 3
Ilaria Maccari	Interplay of spin waves and vortices in the two-dimensional XY model at small vortex-core energy	KTH Royal Institute of Technology SE-100 44 Stockholm Sweden	Sweden	June 1, 2021 16:00 to 16:50 Poster Hall - 2
Irina Grigorieva	MAGNETIZATION SIGNATURE OF TOPOLOGICAL SURFACE STATES IN A NON-SYMMORPHIC SUPERCONDUCTOR	Condensed Matter Physics group, Department of Physics and Astronomy, School of Natural Sciences, University of Manchester, Oxford Rd., Manchester M13 9PL, UK	UK	June 1, 2021 16:00 to 16:50 Poster Hall - 4
Jazmín Aragón Sánchez	Panoramics of vortex matter in FeSe and FeSeS at low fields	Centro Atómico Bariloche and Instituto Balseiro, CNEA, CONICET and Universidad Nacional de Cuyo, Avenida Bustillo, 9500 San Carlos de Bariloche, Río Negro, 8400.	Argentina	May 28, 2021 21:30 to 22:30 Poster Hall - 2
Joaquin Puig	Bridges in micron-sized type-II superconducting samples act as converging lenses for vortices	Centro Atómico Bariloche and Intituto Balseiro, CNEA, CONICET and Universidad Nacional de Cuyo, 8400 San Carlos de Bariloche, Argentina	Argentina	May 29, 2021 21:30 to 22:30 Poster Hall - 3

JORDI ALCALA	RESISTIVE SWITCHING IN NANOSTRUCTURED YBCO THIN FILMS	Montefiore Research Unit, Department of Electrical Engineering and Computer Science,Université de Liège, 4000 Sart Tilman, Belgium	SPAIN	May 31, 2021 16:00 to 16:50 Poster Hall - 3
Kapil Motla	Superconducting Properties of α-Mn High Entropy Alloy Superconductors	Crystal Growth Lab AB-3, Pincode-462066 Indian Institute of Science Education and Research Bhopal (INDIA)	India	June 1, 2021 16:00 to 16:50 Poster Hall - 3
Kyungwha Park	Zero-energy peak induced by a magnetic impurity in a conventional superconductor: first-principles based study	Department of Physics, Virginia Tech, Blacksburg, Virginia 24061, USA	USA	June 1, 2021 21:30 to 22:30 Poster Hall - 2
Leonardo Rodrigues Cadorim	The Resistive State of Two-Band Superconductors	Departamento de Física, Faculdade de Ciências, Universidade Estadual Paulista (UNESP), Caixa Postal 473, 17033-360, Bauru-SP, Brazil.	Brazil	May 29, 2021 21:30 to 22:30 Poster Hall – 1
Maciej Zgirski	Heat hunting in a freezer: direct measurement of quasiparticle diffusion in superconducting nanowire	Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, Warsaw PL 02668	Polska	May 31, 2021 16:00 to 16:50 Poster Hall - 3
Mamta	Study of the Flux Pinning Properties of YBCO: NaNbO3 Nanorods Composite Superconductor	MS-408, Department of Physics, IIT Delhi, New Delhi	India	May 28, 2021 16:00 to 16:50 Poster Hall - 1
MANASI MANDAL	Superconductivity in Chemically Doped Type-II Weyl Semimetal	ROOM NO 409, IISER BHOPAL HOSTEL 2, Bhopal bypass road, Bhopal, Madhya Pradesh, India-462066	India	June 1, 2021 16:00 to 16:50 Poster Hall - 2

Marek Foltyn	Sensing superconducting vortices with Dayem nanobridge	Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, Warsaw PL 02668	Poland	May 31, 2021 16:00 to 16:50 Poster Hall - 2
Masanori Ichioka	NON-MAGNETIC IMPURITY EFFECTS IN VORTEX STATES OF NEMATIC SUPERCONDUCTORS	Department of Physics, Okayama University, Okayama 700-8530, Japan	Japan	May 29, 2021 16:00 to 16:60 Poster Hall - 2
Matthew Smylie	Superconducting phase diagram of magnetically ordered superconductor pristine $RbEuFe_4As_4$ and $RbEu(Fe_{1-x}Ni_x)_4As_4$ for $x \le 0.04$ in large pulsed fields	Department of Physics and Astronomy, Hofstra University, 1000 Hempstead Turnpike, Hempstead, NY 11549 USA	USA	June 1, 2021 21:30 to 22:30 Poster Hall - 2
Maycon Motta	Widening the range of applicability of superconducting NbN thin films by suppressing flux avalanches	Departamento de Física, Universidade Federal de São Carlos, 13565-905 São Carlos, SP, Brazil	Brazil	June 1, 2021 16:00 to 16:50 Poster Hall - 2
Md Arif Ali	A prototype of Superconducting Fault Current Limiter with three dimensional current mapping ability	Department of Physics, Indian Institute of Technology, Kanpur 208016, Uttar Pradesh	India	May 28, 2021 21:30 to 22:30 Poster Hall - 4
Michal Wyszynski	Skyrmion-affected vortex dynamics in a magnet-superconductor heterostructure	Department of Physics, University of Antwerp, Groenenborgelaan 171, B-2020 Antwerp, Belgium	Belgium	May 28, 2021 16:00 to 16:50 Poster Hall - 2
P.Neha, Satyabrata Patnaik	Effect of heavy ion irradiation on Mo_8Ga_{41} superconductor	School of Physical Sciences, Jawaharlal Nehru University, New Delhi-10067.	India	May 28, 2021 16:00 to 16:50 Poster Hall - 4

Pablo Garcia Campos / Klaus Hasselbach	Visualization by scanning SQUID microscopy of the intermediate state in the superconducting Dirac semimetal PdTe2	Institut Néel CNRS, 25 av des Martyrs 38042 Grenoble, France	France	May 28, 2021 16:00 to 16:50 Poster Hall - 3
Pablo Orus	Superconducting properties of in-plane W-C nanowires grown by He+ focused ion beam induced deposition	Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, 50009 Zaragoza, Spain	Spain	May 31, 2021 16:00 to 16:50 Poster Hall - 1
Predrag Miranovic	STRUCTURAL TRANSFORMATION OF VORTEX LATTICE IN LOW-**Κ** SUPERCONDUCTORS	Faculty of Natural Sciences and Mathematics, University of Mointenegro, Džorrdža Vašingtona b.b., 81000 Podgorica, Montenegro	Montenegro	May 31, 2021 16:00 to 16:50 Poster Hall - 1
R. F. Luccas	MONODISPERSE CARBON SPHERES AS PINNING CENTERS FOR ENHANCED PROPERTIES OF MgB2 SUPERCONDUCTOR CABLES	Institute of Physics Rosario (IFIR), CONICET-UNR, Bv. 27 de Febrero 210bis, S2000EZP Rosario, Santa Fe, Argentina.	Argentina.	May 29, 2021 21:30 to 22:30 Poster Hall - 4
Ravi Kumar	Hall Effect for Dirac Electrons in Graphene Exposed to an Abrikosov Flux lattice	Department of Physics, Indian Institute of Science, Bangalore - 560012	India	June 1, 2021 16:00 to 16:50 Poster Hall - 4
Roland Willa	A topological flux trap: Majorana bound states at screw dislocations	Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, Germany	Germany	May 28, 2021 16:00 to 16:50 Poster Hall - 3
Sagar Paul	Enhancement in the micro-SQUID’s flux sensitivity through Stochastic Resonance	Department of Physics, Indian Institute of Technology Kanpur, Kanpur 208016, India	India	June 1, 2021 21:30 to 22:30 Poster Hall - 1

Sajilesh K P	Probing superconducting gap structure in LaMSi(M=Ni,Pt) using muon spin rotation and relaxation	IISER Bhopal, Bhopal By-pass road, Bhauri Bhopal, INDIA, 462066	India	June 1, 2021 16:00 to 16:50 Poster Hall - 3
Sergei Kozlov	Probing vortex dynamics in YBCO nanowire using RF illumination	Laboratoire de Physique et d'Etude des Matériaux, CNRS, ESPCI Paris, PSL Research University, UPMC, 75005 Paris	France	May 29, 2021 21:30 to 22:30 Poster Hall - 3
Siddharatha Thakur	Magneto-optical imaging and manipulation of Abrikosov vortices trapped in high-Tc superconductor	1) Université de Bordeaux, LP2N, F-33405 Talence, France 2) Institut d'Optique & CNRS, LP2N, F-33405 Talence, France.	France	May 28, 2021 16:00 to 16:50 Poster Hall - 1
Simon Collienne	Nb-based nanoscale superconducting quantum interference devices tuned by electroannealing	Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, Sart Tilman, B-4000,Belgium	Belgium	May 31, 2021 16:00 to 16:50 Poster Hall - 2
Somesh Chandra Ganguli	Confinement-engineered superconductor to correlated-insulator transition in a van der Waals monolayer	Postdoctoral Researcher, Department of Applied PhysicsAalto University School of Science, NANO BUILDING N230aPuumiehenkuja 2. 02150 Espoo Finland	Finland	May 29, 2021 21:30 to 22:30 Poster Hall - 3

Taras Golod	Mechanisms of vortex-induced Josephson phase shift	Department of Physics, Stockholm University, AlbaNova University Center, SE-10691 Stockholm, Sweden	Sweden	June 1, 2021 16:00 to 16:50 Poster Hall - 3
Tianzhen Zhang	Observation of distinct spatial distributions of the zero- and non-zero energy vortex modes in (Li0.84Fe0.16)OHFeSe	State Key Laboratory of Surface Physics, Department of Physics, and Advanced Materials Laboratory, Fudan University, Shanghai 200438, China	China	May 29, 2021 16:00 to 16:60 Poster Hall - 3
Timothy Benseman	Intrinsic Josephson junction Bi2Sr2CaCu2O8 terahertz sources: Achieving high power output above 77 K	Department of Physics, CUNY Queens College 6530 Kissena Blvd. Queens, New York 11367	USA	June 1, 2021 21:30 to 22:30 Poster Hall - 4
Tsutomu Nojima	Vortex-Antivortex Dynamics beyond The BKT State in Ion-Gated MoS2	Institute for Materials Research, Tohoku University, 2-1-1Katahira, Aoba-ku, Sendai 980-8577	Japan	May 29, 2021 16:00 to 16:60 Poster Hall - 3
Vadim Plastovets	INTERPLAY BETWEEN KIBBLE-ZUREK MECHANISM AND INVERSE FARADAY EFFECT FOR ABRIKOSOV VORTEX GENERATION	University Bordeaux, LOMA UMR-CNRS 5798, 351 cours de la Libération, F-33405 Talence Cedex, France	France	May 29, 2021 21:30 to 22:30 Poster Hall - 2

VANDERHEYDEN Benoit	METAMORPHOSIS OF D-LINES AND RECTIFICATION OF MAGNETIC FLUX AVALANCHES IN THE PRESENCE OF NON-CENTROSYMMETRIC PINNING FORCES	Montefiore Research Unit, Department of Electrical Engineering and Computer Science, Université de Liège, 4000 Sart Tilman, Belgium	Belgium	May 28, 2021 16:00 to 16:50 Poster Hall - 1
Wei Xie	Magnetic Field Penetration and Magnetizations in Nb, N-doped Nb and NbTi Plates	National Laboratory of Solid State Microstructures and Department of Physics, Center for Superconducting Physics and Materials, Collaborative Innovation Center for Advanced Microstructures, Nanjing University, Nanjing 210093, China	China	May 29, 2021 16:00 to 16:60 Poster Hall - 4
Xiangyu Song	Critical current and magnetic interference effects in topological superconducting arrays of Nb islands coupled through Bi2Se3 epitaxial films	Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL, 61801, USA	United States	June 1, 2021 21:30 to 22:30 Poster Hall - 4

Yoichi Higashi	Microscopic theory for disorder and anisotropy enhanced superconductivity in atomic layer crystalline materials	Research Institute for Advanced Electronics and Photonics, National Institute of Advanced Industrial Science and Technology (AIST) Room# E312b, 2-1E Bldg. AIST Tsukuba Central 2 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan	Japan	May 29, 2021 16:00 to 16:60 Poster Hall - 4
Yusuke Masaki	Vortices in 3P2 Superfluid: Majorana fermion and non-Abelian half-quantum vortex	Department of Physics, Graduate School of Science, Tohoku University 6-3, Aramaki Aza-Aoba, Aoba-ku, Sendai 980-8578, JAPAN	Japan	May 29, 2021 16:00 to 16:60 Poster Hall - 1
Zhongtang Xu	Transport characterization and pinning analysis of BaFe1.9Ni0.1As2.05 thin films	No. 6 Beiertiao, Zhongguancun, Beijing	China	May 29, 2021 16:00 to 16:60 Poster Hall - 1

*You may use the resources given on our website (https://www.iitk.ac.in/vortex2021/program.html)

as well as other time zone converters available on the internet to convert the Indian time zones to your times. We also include a summary below.

Tokyo: 20:30 to 01:00   (IST + 3 hours 30 minutes)
Beijing : 19:30 - 00:00 (IST + 2 hours 30 mins)
India, IST: 17:00 to 21:30
UK : 12:30 to 17:00 (IST - 4 hour 30 minutes)
Brussels: 13:30 to 18:00 (IST - 3 hours 30 mins)
Paris: 13:30 to 18:00 (IST - 3 hours 30 mins)
Sweden: 13:30 to 18:00 (IST - 3 hours 30 mins)
Buenos Aires: 8:30 to 13:00 (IST - 8 hours 30 mins)
Rio de Janerio: 8:30 to 13:00 (IST - 8 hours 30 mins)
New York: 7:30 to 12:00 (IST - 9 hours 30 mins)
Indianapolis:7:30 to 12:00 (IST - 9 hours 30 mins)
Massachusetts:7:30 to 12:00 (IST - 9 hours 30 mins)
Chicago : 6:30 to 11:00 (IST - 10 hours 30 mins.)
Los Angeles/California: 4:30 to 9:00 (IST - 12 hours 30 mins)
New Mexico: 5:30 - 10:00 (IST - 11 hours 30 mins)

Invited Speaker Abstracts

New Paradigms in Driven Soft Matter: Instabilities, Rheo-chaos, Memory encoding and retrieval

A.K. Sood
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The flow behaviour of soft matter is rich and complex, showing shear-thinning, shear thickening, unsteady flows, rheo-chaos, random reorganization and reversibility to irreversibility phase transition, to name a few. This occurs primarily due to strong coupling of flow and internal reorganization of the soft matter in a synergistic manner. Fluids that show unsteady flow have S-shaped flow curve (shear stress vs shear rate) with an intermediate region of negative slope. This leads to heterogenous flow through formation of shear bands, a canonical example being shear thinning of wormlike micelles and associated time-dependent behaviour at fixed shear stress or shear rate (1).

This talk will present our recent work related to unsteady flow in shear-thickening suspensions of colloidal rods (2), statistical similarities between earthquakes and flow of soft solids below yield stress (3) and memory encoding and retrieval in amorphous bubble raft (4). In shear-thickening of colloidal rods suspension, we show that strong coupling between flow and particle orientational order results in rich time-dependent flow. Interestingly. Our recent work on the creep response of a nematic gel and colloidal glass below yield stress shows shear rate fluctuations showing large temporal bursts-like events similar to the seismograph data measuring the ground motion during earthquake avalanches. The statistical properties of the bursts map onto scaling relations for magnitude and frequency distribution of earthquakes given by Gutenberg-Richter and Omori laws. I will also present experiments showing single and multiple memories encoded in a soft glass of bubble rafts. The ability to form memories highlights the interplay between underlying reversibility-irreversibility transition and noise at a threshold strain amplitude.

All these experiments will showcase the new paradigms in nonequilibrium physics provided by soft matter under shear which can have parallel in the electrical current driven flow of vortices. Some of these have been explored in recent years in collaboration with the group of Prof Satyajit Banerji and Prof Arun Grover (5-6).

I thank my all co-authors who have travelled with me in our journey to explore the fascinating area of nonequilibrium physics of driven soft matter including vortex state in superconductors since 2000.

Reference:

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2. V. Rathee, Srishti Arora, Daniel Blair, Jeff S. Urbach, A.K. Sood and Rajesh Ganapathy, **Phys. Rev. E (Rapid Comm) 101, 040601(R)** (2020)
3. P.K. Bera, S. Majumdar, G. Ouillon, D. Sornette and A.K. Sood**, Nature Communications 11:9/DOI:10.1038/s41467-019-13790-2** (2020)
4. Srimayee Mukherji, Neelima Kandula, A.K. Sood and Rajesh Ganapathy, **Phys. Rev. Lett 122, 158001**(2019)
5. S. Mohan, J.Sinha, S.S. Banerjee, A.K.Sood, S.Ramakrishna and A.K.Grover, **Phys. Rev. Lett. 103,** 167001 (2009).
6. G. Shaw, P. Mandal, S.S. Banerjee, A. Niazi, A.K. Rastogi, A.K. Sood, S. Ramakrishnan and A.K. Grover, **Phys. Rev. B 85,** 174517 (2012).; Biplab Bag, Gorky Shaw, Satyajit Banerjee, Sayantan Majumdar, A.K. Sood and Arun Grover, **Scientific. Reports 7, 5531** (2017); Biplab Bag, Dibya Jyoti Sivanada, Pabitra ``Mandal, S.S. Banerjee, A.K. Sood and A.K. Grover, **Phys. Rev. B 97, 134510** (2018)

Direct Visualization of Current-Stimulated Oxygen Migration in $YBa_2Cu_3O_{7-\delta}$ Thin Films

A. V. Silhanek[1,+], S. Marinković[1], A. Fernández-Rodríguez[2], S. Collienne[1], S. Blanco Alvarez[1],S. Melinte[3], B. Maiorov[4], G. Rius[5], X. Granados[2], N. Mestres[2], A. Palau[2]

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[2]*Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Campus UAB, 08193 Barcelona, Spain.*

[3]*Institute of Information and Communication Technologies, Electronics and Applied Mathematics, Université catholique de Louvain, 1348 Louvain-la-Neuve, Belgium.*

[4]*Materials Physics and Applications Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, United States.*

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Keywords: Superconducting devices and applications.

The past years have witnessed major advancements in all-electrical doping control on cuprates. In the vast majority of cases, the tuning of charge carrier density has been achieved via electric field effect by means of either a ferroelectric polarization or using a dielectric or electrolyte gating. Unfortunately, these approaches are constrained to rather thin superconducting layers and require large electric fields in order to ensure sizable carrier modulations. In this work, we focus on the investigation of oxygen doping in an extended region through current-stimulated oxygen migration in $YBa_2Cu_3O_{7-\delta}$ superconducting bridges [1]. The underlying methodology is rather simple and avoids sophisticated nanofabrication process steps and complex electronics. A patterned multiterminal transport bridge configuration allows us to electrically assess the directional counterflow of oxygen atoms and vacancies. Importantly, the emerging propagating front of current-dependent doping δ is probed in situ by optical microscopy and scanning electron microscopy. The resulting imaging techniques, together with photo-induced conductivity and Raman scattering investigations, reveal an inhomogeneous oxygen vacancy distribution with a controllable propagation speed permitting us to estimate the oxygen diffusivity. These findings provide direct evidence that the microscopic mechanism at play in electrical doping of cuprates involves diffusion of oxygen atoms with the applied current. The resulting fine control of the oxygen content would permit a systematic study of complex phase diagrams and the design of electrically addressable devices.

Reference:

[1] S. Marinković *et al.* ACS Nano **14**, 11765 (2020)

SPONTANEOUS CURRENTS AND VORTEX GENERATION VIA THE SPIN-ORBIT MECHANISM AT S/F INTERFACES

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Keywords: Superconductivity in 2D and interface superconductivity; Vortices in meso- and nanoscale systems; Topological superconductors/ hybrids (FM-SC)/Semiconductor – SC.

Rashba spin-orbit coupling at the interface between a superconductor and a ferromagnet is at the origin of the unusual linear over the gradient of the superconducting order parameter term in the Ginzburg-Landau free energy [1]. This term modifies the expression for the superconducting current and results to the helical superconducting ground state. In the uniform system the spontaneous current in such a helical state is absent.

The situation drastically changes in the case of the non-uniform systems (where the spin-orbit coupling varies in space). We review the mechanisms of the spontaneous current generation and its distribution in these systems. The current-carrying states may appear close to a magnetic island on a thin-film superconductor [2] or near an S/F interface within a distance of the London penetration depth of the interface [3]. In thick superconducting films Rashba spin-orbit coupling at the S/F interface produces a spontaneous current in the atomic thickness region near the interface. This current is counterbalanced by the superconducting screening current flowing in the region of the width of the London penetration depth near the interface.

Another example of the spontaneous current generation is provided by a superconducting thin film in contact with a Néel skyrmion [4]. Here the skyrmion can create an Abrikosov vortex, provided the Rasbha coupling exceeds some relatively modest threshold value. The skyrmion occurs to be an effective pinning center for vortex and inversely the vortex can favor the skyrmion emergence. Spontaneous vortices in zero applied magnetic field can be also generated by a ferromagnetic strip on the top of a thin supercomputing film even for small spin-orbit coupling [5].

Finally, spontaneous currents emerge within a thin superconducting loop that is partially proximitized by a ferromagnet [6]. They provide sizable shifts in Little-Parks oscillations and made the critical temperature of the loop dependent on the orientation of magnetization.The superconducting region above the ferromagnet play a role of a “phase battery” and so offers a new device concept for superconducting spintronics.

References:

[1] V. M. Edelstein, J. Phys. : Condens. Matter **8**, 339 (1996).
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[5] L. A. Olde Olthof, X. Montiel, J. W. A. Robinson, and A. Buzdin, Phys. Rev. B **100**, 220505(R) (2019).
[6] J. W. A. Robinson, A. V. Samokhvalov, and A. I. Buzdin, Phys.Rev. B **99**, 180501(R) (2019).

Nonlinear dynamics of a vortex driven by a strong ac Meissner current

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Vortices in meso- and nanoscale systems; Vortex pinning and its applications.

I discuss the nonlinear dynamics of a perpendicular vortex driven by a strong ac Meissner current flowing parallel to the surface of a superconductor. This geometry enables one to probe new dynamic vortex states in which the tip of the vortex can move faster than the Meissner superflow which drives it, and the vortex drag decreases with the vortex velocity. I present results of numerical simulations, taking into account both the Bardeen-Stephen and the Larkin-Ovchinnikov velocity-dependent drag of a strongly driven elastic vortex interacting with various distributions of pinning centers in a film, where the effect of mesoscopic pinning fluctuations is essential. Calculations of the field-dependent surface resistance $R_i(H)$ show that $R_i(H)$ increases with the field amplitude H at low frequencies, but at higher frequencies $R_i(H)$ becomes a nonmonotonic function which decreases with H at strong fields [1].

Acknowledgements:

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Reference:

[1] W.P.M.R. Pathirana and A. Gurevich, Phys. Rev. B **101**, 064504 (2020).

Influence of correlated magnetic fluctuations on parameters of magnetic superconductors

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Keywords: 11. Topological superconductors/ hybrids (FM-SC)/Semiconductor - SC ; 13. Novel superconducting materials and heterostructures.

We consider a clean layered superconductor containing magnetic-moments sublattice in which a magnetic order establishes inside a superconducting state without destruction of superconductivity. We investigate the corrections to the superconducting gap and London penetration depth caused by the weak exchange interactions of Cooper pairs with correlated magnetic fluctuations [1]. The consideration is motivated by the physics of the iron pinictide $RbEuFe_4As_4$. The influence of nonuniform exchange field on superconducting parameters is very sensitive to the relation between the magnetic correlation length, ξ_h, and superconducting coherence length ξ_s defining the 'scattering' ($\xi_h < \xi_s$) and 'smooth' ($\xi_h > \xi_s$) regimes. We quantified this 'scattering-to-smooth' crossover for the case of quasi-two-dimensional magnetic fluctuations realized in $RbEuFe_4As_4$. In the 'scattering' regime, the suppression of superconductivity is similar to the case of magnetic impurities [2] and the exchange corrections are proportional to the magnetic scattering rate, which grows $\propto \xi_h$ until $\xi_h \ll \xi_s$. In the opposite limit, when ξ_h exceeds ξ_s, smoothening of spatial variations of the exchange field strongly diminishes its effect on superconducting parameters leading to much weaker dependence of the corrections on ξ_h. Moreover, the gap correction may even decrease with increasing of ξ_h in the immediate vicinity of the magnetic transition if it is located at a temperature much lower than the superconducting transition. The crossover between the regimes occurs to be unexpectedly broad: the scattering approximation becomes inaccurate already when ξ_h is substantially larger than ξ_s. We applied the developed theoretical framework to modelling the observed behaviour of the London penetration depth extracted from the vortex imaging in $RbEuFe_4As_4$ [3].

Acknowledgements: This work was supported by the US Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

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Dynamics of Andreev edge state at the interface of quantum Hall and superconductor

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Keywords: Andreev reflection, Andreev edge state, Graphene, Quantum Hall, Superconductivity, Shot noise

The existence of Andreev edge states (AESs) is one of the prerequisites to realize emergent excitations like Majorana fermion at the interface of normal or anomalous quantum Hall (QH) insulators and superconductor (SC). At a QH-SC interface the hybridized electron-hole states called AESs carry the current in the zero-bias limit, whereas normal quasi-particles carry the current when the bias energy is higher than the superconducting gap. Here, we report on measurements of both electrical conductance and shot noise in a graphene QH and SC interface at integer filling $\nu = 2$. Remarkably, the Fano factor of shot noise approaches to *half* when the bias energy is less than the superconducting gap (2Δ), whereas it is close to zero above the superconducting gap. This is striking, given that, at the same time the electrical conductance remains at $2e^2h$ within and above the superconducting gap. A quantized conductance is expected to produce zero-shot noise due to its dissipation-less flow. However, at a QH-SC interface, an equal mixing of electron and hole-like states produces *half* of the Poissonian shot noise with quantized conductance. The observed results are in accord with our detailed theoretical calculations of electrical conductance and shot noise based on non-equilibrium Green's function method in the presence of disorder. Our results will have immense significance in the search of exotic topological excitations in QH- superconductor hybrids, specifically using shot noise as a detecting tool.

Conference Topics:
11. Topological superconductors/ hybrids (FM-SC)/Semiconductor – SC

Imaging the drive current effect on the low-field vortex melting phenomenon in a $Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor

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Keywords: **1.** Vortex phase diagram; **2.** Vortex dynamics; **3.** Vortex imaging.

The vortex matter in type-II superconductors exhibits a diverse variety of equilibrium and non-equilibrium phases, which can be explored as a function of varying magnetic field (B), temperature (T), pinning, and current-drive (I). Here we investigate the effect of drive on an underlying equilibrium phase transitions, viz., the low field melting phase boundary, whose presence was first proposed theoretically [1]. Weak intervortex interactions at low fields result in thermal melting at low fields. Here a phase boundary separates a low field liquid phase and a denser solid phase at a higher field. Recently using a sensitive differential magneto-optical imaging technique, we have identified this low field phase boundary in a single crystal of $Ba_{0.6}K_{0.4}Fe_2As_2$ superconductor [2]. While the study of equilibrium vortex phases has been going on for a long, not much is known about how drive affects these equilibrium phase transitions. Using self-field differential magneto-optical imaging technique, we image the low field behavior of the vortex state in the presence of current I. Our study shows a current induced shift of the solid-liquid phase boundary, where the current prepones the vortex melting phenomenon compared to the equilibrium (I = 0 mA) situation [3]. With $I \neq 0$, the melting phenomenon is seen to begin at very low fields. Our analysis shows that the drive induced lowering of the low field vortex melting temperature occurs due to two effects. For $I \geq 50$ mA, Joule heating leads to a lowering of the dilute vortex melting temperature $T_m(I)$ w.r.t. to $T_m(I = 0)$. For $I < 50$ mA, we see a low dissipation regime wherein the shift in melting line is explained by incorporating effects of shaking temperature (T_{sh}) [3]. The concept of shaking temperature [4] is related to fluctuations in vortex velocity as vortices moving over a pinning landscape. These fluctuations appear like an effective '*shaking temperature* (T_{sh})' acting on the vortex lattice moving with velocity (v) [4]. We see the $T_{sh}(v)$ helps in explaining the I dependence of the vortex melting temperature (T_m). For large v, $T_{sh} \rightarrow 0$ and the moving phase freezes into a solid. We observe a transformation from inhomogeneous to homogeneous current flow in the sample which is reconciled via an inverse dependence of the shaking temperature on vortex velocity [3].

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Large Hall angle in the flux flow of high-T_c cuprate superconductors measured by microwave Hall effect

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Keywords: Microwave Hall effect, vortex solid phase, crossed cavity, cryogenic, flux-flow Hall effect

Flux flow is one of the most important phenomena directly related to the quasiparticle electronic state in the vortex core of superconductors. In some materials such as high-T_c cuprate superconductors, novel feature of quantum core has been observed by STM/STS technique. On the other hand, there has been a long-term puzzle that the electronic state of the quasiparticle in the vortex core extracted by the effective viscous drag coefficient measured by the microwave cavity perturbation technique is moderately clean for almost all superconductors[1], which does not agree with the picture obtained by STM/STS studies. To resolve that puzzle, we developed a novel cryogenic microwave Hall measurement system which can measure the Hall angle, tan θ [2], and investigated the Hall angle in two cuprate superconductors, YBCO and BSCCO whose equilibrium B-T phase diagram is rather different[3]. We found that the Hall angle is independent of the magnetic field and reaches an order of unity at low temperatures in BSCCO. However, in YBCO, the angle increases with increasing magnetic field even at low temperatures. We understood that this difference in the magnetic field dependence of the Hall angle is due to the difference in the influence of the pinning, which originated from the difference in the vortex state (liquid vs. solid) between the two materials. However, as a common feature, both materials showed a large tangent of the Hall angle at low temperatures, which was larger by an order of magnitude than those obtained in the effective viscous drag coefficient measurements[1]. We discussed the origin of the discrepancy both in terms of the possible nonlinearity of the viscous drag force and possible hidden dissipation mechanisms. The unexpectedly large Hall angle of the vortex motion in cuprates revealed in our flux-flow Hall effect study poses a serious question on the fundamental understanding of the motion of the quantized vortex in superconductors, and it deserves further investigation. We will also introduce the vortex Hall effect data of Fe chalcogenide superconductors which are other candidates of ultra-clean superconductors.

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Effect of dimensionality on vortex dynamics in type-II superconductor

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Keywords: Vortex phase diagram

The recent advent of two-dimensional materials has led to the discovery of materials with fascinating phases. In this talk, I will discuss the results of our investigations of electrical transport in superconducting regime - in a regime where the vortex dynamics in 2D superconductors is comparatively studied with 3D superconductors. We present affirmation for the existence of a vortex-solid/glass (periodic nature of vortices) to vortex-fluid transition in a conventional 2D type-II superconductor, NbN. The H–T phase diagram for the 2D and 3D superconductors are found to be significantly different near the transition temperature. We establish that this variation has its origin in the differing pinning properties in two different dimensions.

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Imaging the magnetic landscape in chiral superconductor candidate 4Hb-TaS_2

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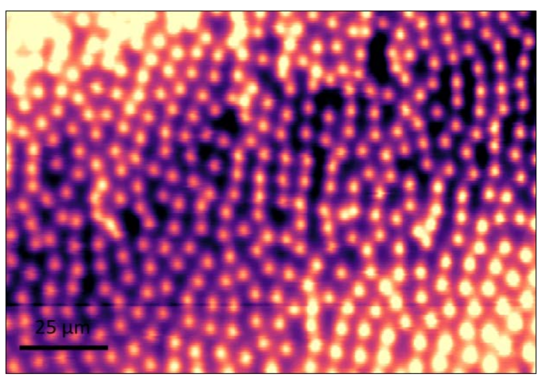
Keywords: Vortex imaging, Emergent flux patterns in novel superconductors, Multi-component superconductivity, Topological superconductors, Novel superconducting materials and heterostructures

A key signature of chiral superconductivity is spontaneous time-reversal symmetry (TRS) breaking, at the superconducting critical temperature. Although the broken TRS is expected to produce detectable magnetic fields at defects and edges, identification of candidate chiral superconductors has been challenging. A promising candidate system is 4Hb-TaS_2, where muon spin relaxation recently revealed time reversal symmetry breaking [1]. In my talk, I will discuss scanning SQUID microscopy measurements, revealing a delicate magnetic landscape below Tc. I will show how the magnetic signals depend on temperature and external fields. Our results can shed light on the elusive relationship between superconductivity and magnetism in this system.



Scanning SQUID image vortices in 4Hb-TaS_2 at 1.7K

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Superconducting Vortex Matter Under Extreme Confinement: The Effect Of Anisotropic Interaction

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Keywords: mesoscopic superconductors, anisotropic vortex-vortex interaction

Most novel superconductors are expected to show unconventional pairing and anisotropic vortex-vortex interaction. However, it is notoriously difficult to provide experimental evidence for an unconventional order parameter and the presence of anisotropic interaction. In this project we investigate superconducting vortex matter under the extreme confinement of nanoscale and mesoscopic samples. We calculate numerically the structure of Abrikosov vortices trapped in mesoscopic samples with a variety of rotational symmetry, such as triangles, squares, disks and other geometries. We use a combination of numerical techniques, such as energy landscape investigation via the eigenvector following method, and self-consistent numerical Ginzburg Landau calculations. We find that the interplay between sample geometry and vortex interaction anisotropy can qualitatively alter the structure of vortex matter under this extreme confinement regime. We argue that containers with low symmetries, in combination with experimental visualization of vortex matter in mesoscopic samples, either via Bitter decoration, or scanning probe (STM or scanning Hall) measurements can be used to detect the presence of interaction anisotropy and consequently unconventional pairing in novel superconductors.

VORTEX AND SKYRMION DYNAMICS ON MOIRE SUPERLATTICES

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Keywords: **7.** Vortex pinning and its applications; **15.** Skyrmions / Soft matter systems and similarities with vortex physics

We examine the pinning and flow of vortices in a type-II superconductor interacting with two triangular pinning lattices where one lattice is rotated with respect to the other so that the substrate forms a moire' pattern [1]. As a function of changing rotation angle, the pinning pattern passes through a series of magic angles in which the overall structure can be viewed as a combination of individual pinning sites and a superlattice of large scale pinning. The critical current shows a series of dips at these magic angles when the vortices form easy flow 1D channels. Additionally we find some angles which produce a peak in the critical current corresponding to where the pinning structure has a quasicrystalline structure which suppresses vortex channeling. We find that at the magic angles, the vortex motion develops a finite Hall angle due to a directional locking with the magic angle itself. We discuss how our results could also be relevant for the depinning of skyrmions [2] or Wigner crystals [3] on moire' patterns. In the case of skyrmions, additional locking steps can occur when the skyrmion Hall angle matches with the magic angle.

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Coupling Topological Solitons in Hybrid Quantum Materials

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Keywords: superconductivity, vortices, skyrmions, artificial hybrid materials.

We created artificial hybrid materials in which superconductivity and magnetism interact through their particle-like topological excitations. Nano-skyrmions inject flux tubes into superconductors, creating a bound pair of topological solitons. This flux is oriented antiparallel to the external magnetic field and hence forms antivortices, which modify the net magnetization of our materials and their flux dynamics in applied electric currents. We also detect signatures of circulating spin-polarized supercurrents. The antivortices facilitate flux motion across a complex magnetic landscape, in a manner analogous to electron tunnelling through potential barriers. The observed coupling of spin and flux topologies demonstrates the viability of such architectures for engineering nontrivial topology in quantum matter and a recipe to controllably create and study topological superconductivity.

Mysteries of Vortex Pinning In Nb47wt.%Ti

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Keywords: Nb-Ti, vortex pinning, dense proximity coupled systems, H_{c2}

Nb47wt% Ti is the world's standard superconductor, effectively optimized in the 1980s and now fabricated world wide. The basic recipe for optimization is to make a two-phase nanostructure of α-Ti ribbons 2-3 nm thick and many μm long, the α-Ti occupying about 20vol.% of the superconducting β-phase matrix. Strong vortex pinning ensues since the non-superconducting α-Ti in principle provides very dense pinning at the coherence length scale. But, actually ξ defined by H_{c2}(4.2K) is 5.3 nm, well above the optimum 2-3 nm nano-ribbon thickness, suggesting that the nanostructure should have homogenized, proximity-coupled properties. And indeed this is what T_c and H_{c2} measurements show: in spite of the precipitation of 20vol% α-Ti that drives the matrix β phase composition from its starting Nb47Ti to Nb36Ti, both T_c and H_{c2} remain very close to their starting single β phase values. ***In effect therefore all optimized Nb47Ti conductors are nanoscale heterogenous from a flux pinning perspective but homogeneous from an H_{c2} point of view, a most remarkable and fortuitous state of affairs for practical applications.*** We present here coupled measurements of H_{c2}, T_c, the pinning force curves from 2-9 K and some specific heat data to explore the evolution of the superfluid density in the system. Nanostructural examination shows that the α-Ti ribbons intercurl within their β-Nb-Ti matrix in such a way that they are proximity coupled to produce the undegraded H_{c2} and T_c of the original homogeneous alloy. Since the scale of the nanostructure is smaller than ξ, we must expect that there is a no longer a well defined Abrikosov vortex array in the system and that vortex pinning properties are highly sensitive to measurement temperature as we in fact find. It is a system in which measurements of the whole superconducting phase space can be made and the vortex pinning strength tuned from sparse to very dense. And it is by far the most widely used superconductor. Calculations of vortex pinning strength in real systems are becoming increasingly sophisticated and we here pose the question as to whether a new fundamental look at Nb-Ti is now appropriate.

CROSSOVER FROM FERROMAGNETIC SUPERCONDUCTOR TO SUPERCONDUCTING FERROMAGNET IN P-DOPED $EuFe_2(AsP)_2$

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Keywords: Vortex phase diagram, Vortex dynamics in bulk/nano/heterostructures/hybrids, Vortex imaging, Emergent flux patterns in unconventional SC or hydrids / novel HTSC superconductors.

In P-doped pnictide $EuFe_2(As_{1-x}P_x)_2$ superconductivity coexists with a ferromagnetism of Eu-4f spins. Above $x \approx 0.26$, superconductivity vanishes whereas ferromagnetism remains. We focus on the crossover region of the phase diagram and study two single crystals of the compound with $x = 0.21$ and $x = 0.25$; the superconducting critical temperature of the first one is slightly higher and of the second one is slightly lower than the Curie temperature. Despite similar compositions, characteristic temperatures and bulk magnetic properties, the local magnetic structures and superconducting vortex-antivortex phases of the two systems are found drastically different in the MFM experiments. We demonstrate that the interplay between superconductivity and magnetism is strongly dominated by the superconducting order in the first system, whereas it is mainly governed by ferromagnetism in the second one. Our discovery raises several fundamental questions on the vortex nucleation and dynamics in magnetic superconductors.

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Competing phases of correlated Chern insulators in Superconducting Twisted Bilayer Graphene

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Keywords: superconductivity in 2D Quantum materials and interfaces.

Flat-bands in magic angle twisted bilayer graphene (MATBG) have recently emerged as a rich platform to explore strong correlations, superconductivity and magnetism. Here we use magneto-transport and Hall measurements to reveal a rich sequence of wedge-like regions of quantized Hall conductance with Chern numbers C = ±1, ±2, ±3, ±4 which nucleate from integer fillings of the moiré unit cell $\nu = \pm3, \pm2, \pm1, 0$ correspondingly. We interpret these phases as spin and valley polarized many-body Chern insulators. The exact sequence and correspondence of Chern numbers and filling factors suggest that these states are driven directly by electronic interactions, which specifically break time-reversal symmetry in the system. In addition we observe correlated Chern insulator in zero magnetic field in hBN non-aligned MATBG, which manifests itself in an anomalous Hall effect around a filling of one electron per moiré unit cell n = +1 with a Chern number of C = 1 and has a relatively high Curie temperature of Tc ≈ 4.5 K. Slight gate tuning away from this state exposes strong superconducting phases with critical temperatures of up to Tc ≈ 3.5 K. In a perpendicular magnetic field above B > 0.5 T we observe a transition of the n = +1 Chern insulator from a Chern number C = -1 to a higher C = 3, which is characterized by a quantized Hall plateau with Ryx = h/3e2. These observations show that interaction-induced time-reversal symmetry breaking in MATBG leads to a zero-field ground state which consists of almost degenerate and closely competing Chern insulators, where the B-field always couples strongest to states with higher Chern numbers. Our study is also the first demonstration of a system which allows gate-induced transitions between magnetic and superconducting phases, and hence marks a major milestone in the creation of a new generation of quantum electronics.

SQUID-on-tip imaging of topological currents in magic-angle graphene

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Keywords: Superconducting devices and applications

Utilizing a scanning SQUID-on-tip, we develop a method for direct imaging of equilibrium currents flowing in the quantum Hall regime in graphene. We reveal that the edge states, which are commonly assumed to carry only a chiral downstream current, in fact carry a pair of counterpropagating currents, in which the topological downstream current in the incompressible region is counterbalanced by a non-topological upstream current flowing in the adjacent compressible region [1]. In twisted bilayer graphene, the emergence of flat bands and of strongly correlated and superconducting phases crucially depends on the interlayer twist angle upon approaching the magic angle. The scanning SQUID-on-tip provides a tomographic imaging of the Landau levels and renders nanoscale high precision maps of the twist-angle disorder in high quality hBN encapsulated devices, which reveal substantial twist-angle gradients and a network of jumps [2]. We show that the twist-angle gradients generate large gate-tunable in-plane electric fields, unscreened even in the metallic regions, which drastically alter the quantum Hall state by forming edge channels in the bulk of the samples. The correlated states are found to be particularly fragile with respect to twist-angle disorder. We establish the twist-angle disorder as a fundamentally new kind of disorder, which alters the local band structure and may significantly affect the correlated and superconducting states.

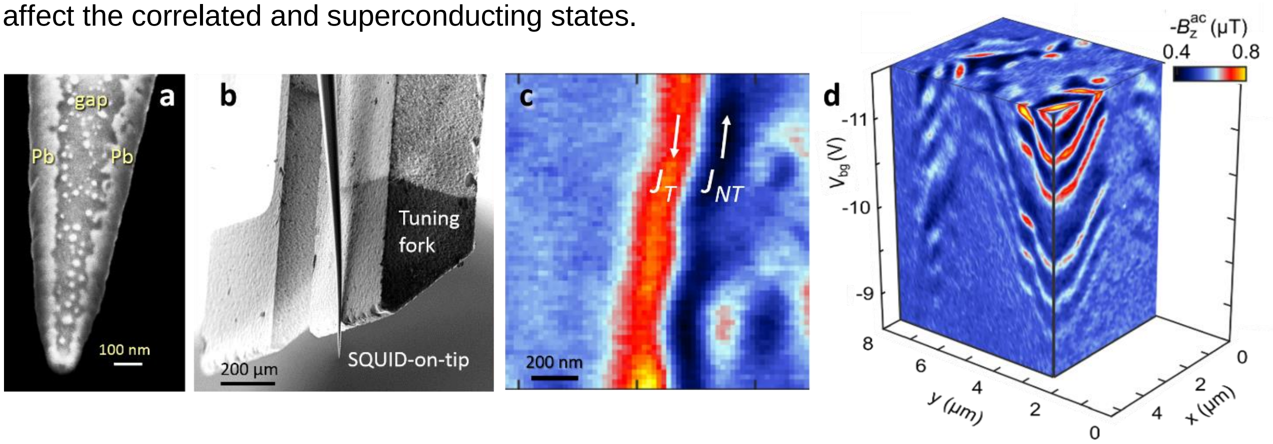

Fig. 1. (a) SEM image of a Pb SQUID-on-tip. (b) SQUID-on-tip attached to a quartz tuning fork for force sensing. (c) Direct imaging of the counterpropagating topological (red) and nontopological (dark blue) currents flowing in the quantum Hall edge state in graphene at 300 mK and 1 T magnetic field. (d) Tomographic imaging of the equilibrium currents and the Landau levels in magic angle graphene as a function of position and back gate voltage.

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RESHAPING THE PHASE DIAGRAM OF HTS BY nm THIN FILMS AND NANODEVICES

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Keywords: Superconductivity in 2D, vortices in meso and nanoscale systems.

The phase diagram of the high-Tc cuprate superconductors (HTS) is shaped by the spontaneous emergence of various ordered states, tuned by doping and driven by many competing degree of freedom. Here the ”strange normal metal phase” dominates the phase diagram and manifests in transport as a T-linear behaviour of the resistivity, at the optimal doping. It is confined by a mysterious doping and temperature dependent pseudogap regime, characterized by various local orders and symmetry breaking states of which *Charge Density Waves* is the most prominent. The local orders are intertwined in a complex way and the consequences of the local arrangements of charge and spin on the transport properties of HTS devices remain to be seen. Understanding the strange metal phase and how it is affected by the appearance of local orders is instrumental to disclose the mechanism for HTS:

We have developed YBCO nm thin films [1] and nanowires [2] where strain induced effects and reduced dimensionality allows to strongly modify the normal and superconducting state of the material. Using Resonant Inelastic X-ray Scattering we have discovered that the CDW is suppressed along the a-axis in nm YBCO thick films which has profound implications on the properties of nanodevices. We observe that a) the *T*-linear resistivity of underdoped nm thick YBCO films films is restored [3], b) that the superconducting temperature onset is enhanced along the a-axis where CDW is suppressed and c) that the dynamics of phase slips phenomenon in nanowires become very different along the a-axis and b-axis (where CDW is still present). These effects demonstrate how strain control and nanoscale dimentions allow to manipulate the ground state of HTS which is crucial to get novel insights into the mechanism for high critical temperature superconductivity .

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Tip-induced superconductivity

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Keywords: superconductivity, Topological materials, STM, Andreev reflection

It is widely believed that topological superconductivity, a hitherto elusive phase of quantum matter, can be achieved by inducing superconductivity in topological materials. In search of such topological superconductors, certain topological insulators (like, Bi_2Se_3) were successfully turned into superconductors by metal-ion (Cu, Pd, Sr, Nb etc.) intercalation. Superconductivity could be induced in topological materials through applying pressure as well. For example, a pressure-induced superconducting phase was found in the topological insulator Bi_2Se_3. However, in all such cases, no conclusive signature of topological superconductivity was found. In this talk, we will discuss about another novel way of inducing superconductivity in a non-superconducting topological material -- by creating a mesoscopic interface on the material with a non-superconducting, normal metallic tip where the mesoscopic interface becomes superconducting. Such a phase is now known as a tip-induced superconducting (TISC) phase. This was first seen in 2014 on Cd_3As_2 at IISER Mohali, India. Following that, a large number of other topological materials were shown to display TISC. Since the TISC phase emerges only at a confined region under a mesoscopic point contact, traditional bulk tools for characterizing superconductivity cannot be employed to detect/confirm such a phase. On the other hand, such a point contact geometry is ideal for probing the possible existence of a temperature and magnetic field dependent superconducting energy gap and a temperature and magnetic field dependent critical current. We will review the details of the experimental signatures that can be used to prove the existence of superconductivity even when the "text-book" tests for detecting superconductivity cannot be performed. Then, we will talk about various systems where a TISC phase could be realized.

Vortex and its bound states in a layered superconductor $KCa_2Fe_4As_4F_2$

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Keywords: Vortex imaging, Vortex matter vs. pairing symmetry, Multi-component superconductivity

Vortices are observed in a newly found iron based superconductor $KCa_2Fe_4As_4F_2$ through scanning tunneling microcopy. We further observe discrete vortex bound states with the energy levels deviating from the widely believed ratio of 1:3:5. Meanwhile Friedel oscillations of vortex bound states are also observed for the first time in related vortices. By doing self-consistent calculations of Bogoliubov-de Gennes equations, we find that at extreme quantum limit, the superconducting order parameter exhibits a Friedel-like oscillation, which modifies the energy levels of the vortex bound states and explains why it deviates from the ratio of 1:3:5. The observed Friedel oscillations of the bound states can also be roughly interpreted by the theoretical calculations, however some features at high energies could not be explained. We attribute this discrepancy to the high energy bound states with the influence of nearby impurities. We also observe a necklace-like vortex bound state which may be induced by a cooperative influence of the vortex confinement and quasi-particle interference. Our combined STM measurement and the self-consistent calculations illustrate a generalized feature of the vortex bound states in type-II superconductors.

In collaboration with H. Yang, X. Y. Chen, W. Du, X. W. Fan, K. L. Chen, W. S. Hong, H. Q. Luo and S. L. Li

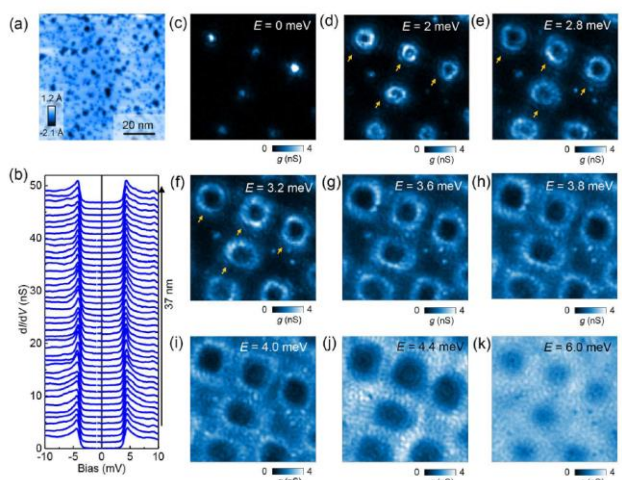

Figure 1. Topography, tunnelling spectra and vortex image in $KCa_2Fe_4As_4F_2$

Scanning tunnelling microscopy of bound states in superconductors

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Keywords: Vortex imaging, superconductivity in 2D and interface superconductivity, novel superconducting materials and heterostructures.

Scanning tunnelling microscopy measures the superconducting properties at atomic scale and is a useful tool to visualize the consequences of localized perturbations of the superconducting condensate. Such perturbations create bound states within the superconducting gap and are located at magnetic impurities (Yu-Shiba-Rusinov, YSR states) and at vortex cores (Caroli de Gennes Matricon, CdGM states). YSR states provide mixed electron-hole excitations which oscillate at the Fermi wavelength scale. CdGM in vortices are most often lying close together and their electron-hole asymmetry is difficult to observe. In this talk, I will discuss measurements that show vortices without axial electron-hole asymmetry due to the presence of magnetic impurities in 2H-$NbSe_2$ and in 2H-$NbSe_{1.8}S_{0.2}$. I will show that this asymmetry is the consequence of the coupling between YSR and CdGM bound states. The electron-hole asymmetric properties of YSR states are shown at much larger length scales within vortex cores[1]. Furthermore, I will present a detailed characterization of the influence of electron-hole asymmetry due to YSR states in 2H-$NbSe_{1.8}S_{0.2}$ and discuss new results on Josephson tunnelling spectroscopy.

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MAGNETIZATION SIGNATURE OF TOPOLOGICAL SURFACE STATES IN A NON-SYMMORPHIC SUPERCONDUCTOR

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Keywords: Novel superconducting materials and heterostructures. Multi-component superconductivity.

Superconductors with non-trivial band structure topology represent a class of materials with unconventional and potentially useful properties. Recent years have seen much success in creating artificial hybrid structures exhibiting main characteristics of two-dimensional (2D) topological superconductors. Yet, bulk materials known to combine inherent superconductivity with nontrivial topology remain relatively scarce, largely because distinguishing their central characteristic – topological surface states – proved challenging due to a dominant contribution from the superconducting bulk. We report a highly anomalous behaviour of surface superconductivity in topologically nontrivial 3D superconductor In_2Bi where the surface states result from its nontrivial band structure, which itself is a consequence of the non-symmorphic crystal symmetry and strong spin-orbit coupling [1,2]. In contrast to smoothly decreasing diamagnetic susceptibility above the bulk critical field H_{c2}, associated with surface superconductivity in conventional superconductors [3,4], we observe near-perfect, Meissner-like screening of low-frequency magnetic fields well above H_{c2}. The enhanced diamagnetism disappears at a new phase transition close to the critical field of surface superconductivity H_{c3}. Using theoretical modelling, we demonstrate that the anomalous screening arises from superconductivity of the topological surface states, as their contribution leads to a strongly reduced magnetic field sensitivity of the order parameter in the superconducting surface sheath. The demonstrated possibility to detect the surface states using macroscopic magnetization measurements provides an important new tool for discovery and identification of topological superconductors.

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Revisiting photodoping, photoconductivity and photosuperconductivity in the cuprates

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Keywords: electronic properties of superconducting cuprates, photoconductivity, .

It is well known that the electrical and superconducting properties of underdoped $YBa_2Cu_3O_{7-\delta}$ can be persistently modified upon illumination with visible or UV light. These so-called persistent photoconductivity (PPC) and photosuperconductivity (PPS) attracted a great deal of attention over three decades ago. Despite a significant amount of work, a clear picture of the governing microscopic mechanism did not emerge, leaving open an ongoing debate between theories based on doping due to photocarrier excitation and those based on doping by the photoinduced oxygen ordering in the crystal structure. Here we describe a series of transport experiments that compare PPS and PPC in oxygen depleted YBCO films and in YBCO films that present controlled disorder due to ion irradiation. We find that, contrary to as expected from earlier work, the photoinduced changes in Tc correlate with changes in the carrier mobility rather than with changes in the carrier concentration. Furthermore, we evidence that photodoping and photoinduced changes in the mobility are caused by different microscopic mechanisms, as proved by the striking observation that the relaxation of photoinduced changes of the carrier density and mobility occur over different temperatures and time scales. The results are consistent with the idea the idea that PPS is intimately connected with illumination induced structural changes. This is supported by preliminary resonant inelastic X-ray scattering experiments in the oxygen depleted set of samples.

* In collaboration with R. El Hage, V. Humbert, A Sander, S. Mesoraca, J. Briatico, J. Trastoy, A. Nicolau, N. Jaouen and J. Santamaría

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Giant fractional Shapiro steps in anisotropic Josephson junction arrays

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Josephson phenomena

The current phase relationship ($\mathrm{C\Phi R}$), describes the relation between the supercurrent, $\mathrm{I_s}$, through a Josephson junction (JJ) and the gauge invariant phase difference across the junction, $\Delta\theta$. The exact relation, is determined by the details of the Andreev bound state spectrum that exists in the junction. For conventional SIS junctions, the $\mathrm{C\Phi R}$ is sinusoidal, $\mathrm{I_s = I_c \sin(\Delta\theta)}$, where $\mathrm{I_c}$ is the junction critical current. With the advances in materials sciences and the realization of novel link materials, exhibiting non-conventional $\mathrm{C\Phi Rs}$, JJ with new functionalities arise.

The harmonic content of the $\mathrm{C\Phi R}$ in these novel weak link materials can be revealed by experiments relying on detecting the phase-locked response of a current driven Josephson junction when subjected to a high frequency radiation field of frequency, ν_{rf} [1]. In case the weak link is characterized by a conventional sinusoidal $\mathrm{C\Phi R}$, this resonant response manifests itself as constant voltage plateaus, so called Shapiro steps, in the VI-characteristics at voltages $\mathrm{V_n} = \mathrm{n}\,\Phi_0\nu_{\mathrm{rf}}$, where $\mathrm{n} \in \mathbb{Z}$ and Φ_0 the flux quantum. However, for a weak link having a non-sinusoidal $\mathrm{C\Phi R}$, the response exhibits, in addition to the conventional integer Shapiro steps, steps at fractional values $\mathrm{V_{n/q}} = (\mathrm{n/q})\,\Phi_0\nu_{\mathrm{rf}}$, where the $\mathrm{q^{th}}(\mathrm{q} \neq \mathrm{n})$ fractional step originates from the phase-locked response with the $\mathrm{q^{th}}$ harmonic of the $\mathrm{C\Phi R}$.

Despite the experimental accessibility of these techniques, the detailed interpretation of such experiments is complicated by the non-linear nature of the Josephson response. Moreover, the use of a single junction makes these experiments challenging mainly due to its low response. Josephson junction arrays (JJAs) containing many junctions provide the natural alternative to provide the necessary enhancement of the coherent response. We investigate the potential of anisotropic JJAs to study the harmonic content of the $\mathrm{C\Phi R}$ in a broad frequency range (down to 50 MHz). Introducing anisotropy results in a giant collective high frequency phase-locked response that reflects the properties of a single junction. We demonstrate the appearance of giant fractional Shapiro steps in anisotropic JJAs as unambiguous evidence of a skewed current phase relationship. This in contrast to prior observations of giant fractional Shapiro steps in JJAs as resulting from magnetic flux quantization in the two-dimensional array.

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QUANTUM CRITICALITY IN THE FIELD-INDUCED METALLIC STATE OF DISORDERED SUPERCONDUCTING THIN FILMS PROBED BY THERMOELECTRIC EFFECTS

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Keywords: Vortex phase diagram, Superconductivity in 2D and interface superconductivity

The field-induced superconductor-insulator transition (SIT) in disordered thin films is a typical example of a quantum phase transition (QPT). The SIT originates from the requirement that in two dimensions electrons should be localized at zero temperature (T = 0), otherwise condense. The quantum criticality of SIT has been demonstrated by a scaling analysis of resistance [1], and quite recently by thermoelectric Nernst signals [2]. Meanwhile, in some two-dimensional systems, including amorphous films [3], Josephson junction arrays [3], and recently-developed highly crystalline films [4], an emergence of the anomalous metallic state between the superconducting and insulating phases has been reported. The superconductor-metal-insulator transition (SMIT) cannot be explained by the QPT picture for SIT and its origin has not been fully revealed from resistance measurements. Therefore, it is necessary to uncover the role of quantum fluctuations and critical behavior associated with the SMIT.

In this talk, we present thermoelectric Nernst measurements down to 0.1 K for a 12 nm-thick amorphous Mo_xGe_{1-x} thin film, which shows the field-induced SMIT [5]. The Nernst signals in a superconductor originate from quasiparticles and fluctuations of the superconducting order parameter [6]. The quasiparticle contribution is negligible in amorphous samples because the mean free path of electrons is very short. Thus, the Nernst measurement is a sensitive tool to the superconducting fluctuations. Over the whole field range studied, the amplitude and phase fluctuations (vortex liquid) of the order parameter are clearly detected. As $T \to 0$, the field range where the vortex-liquid signals are observable shrinks but remains finite within the metallic state, indicating that the metallic state stems from a quantum vortex liquid (QVL). Moreover, the transport entropy in the vortex core decays slowly at $T \to 0$ in the QVL phase, which evokes the behavior of a quantum critical point. These results suggest that the metallic state results from broadening of the quantum critical point of SIT.

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DYNAMICAL SIGNATURES OF A FRAGILE GLASS TRANSITION IN THIN SUPERCONDUCTING FILMS

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Keywords: Vortex phase diagram. Superconductivity in 2D and interface superconductivity.

The vortex lattice in two-dimensional type II superconductor is a paradigmatic example of 2D solid, which is expected to melt in two dimensions via a BKT transition through an intermediate liquid phase which preserves orientational order. For vortex lattices it is named hexatic because of the hexagonal symmetry of the lattice. In a recent STS studies in amorphous MoGe[1] it has been shown that the hexatic state carries additional signatures in transport, with a rather strong suppression of the vortex diffusivity in the hexatic state as compared to the isotropic liquid. Here we use numerical simulations on the XY model in transverse field to study the dynamical behavior of the vortex lattice and to simultaneously characterize the solid phase via the superfluid stiffness. We show that, in analogy with previous work in soft colloids, a so-called heterogeneous dynamics emerges at the verge of the isotropic to the hexatic transition. In our case this manifest through a strong suppression of the diffusivity well reproduced by a Vogel-Fulcher-Tamman (VFT) law. The temperature T_0 where vortex diffusivity vanishes coincides with the temperature where a true solid phase is established, as characterized by a finite superfluid stiffness. These theoretical results are compared to recent magnetotransport measurements in thin MoGe films.

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Using vortex dynamics tools to explore magnetic configurations in non-superconducting materials

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Keywords: vortex-like dynamics in magnetic materials

The unexpected discovery of a very fast vortex dynamics in the oxide high T_c superconductors generated a huge amount of experimental and theoretical research, as the expert audience in this Workshop is very aware of. As a result, decades later we have developed a deep understanding of superconducting vortex matter. It is interesting to explore how this robust body of knowledge can help us to understand other physical phenomena. The purpose of this talk is to describe one such example.

The non-superconducting compound $Ca_3Co_2O_6$ has non-trivial magnetic ordering originating in its crystal structure. Due to the ferromagnetic coupling between Co atoms along the crystallographic c-axis, it forms spin chains along this direction. In ab-plane, however, these chains form triangular lattice which, in conjunction with the antiferromagnetic intra-chain interaction, produces geometric frustration. Seemingly simple, this structure gives rise to rich magnetic phenomena. We applied analytic tools, initially developed to study superconducting vortices, for examination of magnetic properties of $Ca_3Co_2O_6$. At low temperatures and for **H** parallel to the spin chains, the equilibrium state above a critical field H_c=3.6T is the fully aligned state characterized by a saturation magnetization M_{sat}. Below H_c, the ground state is the ordered state with two chains magnetized along **H** and one chain in the opposite direction, resulting in $M=M_{sat}/3$. However, isothermal M(H) curves exhibit a rich hysteretic behavior with steps that indicate the existence of low energy metastable configurations. In the lower (increasing H) branch of the M(H) loop, one step at $H<H_c$ has M higher than $M_{sat}/3$, showing that there is an energy barrier precluding the decay of the metastable state to the ground state. We investigated the time evolution of the magnetization, M(t), in the metastable states. The evolution is not exponential in time, consistent with interacting magnetic objects, and in extensive portions of the T-H diagram M(t) is accurately described by the logarithmic law typically observed in vortex dynamics. Long-term relaxation studies and Maley analysis show evidence of glassy dynamics. In some T-H conditions, M(t) evolves in the direction opposite to the equilibrium, hinting to the presence of hidden metastable configurations. In some cases, M(t) evolves non-monotonically, first increasing and then decreasing, as the hidden configuration in turn evolves towards equilibrium.

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Tuning and modification of superconductivity in a 2D high T_c superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$

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Keywords: $Bi_2Sr_2CaCu_2O_{8+\delta}$, high-temperature superconductors, superconducting CuO_2 planes, tuning of superconductivity, van der Waals materials

Starting with graphene, 2D materials have been of interest for electronics and optoelectronics. In the last few years, there is a renewed interest in topological and superconducting properties of 2D materials as the systems offer unique experimental knobs.

High-temperature superconductors are important for potential applications and for understanding the origin of strong correlations. $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO), a van der Waals high-temperature superconducting material (Tc of ~85 K), offers a platform to probe the physics down to a unit-cell. Modifying superconductivity in HTS locally, on a small length scale, is of immense interest for superconducting electronics. We develop a simple route to modify superconductivity locally by depositing metal on the surface of a few unit-cell thick BSCCO. This opens up avenues for new superconducting devices.[1]

I will present our efforts to make photo detectors using nanowires of BSCCO.

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Tuning of Composition - Temperature Phase Diagram of Iron-Based Superconductors by Disorder

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Keywords: Vortex matter vs. pairing symmetry.

Canonical composition – temperature phase diagram of 122 family of iron-based-superconductors (IBS) is composed by two phase transition lines, superconducting (SC) dome intersected by magnetic transition from paramagnetic to antiferromagnetic, spin density wave (SDW) phase. Both transition are sensitive to disorder and not universal [1]. Here we present the effect of point disorder consisted by vacancies introduced by irradiation with 2.5 MeV electrons of $Ba(FeAs_{1-x}P_x)_2$ crystals. Depression of critical temperature, T_c of optimally doped (x=0.33) is linear in function of dose and residual resistivity up to highest explored disorder range. T_c drops from initial value of 30K down to 6.7K without any sign of saturation. In the temperature interval corresponding to T_c depression, resistivity vs. temperature curve becomes non-linear, marking departure from non-Fermi liquid behaviour. SDW transition in underdoped crystals (x< 0.29) is also depressed by point disorder, but at higher rate than T_c. This open an unique opportunity to switch the ground state from antiferromagnetic (SDW) to paramagnetic by introduction of disorder in slightly underdoped material. Extension of SDW transition line in SC region is marked by sudden increase of critical current, possibly due to change in pinning of vortices with para- and antiferromagnetic cores

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JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN, 86, 083706 (2017)

PROXIMITY INDUCED SUPERCONDUCTIVITY IN MONOLAYER MoS_2

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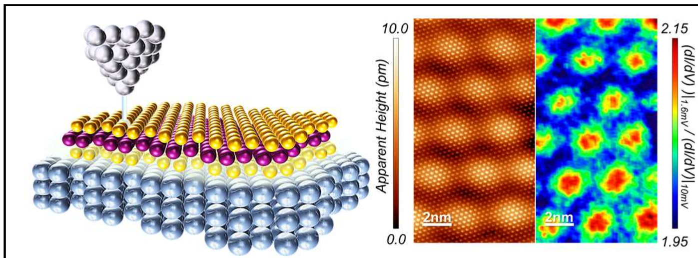

Figure Schematics of a monolayer MoS_2 on Pb probed by the STM tip (left). Topography and conductance map acquired at the energy corresponding to the coherence peak in the tunnelling spectrum (right).

Molybdenum disulphide (MoS_2) has emerged as a prototypical materials among the 2D transition metal dichalcogenides for its stability, low cost and unique electronic, optical and mechanical properties. Its electronic properties can be tuned using different control parameters. This great sensitivity presents an opportunity to functionalize its properties through defect engineering, strain or by proximity to another material. We use high resolution low temperature STM/STS to study the local electronic properties of monolayer MoS_2 and the proximity induced superconductivity in monolayer MoS_2 placed on top of a Pb this film. We find a coherence peak amplitude modulated spatially on the surface of MoS_2 [1]. Our study indicates that the local modulation of induced superconductivity in MoS_2 could be controlled via geometrically tuning. This study suggests that heterostructures based on MoS_2 offer a viable possibility to tune its electronic properties and open unprecedented possibilities of combining them for technological use.

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AN UNSTABLE GIANT VORTEX IN THE MESOSCOPIC TYPE I SUPERCONDUCTOR - THE SPIKE STATE

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Keywords: Vortex phase diagram, Vortex dynamics in bulk/nano/heterostructures/hybrids, Vortices in meso- and nanoscale systems

We study here the spike state, a giant vortex state found in mesoscopic type I superconductors whose existence is confined to the single applied field that marks the onset of the superconducting state from the normal state in descending field. The creation and the disappearance of this giant vortex define a finite lifetime obtained here using the time dependent Ginzburg-Landau (TDGL) equations and found to fall in the nanosecond regime. The spike state undergoes a process of deformation after its creation when several bubbles of vortices are expelled causing the order parameter to reorganize itself and form new but deformed giant vortices. The process lasts until there are no more vortices left in the superconductor. The spike state belongs to the family of non-equilibrium vortex states together with phase slip canters, phase-slip lines and kinematic vortices. The mesoscopic type-I superconductor possesses distinct κ regimes due to its richer critical field structure as compared to the macroscopic scale superconductor [1] and among them is the so-called genuine type I regime which features no vortices at all below the critical field that sets the onset and disappearance of the spike state.

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Advances in multiscale simulations of fluxonic devices

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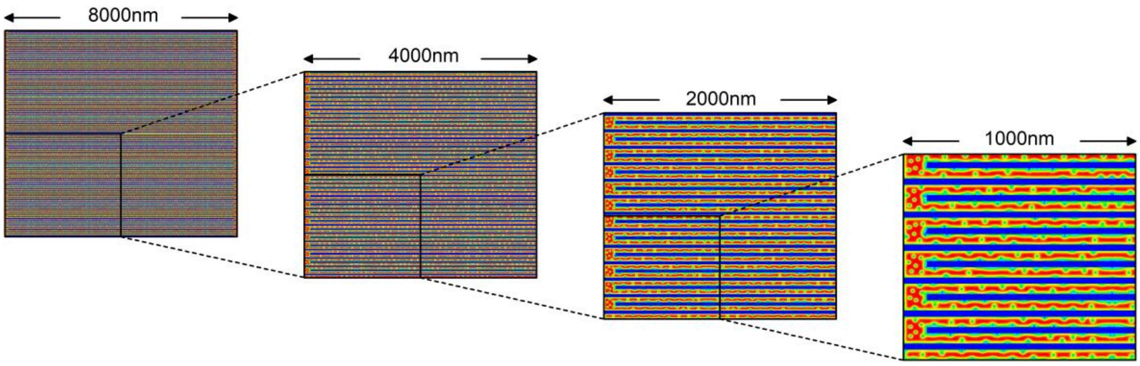
Keywords: fluxonics, superconducting electronics, multiscale simulations

At present, the only tool able to address the needed multi-scale modelling of nanopatterned superconducting circuitry are the advanced Ginzburg-Landau simulations. Such simulations can be rather precisely parametrized using *ab initio* or direct experimental input for the materials of interest, to nearly ideally capture the behavior of the sample in question in applied magnetic field and electric current.

In this talk, I will review our recent further breakthroughs in that respects, and show realized numerical experimentation on circuits of arbitrary shape (on advanced size and time scale), variable thickness, spatially-varied parameters, nanopatterning, coupling to an adjacent ferromagnetic layer (with magnetic domains, skyrmions, or magnons), with self-consistent account for magnetic field distribution, the electric field generated under applied current, incorporated heating effects, thus fully characterized behavior of the superconducting condensate in non-equilibrium conditions that reveals (often novel) physics behind improved or worsened performance of various realistic transport devices [1-5], all of relevance to the fast developing superconducting quantum technology and metrology.



Snapshot of the simulated vortex dynamics in a NbN superconducting meander of size and geometry as typically used for single-photon detection.

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LOCALIZED AND REVERSIBLE ORDERING AND DISORDERING OF THE VORTEX LATTICE IN UPt_3

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Keywords: Vortex phase diagram; Vortex imaging; Emergent flux patterns in unconventional SC; Vortex matter vs. pairing symmetry.

Understanding and controlling vortex matter is of both fundamental interest and practical importance. In an idealized scenario, vortices will arrange themselves in a perfectly ordered vortex lattice (VL) due to their mutual repulsion. In reality, however, thermal effects and/or pinning to material defects is always present, and the balance between these competing factors determines the structural and dynamic properties of vortex matter. This leads to a complex, high-dimensional phase diagram, where transitions between different states are driven not only by changes in intensive quantities, such as the field or temperature, but also the amount of imperfection or impurities which affect the vortex pinning.

Here we demonstrate a novel approach to structural studies of vortex matter whereby reversible quenched disorder can be introduced locally without permanently affecting the host superconducting material [1]. Specifically, we used small-angle neutron scattering (SANS) to study the VL in the topological superconductor UPt_3, which undergoes a gradual disordering on a time scale of tens of minutes as it is subjected to a beam of cold neutrons. The disordering is due to local heating events caused by neutron induced fission of ^{235}U, which leaves an increasing fraction of the sample in a quenched vortex glass state. The disordering rate is proportional to the vortex density, suggesting a direct relation to collective VL properties such as the elastic moduli. While the system does not spontaneously re-order once the local heating has been dissipated, it is possible to re-anneal the VL by the application of a damped field oscillation. This shows that no permanent radiation damage of the UPt_3 crystal occur within experimental time scales. Our results demonstrate a novel avenue for vortex matter studies, allowing an introduction of localized and reversible quenched disorder.

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Nonlinear THz electrodynamics of unconventional and disordered superconductors

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Keywords: Josephson Phenomena, Novel superconducting materials and heterostructures

I will discuss our recent results using the nonlinear THz response to probe fluctuating superconductors. In both cuprate systems and highly disordered NbN we observe a strong nonlinear response in their normal state that is completely unlike the response of normal metals. Nonlinear response is a sensitive probe of superconducting correlations and in this regard our results suggest the presence of superconducting fluctuations and correlations into parts of phase diagrams (with doping or disorder) that have not traditionally been considered. I will also discuss our application of the new technique of THz 2D coherent spectroscopy to get insight into these phenomena.

MICROWAVE STIMULATION OF SUPERCONDUCTIVITY IN THE VORTEX STATE

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids

It is well known that a sufficiently high-power electromagnetic field of GHz frequency can stimulate superconductivity [1] because of the irradiation-induced redistribution of quasiparticles away from the superconducting gap edge [2]. By contrast, the fast motion of large-current-driven Abrikosov vortices usually triggers a flux-flow instability (FFI) [3,4] because of a decrease in the number of quasiparticles in the vortex cores. Can one, however, make these phenomena competing? For low magnetic flux densities (small magnetic fields), we have revealed that a dynamical quenching of the vortex state in Nb thin films *can be advanced* or *delayed* (Fig. 1) by tuning the power and frequency of the *microwave ac stimulus added to a dc bias current* [5]. The experimental findings are supported by time-dependent Ginzburg-Landau simulations and they can be explained, qualitatively, based on a model of "breathing mobile hot spots", implying a competition of heating and cooling of quasiparticles along the trajectories of moving fluxons whose core sizes vary in time.

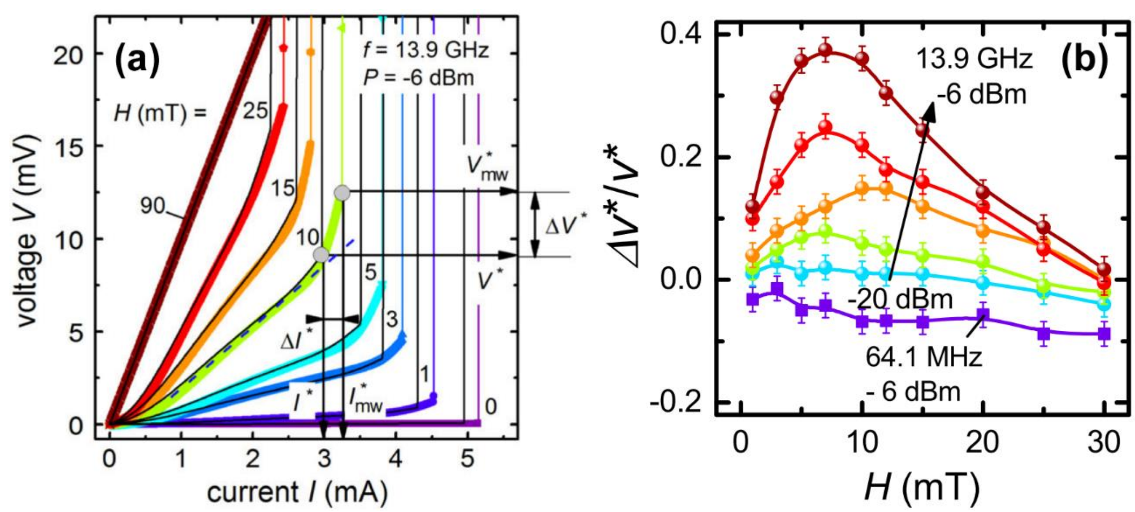

Fig. 1. (a) I-V curves of a Nb film at a $T = 0.988T_c$ in the unexcited state (solid lines) and in the presence of a rather high-power-level ac current (symbols). (b) Relative changes of the vortex velocity at the instability point for a series of microwave power levels at 13.9 GHz in comparison with the -6 dBm/64.1 MHz ac excitation.

This work was done in collaboration with C. González-Ruano, A. Lara, R. Sachser, V. M. Bevz, V. A. Shklovskij, A. I. Bezuglyj, R. V. Vovk, M. Huth, and F. G. Aliev

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Moiré Magic 3.0

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Keywords: superconductivity in 2D Quantum materials and interfaces.

Moiré superlattices have recently emerged as a novel platform where correlated physics and superconductivity can be studied with unprecedented tunability. Although correlated effects have been observed in several other moiré systems, magic-angle twisted bilayer graphene (MATBG) remains the only one where robust superconductivity has been reproducibly measured. In this talk I will present a new moiré superconductor, mirror symmetric magic-angle twisted trilayer graphene (MATTG) with dramatically richer tunability in electronic structure and superconducting properties. Hall effect and quantum oscillations measurements as a function of density and electric field allow us to determine the system's tunable phase boundaries in the normal state. Zero magnetic field resistivity measurements then reveal that the existence of superconductivity is intimately connected to the broken symmetry phase emerging at two carriers per moiré unit cell. Strikingly, we find that the superconducting phase gets suppressed and bounded at the van Hove singularities (vHs) partially surrounding the broken-symmetry phase, which is difficult to reconcile with weak-coupling BCS theory. Moreover, the extensive in situ tunability of our system allows us to achieve the ultra-strong coupling regime, characterized by a Ginzburg-Landau coherence length reaching the average inter-particle distance and very large T_BKT/T_F ratios in excess of 0.1. These observations suggest that MATTG can be electrically tuned close to the two-dimensional BCS-BEC crossover. In addition, I will present recent measurements of MATTG in the presence of an in-plane magnetic field, which show that MATTG violates the Pauli paramagnetic limit and exhibits re-entrant superconductivity at high field. These observations suggest that MATTG is likely a non-spin-singlet superconductor. Our results establish a new generation of tunable moiré superconductors with the potential to revolutionize our fundamental understanding and the applications of unconventional superconductivity.

Toward realization of novel superconductivity based on twisted van der Waals Josephson junction in cuprates

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Keywords: superconductivity in 2D Quantum materials and interfaces.

Engineering moire superlattices by twisting and stacking two layers of Van der Waals materials has proved to be an effective way to promote interaction effects and induce exotic phases of matter. The high-temperature superconductor $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) represents a prototypical cuprate superconductor, with weakly bonded van der Waals (vdW) layers. Using a novel cryogenic van der Waals pickup technique, we have fabricated Josephson junctions between two exfoliated Bi-2212 crystals with controlled relative twist angles. To preserve the air- and heat-sensitive Bi-2212 surface's integrity, we handled the devices entirely within argon or high-vacuum environment and kept the devices cold throughout the fabrication process. The resulting junctions support a Josephson critical current density of similar magnitude as the bulk c-axis intrinsic junctions and with Tc within a few Kelvin of the bulk value. With no need of a post-stacking anneal step, the interface shows minimal signs of surface degradation or reconstruction. The junctions' critical current evolves as expected for a d-wave superconductor. Our new fabrication methods open the possibility of creating arbitrarily complex, monolayer Bi-2212 heterostructures. I will discuss the most recent experimental results that hint novel superconducting states appeared at the twisted interface of cuprates vdW Josephson junctions.

Collective dynamics of driven colloids on ordered and disordered magnetic landscapes

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Keywords: Magnetic colloids, domain walls, transport on disordered systems.

In this talk I will discuss recent results obtained in my group by using paramagnetic colloidal particles driven across two dimensional periodic and random magnetic landscapes. These landscapes are generated by thin ferromagnetic films that provide an array of cylindrical ferromagnetic domains, also named “magnetic bubbles”. An external rotating magnetic field can modulate the periodic energy landscape and induce a directed particle transport via a travelling-wave like mechanism [1,2].

In the first part of the talk, I will show that when the particles are forced to cross a direction that intersect two crystallographic axes of the lattice, collective effects induce transversal current and directional locking at high density via a spontaneous symmetry breaking [3,4]. In the second part of the talk, I will explore the case of disordered systems, and the corresponding current density relationship. I will explain two novel effects. The first one originates from particle sizes nearly commensurate with the substrate in combination with attractive pair interactions that we explain by an exactly solvable model of constrained cluster dynamics. It governs the colloidal flow at small densities and leads to a superlinear current increase. The second effect is a defect-induced breakup of coherent cluster motion, leading to an effective jamming of particle flow at higher densities. Finally, I will show that a lattice gas model with parallel update is able to capture the experimental findings of this complex manybody system.

Acknowledgements: P. T. acknowledges support from the ERC Consolidator Grant "ENFORCE" (No. 811234) and from the Generalitat de Catalunya under program "Icrea Academia"

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Long-range connectivity in superconducting qubits using a ring resonator

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Keywords: superconducting qubits, quantum computing

Qubit coherence and gate fidelity are typically considered the two most important metrics for characterizing a quantum processor. An equally important metric is inter-qubit connectivity as it minimizes gate count and allows implementing algorithms efficiently with reduced error. However, inter-qubit connectivity in superconducting processors tends to be limited to nearest neighbour due to practical constraints in the physical realization. In this talk, I will introduce a novel superconducting architecture that uses a ring resonator as a multi-path coupling element with the qubits uniformly distributed throughout its circumference. This enables long range connectivity between qubits while maintaining physical separation between them, leading to negligible qubit cross-talk. Our planar design provides significant enhancement in connectivity over state of the art superconducting processors without any additional fabrication complexity. I will discuss the basic theory of the ring resonator based coupler and present experimental results from a device capable of supporting up to twelve qubits where each qubit can be connected to nine other qubits. Our concept is scalable, adaptable to other platforms and has the potential to significantly accelerate progress in quantum computing, annealing, simulations and error correction.

Time Reversal Symmetry Breaking in Noncentrosymmetric Superconductors

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Keywords: Time Reversal Symmetry, Noncentrosymmetric, Unconventional Superconductors

The symmetry of a material plays a fundamental role in determining its physical properties. Symmetry breaking can modify the physics of a system and produce new and unusual behaviour. Superconductivity is one of the best examples of a symmetry-breaking phenomenon. In conventional superconductors, gauge symmetry is broken, while in unconventional superconductors, other symmetries may also be broken. Recently noncentrosymmetric superconductors emerged as a prime candidate to exhibit time-reversal symmetry breaking due to mixed spin-single and spin-triplet state. In this talk, I present recent results on time-reversal symmetry breaking in superconducting hexagonal noncentrosymmetric compounds.

Conference Topics: Novel superconducting materials and heterostructures

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Temperature-dependent anisotropy of London penetration depth in single- and two-band superconductors

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Keywords: 10. Multi-component superconductivity

Temperature-dependent anisotropy, $\gamma_\lambda(T) \equiv \lambda_c(T)/\lambda_{ab}(T)$, of the London penetration depth, λ, is often considered as a hallmark of multi-gap superconductivity [1,2]. Similarly, a larger than 1.763 value of the measured $\Delta(0)/k_B T_c$ ratio is often considered to be the signature of the strong coupling. Here we use weak-coupling self-consistent theory applied to several types of the order parameter and show that $\gamma_\lambda(T)$ can be temperature-dependent and can both decrease or increase, and be non-monotonic as a function of temperature, even for a single gap on a spherical (cylindrical) Fermi surface. On the other hand, if observed, temperature-dependent $\gamma_\lambda(T)$ imposes certain restrictions on the possible order parameter structure, $\Delta(T,\varphi,\theta)$. For example, pure *d*−wave order parameter results in temperature-independent $\gamma_\lambda(T)$ even on anisotropic Fermi surface, whereas Maki's $s+g$ order parameter leads to a non-monotonic variation of $\gamma_\lambda(T)$ [2]. For two-band systems, the behavior of anisotropy is affected by the ratios of bands partial densities of states, Fermi velocities, anisotropies, and the structure of the order parameters [1]. For all considered order parameters the self-consistency equation was solved the obtained $\Delta(0,\varphi,\theta)/k_B T_c$ ratios will be discussed with respect to the isotropic s-wave value [2]. Finally, the method for the experimental evaluation of $\gamma_\lambda(T)$ from the small-amplitude AC susceptibility in realistic cuboidal samples will conclude the discussion.

Acknowledgements: This work was supported by the US Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

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Fulde-Ferrell-Larkin-Ovchinnikov States in the BCS-BEC-Crossover Superconductor FeSe

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Keywords: Fulde-Ferrell-Larkin-Ovchinnikov State, BCS-BEC crossover, Iron-based superconductors

The iron-chalcogenide FeSe is argued as a strong candidate superconductor located in the crossover regime between the weakly coupled BCS and the strongly coupled BEC limits [1,2]. Its extremely small and shallow Fermi pockets, large superconducting gap, and consequently a large Maki parameter suggest that FeSe offers an ideal platform to study the potential Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) superconducting state, in which a new pairing ($\boldsymbol{k}$, -$\boldsymbol{k}$+$\boldsymbol{q}$) with nonzero q is formed. Here, we present several pieces of evidence for the emergence of distinct high-field superconducting phases in FeSe. For $\boldsymbol{H}$ || *ab*, our state-of-the-art high-field thermal transport up to 33 T shows a discontinuous downward jump within the superconducting state, indicating a first-order phase transition to a distinct high-field superconducting phase [3]. For $\boldsymbol{H}$ || *c*, the presence of a high-field phase is shown by an anomalous kink of the heat capacity, which occurs well below the irreversibility field. We attribute these high-field superconducting phases to the FFLOsuperconducting states. We also point out the importance of the multi-band nature and the orbital dependent pairing for the formation of the FFLO phase in FeSe.

This work has been done in collaboration with Y. Sato, Y. Suzuki, Y. Masuda (Kyoto Univ.), T. Shibauchi (Univ. of Tokyo), T. Hanaguri, T. Machida (RIKEN), S. Licciardello, M. Čulo, N. E. Hussey (Radboud Univ. and HFML Nijmegen), S. Arsenijević, J. Wosnitza (HZDR), J. Böker, I. Eremin (Ruhr-Universität Bochum).

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Imaging the Suppression of Superconductivity by Correlated Magnetic Fluctuations in $RbEuFe_4As_4$

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Keywords: Vortex imaging; Novel superconducting materials and heterostructures.

The possible coexistence of superconductivity and magnetism has fascinated scientists for many decades and remains to be fully understood. Here we use quantitative vortex imaging to investigate the unusual interaction between the magnetic and superconducting sublattices in the iron-based superconductor, $RbEuFe_4As_4$, which becomes superconducting below T_c~37K and exhibits an additional magnetic ordering transition at T_m~15K [1]. Previous optical conductivity [2] and angle resolved photoemission spectroscopy [3] measurements on this material have suggested a nearly complete separation of the two sublattices. In contrast our scanning Hall microscopy images of vortices reveal a substantial increase in the penetration depth near the magnetic ordering temperature, T_m, followed by a gradual reduction at lower temperatures (c.f., Fig. 1), indicating that the magnetic order leads to a significant reduction in the superfluid density. Our observations are compared with a recently-developed model of the suppression of superconductivity by correlated magnetic fluctuations [4]. Based on the qualitative agreement between the model and our data, we infer that the coupling between the Eu moments and Cooper pairs is weak enough that superconductivity is never completely destroyed, yet still strong enough to noticeably impact the superconducting parameters. Our results should have important implications for understanding coexistence phenomena in other materials systems.

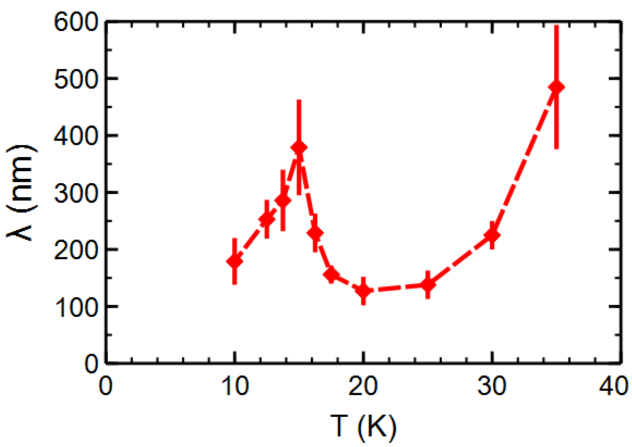

Fig. 1 Plot of λ(T) extracted from vortex fits.

Acknowledgements:

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Observation of two-dimensional melting and zero-point fluctuation of vortices in a very weakly pinned a-MoGe thin film

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Keywords: Vortex, BKTHNY melting, Hexatic fluid, Quantum zero-point fluctuation, Scanning tunnelling spectroscopy (STS).

Recently, we have shown that the vortex lattice melts in two steps with increasing magnetic field using scanning tunnelling spectroscopy (STS) in a weakly pinned amorphous MoGe thin film (conventional S-wave superconductor) [1]. First, vortex solid transforms into hexatic fluid and then hexatic fluid turns into isotropic vortex liquid. Our observed melting process qualitatively agrees with BKTHNY melting. Another interesting aspect of the vortex state is that the observation of a soft gap in the tunnelling conductance inside the vortex core. This observation contradicts the usual picture of the vortex core of a conventional type II superconductor where the tunnelling conductance inside the vortex core remains either flat or exhibits a zero-bias peak (for a very clean crystal) due to the formation of Caroli-De Gennes-Matricon bound state. We ascribe this observation to rapid fluctuation of vortices about their mean position that blurs the boundary between the gapless normal core and gapped superconducting region outside. Through a detailed theoretical analysis, we show that the variation of fluctuation amplitude as a function of magnetic field is consistent with the quantum zero-point motion of vortices [2].

Acknowledgements:

SD and IR performed the STS measurements and analysed the data. JJ optimized deposition conditions and synthesized the samples. The theoretical analysis was carried out by SD, SS and PR. PR conceived the problem, supervised the experiments.

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High-field superconducting phase in FeSe investigated by spectroscopic-imaging scanning tunneling microscopy

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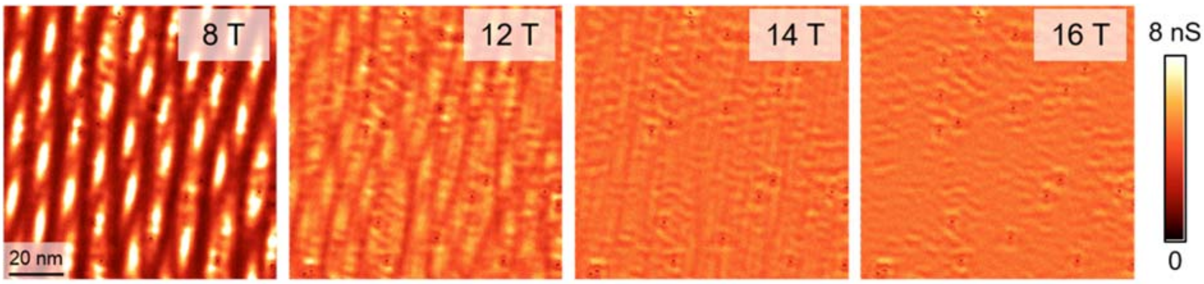
Keywords: Vortex imaging;

The Fermi surface of iron-based superconductor FeSe consists of hole and electron pockets, which have very small Fermi energies comparable to the superconducting gap amplitude. This is the situation where the so-called Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state with Copper pairing at finite total momentum **q** is expected near the upper critical field and at low temperatures. In FeSe, magnetic-field dependence of thermal conductivity exhibits an anomaly below the upper critical field, which is argued as a signature of the transition from the low-field normal vortex state to the high-field FFLO state [1,2]. However, modulation of the superconducting gap expected from finite-**q** pairing has been elusive. We performed high-field spectroscopic-imaging scanning tunneling microscopy (SI-STM) at an ultra-low temperature below 90 mK to investigate the change in the electronic state across the phase boundary. We applied magnetic fields perpendicular to the *ab* plane imaged by SI-STM. The vortex image diminishes at 14.5 T where the thermal conductivity shows an anomaly. Even though bulk superconductivity survives up to 16.5 T, no signature of superconductivity is observed above 14.5 T. This result indicates that the superconducting gap diminishes at the surface and suggests that the nodal plane of the putative FFLO state is pinned at the surface.



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Destruction of a sign-changing order parameter by artificial atomic defects in multiband superconductor $PrOs_4Sb_{12}$

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Keywords: Multi-component superconductivity; Topological superconductors;

Chiral superconductivity is a highly interesting and long-sought unconventional state of matter that spontaneously breaks time-reversal symmetry through the development of Cooper pairing with finite angular momentum. Chiral superconductivity is a type of topological state which provides a natural platform for realizing Majorana edge modes being central to various proposals for quantum computation. However, despite intensive theoretical studies and huge experimental efforts, no material has been proven definitively to be a chiral superconductor.

The heavy-fermion and multiband superconductor $PrOs_4Sb_{12}$, for which a *μ*SR study and polar Kerr effect measurements showed evidence of broken time-reversal symmetry below the critical temperature $T_c \simeq 1.85$ K, is a leading candidate to display chiral superconductivity. Based on measurements of the temperature dependence of the lower critical field $H_{c1}(T)$, we have recently proposed a multiband and multisymmetric scenario, in which a superconducting condensate is composed of a sign-changing smaller gap and a large isotropic *s*-wave gap [1].

To develop a detailed understanding of multicomponent superconductivity in $PrOs_4Sb_{12}$, we have extended measurements of $H_{c1}(T)$ down to temperatures as low as 7 mK utilizing a 2DEG Hall magnetometry. We observe a sudden increase in $H_{c1}(T)$ deep in a superconducting state, indicative of a rare case of two nearly decoupled bands. Furthermore, a non-saturating and concave behavior of $H_{c1}(T)$ below about 0.45 K, clearly points at a sing-changing symmetry of the smaller gap. Equally remarkable is a high sensitivity of this characteristic to electron irradiation. Indeed, even small concentration of artificial atomic defects apparently destroys a sing-changing order parameter, as evidenced from both a saturated dependence of $H_{c1}(T)$ and a strong suppression of its enhancement. In addition to this, a possible theoretical description and results of a comparative study on the two-band isotropic *s*-wave homologue $LaRu_4As_{12}$ will be discussed in the context of a putative chiral spin-triplet pairing state in $PrOs_4Sb_{12}$.

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IMPACTS OF DEFECTS ON THE PEAK EFFECT IN $NbSe_2$

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Keywords: $NbSe_2$, Peak effect, Artificial defects, Vortex pinning

Anomalous increases in the critical current density (J_c) as a function of magnetic field, called peak effects, are observed in various kinds of superconductors. In a canonical layered superconductor $NbSe_2$, it has been known that a distinct peak effect appears close to the upper critical field, H_{c2}. It has been interpreted that the peak effect is caused by softening of vortex lattice near H_{c2} [1], but now it is understood that the peak effect is caused by order-disorder transition of vortices. In this talk we report the impacts of defects on the peak effect in $NbSe_2$. Defects are introduced either chemically by Co-substitution or physically by irradiations of energetic particles, such as protons and heavy-ions. We used 3 MeV protons, 320 MeV Au, 800 MeV Xe, and 2.6 GeV U to create physical defects.

It was clarified that both Co-doping and proton irradiation enhance the peak effect and make the peak field lower, possibly due to the introduction of point defects (PDs). Obviously, the peak effect in these cases are natural continuation of the order-disorder transition observed in the pristine or weakly-disordered $NbSe_2$. Actually, even after the introduction of defects, first-order nature of the transition remains. On the other hand, in the case of heavy-ion irradiation, depending on the configuration of columnar defects (CDs), a new kind of peak effect appears at low fields [3,4]. In the case of CDs parallel to the *c*-axis, only the enhancement of J_c occurs without the peak effect [5]. On the other hand, in the case of tilted [3,4] and splayed CDs [4], peak effects appear above some B_Φ at fields below 1 T. The peak field increases at small B_Φ and shows a tendency of saturation beyond $B_\Phi \sim 4$ T. Judging from the B_Φ dependence of the peak field, origins of the peak effects induced by PDs and CDs are different. Through systematic measurements of $J_c - H$ characteristics in $NbSe_2$ with different configuration (direction) and density of CDs, we discuss the origin of the low-field peak effect in $NbSe_2$.

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Superconductivity and Magnetism in $RbEuFe_4As_4$

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Keywords: Novel superconducting materials and heterostructures; Topological superconductors/ hybrids (FM-SC)/Semiconductor – SC; Vortex dynamics in bulk/nano/heterostructures/hybrids

$RbEuFe_4As_4$ is a recently discovered [1-3] member of the so-called 1144 family [4] of Fe-based superconductors in which superconductivity and magnetism coexist at remarkably high temperatures enabling the study of the interplay of these ordered ground states in great detail. A mean-field like step in the specific heat at 37 K and a non-singular cusp at 15 K mark the superconducting and magnetic transitions. Field-dependent measurements near T_c yield steep upper critical field curves with surprisingly low anisotropy of 1.8. On increasing field, deviations from linearity arise as manifestation of the coupling of superconductivity to Eu-paramagnetism. Measurements in pulsed fields up to 65 T show clear signatures of paramagnetic limiting with $H_{c2}(0) \sim 80$ T [5]. At 15 K, the Eu-magnetic moments order into a helical antiferromagnetic state in which neighboring ferromagnetic Eu-layers twist by 90 degrees. Such magnetic structure can be accounted for in a model of competing superconducting and ferromagnetic interactions [6]. Furthermore, this structure may induce topological surface states on the c-axis surfaces. The large magnetization associated with the ordered Eu-moments induces vortices at the sample surfaces, leading to a self-induced critical state with highly inhomogeneous internal fields [7].

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Creep effects on the Campbell response in type II superconductors

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Keywords: **1.** Vortex phase diagram; **2.** Vortex dynamics in bulk/nano/heterostructures/hybrids; **7.** Vortex pinning and its applications

Within the strong pinning formalism, we study the effect of thermal fluctuations (creep) [1] on the penetration of an ac magnetic field into the mixed state of a type II superconductor (Campbell length) [2|. We find that the evolution of the Campbell length $\lambda_C(t)$ is the result of two competing effects, the change in the force jumps $\Delta f_{pin}(t)$ and, furthermore, a change in the trapping area $S_{trap}(t)$ of vortices; the latter describes the area around the defect where a nearby vortex gets trapped. Contrary to naive expectation, we find that in the relaxing critical state (ZFC) the Campbell length $\lambda_C(t)$ always first increases with time t and starts decreasing for long waiting times, predominantly for very strong pinning. The relative change of the Campbell length during relaxation is parametrically smaller than that of the persistent current. Above the irreversibility line where thermal equilibrium is reached and the magnetisation vanishes, the Campbell length remains constant and is not much different from the one without relaxation. Finally, measuring the Campbell length λ_C for different states, zero field cooled, field cooled, and relaxed, as a function of different waiting times at different temperatures allows to 'spectroscopyse' the pinning potential of the defects.

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SUPERCONDUCTING SENSORS: FROM BASIC PHYSICS TO LARGE SCALE SCIENCE EXPERIMENTS

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Keywords: Transition edge sensors, superconducting resonators, superconducting nanowire single photon detectors

Superconducting sensors and detectors are a rapidly growing field in superconductivity. They play an essential role in a wide range of research and development areas where high sensitivity, detection, and manipulation with a small number of photons is crucial.

In this presentation, we will discuss the work at Argonne toward the development of superconducting devices, including Transition Edge Sensors for ground-based Cosmic Microwave Background studies [1] and bolometric detection of neutrinoless double-beta decay events [2], low-loss resonators for Quantum Information Science [3, 4], and superconducting nanowires as particle detectors [5]. We will overview basic concepts of these devices and will touch on some aspects and challenges of their fabrication and related thin film materials science and engineering [6,7].

The work at Argonne National Laboratory, including the use of the facilities at the Center for Nanoscale Materials, was supported by the US Department of Energy, Office of Science, and Office of Basic Energy Sciences under Contract No. DE-AC02-06CH11357 and Office of Nuclear Physics under Contract No. DE-FG02-08ER41551.

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TOPOLOGICAL NATURE OF HIGH TEMPERATURE SUPERCONDUCTIVITY

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Keywords: Topological superconductivity; High-Tc; Pseudogap state; Superconductor-insulator quantum phase transition. Topic: **11.** Topological superconductors/ hybrids (FM-SC)/Semiconductor - SC

The key to unraveling the nature of high-temperature superconductivity (HTS) lies in resolving the enigma of the pseudogap state. The pseudogap state in the underdoped region is a distinct thermodynamic phase characterized by nematicity, temperature-quadratic resistive behavior, and magnetoelectric effects. Till present, a general description of the observed universal features of the pseudogap phase and their connection with HTS is lacking. The proposed work constructs a unifying effective field theory capturing all universal characteristics of HTS materials and explaining the observed phase diagram. The pseudogap state is established to be a phase where a charged magnetic monopole condensate confines Cooper pairs to form an oblique version of a superinsulator. The HTS phase diagram is dominated by a tricritical point at which the first order transition between a fundamental Cooper pair condensate and a charged magnetic monopole condensate merges with the continuous superconductor-normal metal and superconductor-pseudogap state phase transitions. The universality of the HTS phase diagram reflects a unique topological mechanism of competition between the magnetic monopole condensate, inherent to antiferromagnetic-order-induced Mott insulators and the Cooper pair condensate. The obtained results establish the topological nature of the HTS and provide a platform for devising materials with the enhanced superconducting transition temperature.

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Low dissipative Josephson vortex dynamics

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Keywords: superconductivity, Josephson vortex.

Josephson vortices play an important role in superconducting devices in quantum electronics. Often viewed as purely conceptual topological objects, 2π-phase singularities are difficult to observe and manipulate. We show that in planar Superconductor-Normal metal-Superconductor Josephson junctions, Josephson vortices have a specific magnetic imprint that we find by magnetic force microscopy (MFM) experiments. Based on this discovery, we demonstrate the ability to generate and manipulate a Josephson vortex with an MFM magnetic tip, thereby paving the way for remote monitoring and control of individual nanocomponents in superconducting quantum circuits.

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VORTEX-BASED ELECTRONICS

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Keywords: Superconducting devices and applications, Vortices in meso- and nanoscale systems, Josephson phenomena,

Superconducting electronics usually operates with the phases of wave functions of the superconducting condensate. Abrikosov vortex is a robust topological object in a superconductor with a 2π phase rotation. This phase rotation can induce a Josephson phase shift in nearby Josephson junctions [1] and devices. Since the Abrikosov vortex represents the most compact magnetic object in superconductors with the size ~100 nm, it facilitates significant variation of the induced phase shift by nanoscale manipulation of the vortex. Whence, the vortex may be used for creation of compact superconducting devices both for classical (digital) and quantum electronics. In this talk I will describe recent development of two types of devices: a vortex-based memory [2] and a reconfigurable phase shifter. Figure 1 shows that the vortex-induced phase shift can vary from zero (a vortex far away) to 2π (a vortex very close to the junction). The specific shape of this curve reveals two distinct mechanisms (vortex stray fields and circulating currents) of generation of the vortex induced Josephson phase shift [3].

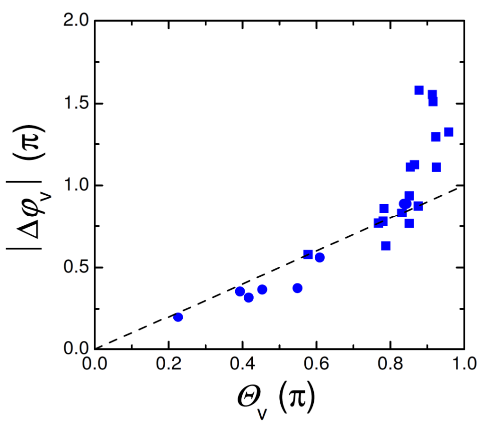

Figure 1. *Measured Josephson phase shift from a single vortex as a function of the vortex polar angle, $\Theta_v=2\mathrm{arctg}(L/2z_v)$, where L is the junction length and z_v is the distance from the vortex to the junction (data from Ref. [3]).*

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TOPOLOGICAL EFFECTS IN ADVANCED SUPERCONDUCTOR NANOARCHITECTURES

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Keywords: Vortices in meso- and nanoscale systems; Novel superconducting materials and heterostructures; Vortex dynamics in bulk/nano/heterostructures/hybrids

Topological defects such as vortices and phase slips in a superconductor system manifest spatial patterns and dynamics that are closely associated with the geometric design in complex micro- and nanoarchitectures of superconductors. Our study is motivated by the recent progress in fabrication of complex 3D nanoarchitectures (e.g., open nanotubes and nanohelices) by using the advanced strain-driven roll-up self-organization [1]. To simulate the superconducting properties of micro- and nanoarchitectures, a numerical platform has been developed based on a set consisting of the time-dependent Ginzburg-Landau equation coupled with the Maxwell equations [2]. We report on a topological transition between the vortex-chain and phase-slip transport regimes under a strong transport current in an open SC nanotube with a submicron-scale inhomogeneity of the normal-to-the-surface component of the applied magnetic field. When the magnetic field is orthogonal to the axis of the nanotube, which carries a transport current in the azimuthal direction, the phase-slip regime is characterized by the vortex/antivortex lifetime of 10^{-14} s versus the vortex lifetime of 10^{-11} s for vortex chains in the half-tubes [3]. In particular, the non-monotonous magnetic-field–voltage and current–voltage characteristics are found in open rolled-up Nb and Sn microtubes under a strong transport current. This non-monotonous behavior is attributed to the occurrence of a phase-slip area at certain magnetic fields, followed by reentrance of the superconducting state with a chain of moving vortices when the magnetic field further increases. A three-fold voltage peak occurs in an ultrathin open Nb tube of radius 400 nm at the magnetic field about 10 mT. The unveiled topological transitions in curved superconductor nanoarchitectures open up a possibility to efficiently tailor the superconducting properties of nanostructured materials by inducing a nontrivial topology of superconducting screening currents.

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RECORDING MAGNETIC FLUX IN THE MIXED STATE OF SUPERCONDUCTING THIN FILMS

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Keywords: Vortex phase diagram; Vortex dynamics in bulk/nano/heterostructures/hybrids; Vortex imaging

Local polarization of magnetic materials has become a well-known and widely used method for storing binary information. Numerous applications that are now part of our daily life, such as credit cards and computer hard drives, rely on this principle. In this presentation, based mostly on two recent articles [1,2], I will review some of the latest advances on the magnetic recording of inhomogeneous magnetic landscapes produced by superconducting films. Of major interest is the evidence that magnetic recording can be applied for imprinting – in a soft magnetic layer – the flux trajectory taking place in a superconducting layer at cryogenic temperatures. This approach enables ex-situ further observation, at room temperature, of the imprinted magnetic flux landscape obtained below the critical temperature of the superconducting state. The undeniable appeal of this approach lies on its simplicity and the potential to improve the spatial resolution, possibly down to the scale of a few vortices.

The authors of references [1] and [2] – too many to have their affiliations and addresses listed here – are to be seen as coauthors of this invited talk.

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NON-GAUSSIAN TAIL IN THE FORCE DISTRIBUTION: A HALLMARK OF CORRELATED DISORDER IN THE HOST MEDIA OF ELASTIC OBJECTS

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Keywords: Vortex imaging; Vortex pinnning and its applications

Inferring the nature of disorder in the media where elastic objects are nucleated is of crucial importance for many applications but remains a challenging basic-science problem. We propose a method to discern whether weak-point or strong-correlated disorder dominates based on characterizing the distribution of the interaction forces between objects mapped in large fields-of-view. We illustrate our proposal with the case-study system of vortex structures nucleated in type-II superconductors with different pinning landscapes. Interaction force distributions are computed from individual vortex positions imaged in thousands-vortices fields-of-view in a two-orders-of-magnitude wide vortex-density range. Vortex structures nucleated in point-disordered media present Gaussian distributions of the interaction force components. In contrast, for media with dilute and randomly-distributed correlated disorder, the distributions have non-Gaussian algebraically-decaying tails for large force magnitudes. We propose that detecting this deviation from the Gaussian behavior is a fingerprint of strong disorder, in our case originated from a dilute distribution of correlated pinning centers.

* Work in collaboration with J. Aragón Sánchez, G. Rumi, R. Cortés Maldonado, N. R. Cejas Bolecek, J. Puig, P. Pedrazzini, G. Nieva, M. I. Dolz, M. Konczykowski, C. J. van der Beek, A.B. Kolton.[1]

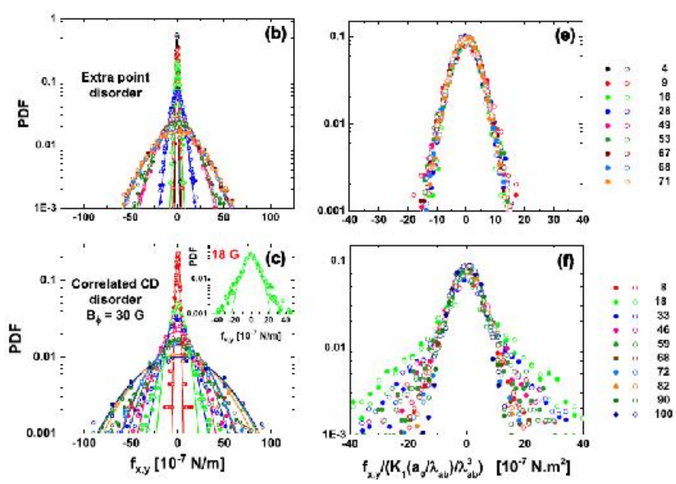

Figure: Probability density functions of the vortex-vortex interaction force imaged in thousands-of-vortices fields-of-view for lattices nucleated in samples with (b,e)point and (c,f)correlated disorder.

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DNA-ASSEMBLED SUPERCONDUCTING NANOSCALE ARCHITECHURES

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Keywords: Josephson phenomena; Superconducting devices and applications.

In recent years, DNA origami has emerged as a powerful technique for fabrication of complex shaped, highly engineered nano-scale objects. However, in order to functionalize such objects for use in application such as nanoelectronic circuits, they must be converted into rigid and highly conductive structures. In this work we explore the possibility of fabricating superconducting nanostructures using DNA origami as a platform. We are particularly interested in applying such a "bottom-up" method in creating 3D superconducting structures where the conventional "top-bottom" techniques, such as e-beam lithography, show their limitations. In this talk, I describe the fabrication and characterization of superconducting nanowires [1] and a 3D network of Josephson junctions [2], using 1D and 3D DNA origami structures as templates.

Nanowires formed by deposition of superconducting NbN exhibit thermally activated and quantum phase slips as well as exceptionally large negative magnetoresistance. The latter effect can be utilized to suppress a significant part of the low temperature resistance caused by the quantum phase slips.

Deposition of superconducting Nb on a 3D superlattice assembled from octahedral DNA frames created a 3D array of weakly linked superconducting grains, suggesting a 3D array of Josephson junctions. Measurements of the I–V characteristics and the magnetoresistance confirm the Josephson junction behavior. The results of this work can potentially be utilized in various applications, e.g. nanoelectronics and novel devices such as 3D magnetometer and highly sensitive 3D Quantum Interference Filters (SQIFs).

Acknowledgements: Financial support from the Israeli Ministry of Science and Technology is acknowledged.

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Two-dimensional BCS-BEC crossover

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Keywords: **12.** Superconductivity in 2D and interface superconductivity

The Bardeen-Cooper-Schrieffer (BCS) condensation and the Bose-Einstein condensation (BEC) are the two extreme limits of the ground state of the paired fermion systems, which are theoretically predicted to continuously connected through an intermediate regime [1]. To approach this phenomenon from the usual BCS superconductivity, the carrier density should be tuned to the low density limit to realize the comparable Fermi energy and superconducting gap. For this purpose, electric field effect is a powerful method, which offers two ways. One is the ionic gating on layered materials [2], and the other is the solid gating on twisted bilayer graphene [3].

We report the two-dimensional (2D) BCS-BEC realized in a gate-controlled superconductor, electron doped layered material ZrNCl. We have succeeded in controlling the carrier density by nearly two-orders of magnitude, and established an electronic phase diagram through the simultaneous experiments of resistivity and tunneling spectra on the ionic gating devices. We found T_c exhibits dome-like behaviour, and more importantly, a wide pseudogap phase was discovered in the low doping regime. In the low carrier density limit, T_c scales as $T_c/T_F = 0.12$, where T_F is the Fermi temperature [4], which shows fair agreement with the theoretical prediction in the 2D limit of BEC [5].

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Poster Presenters Abstracts

TAILORED SPIN-TEXTURES IN HYBRID SUPERCONDUCTING-FERROMAGNETIC STRUCTURES

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Keywords: Superconducting devices and applications; Hybrids (SC-FM)

In the last decade, the information processing has been a focus of interest for its potential applications in many fields of the society. Nowadays, there are a lot of systems able to storage and process information in a fast way. However, the desire of apply the Internet of Things in all possible objects and places, requires the development of new processing technologies that work in nano and micro scale in an efficient and sustainable way.

Regarding to this field, multifunctional oxides have attracted special attention for their capacity to modify their magnetic or electric properties by applying an adequate stimulus. In specific, superconducting cuprates mixed with ferromagnetic materials (FM-SC hybrids) have presented novel and unique magnetic tunability. Here, we show that by combining YBCO (SC) and permalloy (FM) materials in hybrid devices, one can manipulate magnetic textures, through loss-less superconducting stray fields or transport super-currents. Multiple magnetic states with different magnetoresistance signal can be stabilized at remanence, and modified by applying small magnetic fields or currents [1]. The proposed approach opens new venues for energy-efficient information storage and manipulation.

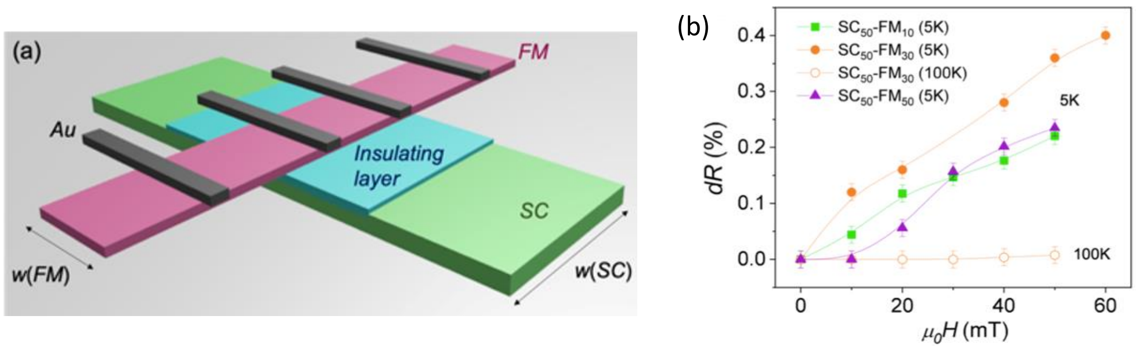

Figure 1. (a) Schematic representation of SC-FM devices. (b) Evolution of the remanent magnetoresistance ratio as a function of the applied magnetic field for different devices at 5K (closed symbols) and 100K (open symbols)

Acknowledgements: Financial support from Spanish Ministry of Science, Innovation and Universities through the "Severo Ochoa" Programme for Centres of Excellence in R&D (CEX2019-000917-S-20-2), SUMATE project (RTI2018-095853-B-C21, co-financed by the European Regional Development Fund, MCIU/AEI/FEDER, UE), the European Union for NanoSC Cost Action NANOCOHYBRI (CA 16218), and the Catalan Government with 2017-SGR-1519.

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Imaging the destruction of superconductivity in MoSi rings

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Keywords: Vortex imaging, Superconducting devices and applications.

When a current carrying, infinitely long coil, pierces a superconducting hollow cylinder, the flux in the coil can be large enough to destroy superconductivity in the cylinder. Analysis of the Ginzburg and Landau equations was used to describe the progress of the front between the superconducting and the normal regions. In my poster I will present scanning SQUID images that capture the behavior of this front and reveal an unexpected behavior. I will show maps of super-currents flowing in the ring, as well as local maps of superconductivity, and discuss the applications of this result.

TOPOLOGICAL BARRIER FOR SKYRMION LATTICE FORMATION IN MnSi

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Keywords: Skyrmions, skyrmion lattices, chiral magnetism, topological stability.

We report the observation of a topological skyrmion energy barrier through a hysteresis of the skyrmion lattice in the prototypical helimagnet MnSi [1]. Measurements of the energy barrier were made using small-angle neutron scattering and a bespoke DC field coil to allow for high-precision hysteresis loops. Data has been analyzed using an adapted Preisach model to quantify the energy barrier for skyrmion formation and the magnetic behavior of the sample as a whole. This analysis was then compared with minimum-energy path analysis based on atomistic spin simulations to verify the topological nature of the barrier. This reveals that the skyrmion lattice in MnSi forms with an activation barrier of several eV and in domains that are several hundred skyrmions in size.

Conference Topics:
15. Skrymions / Soft matter systems and similarities with vortex physics

Acknowledgements:

Reference:

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Unconventional superconducting properties of a new Re-rich non-centrosymmetric α-Mn superconductor, $Re_{5.5}Ta$

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Keywords: Novel superconducting structures and heterostructures

Study of non-centrosymmetric superconductors (NCS), not only enrich the existing theoretical framework of physics but also provide fertile ground for investigations of the unconventional superconducting ground state. Due to the relaxed space-symmetry requirement in the crystal structure of NCS, antisymmetric spin-orbit coupling allows the mixture of spin-singlet and triplet component in the superconducting pairing wave function. The parity mixing effect gives rise to several associated properties such as line/point nodes, anisotropic/multigap, anomalous upper critical field (H_{c2}) value, and time-reversal symmetry breaking (TRSB) [1]. NCS has also been theoretically predicted to exhibit surface states required by the bulk topology [2]. Recently, Re based superconducting binary alloys [1] crystallizing in non-centrosymmetric (NC) α-Mn structure have received huge attention due to the frequent occurrence of TRSB in this series of compounds, and the absence of inversion symmetry was thought of contributing for the same. However, the role of NC crystal structure is called into question in originating the TRSB due to independence of strength of TRS breaking signal of the X site transition metal in Re-X alloys [1], and signatures of TRS breaking in centrosymmetric elemental Re [3]. At the same time, the absence of TRSB in Re_3W [4] and Re_3Ta [5] despite their crystallization in α-Mn NC structure raises further questions. All the above statements suggest a critical amount of rhenium in a crystal structure to give rise to exotic superconducting features over inversion symmetry. In order to get a clear picture of the role of pure Re in NCS and inversion symmetry in inducing TRSB, it is required to study new Re-rich NCS superconductors.

In this regard, we present a detailed investigation of the superconducting and normal state properties of $Re_{5.5}Ta$, which also has the α-Mn structure. Magnetization, specific heat and transport measurements confirm the bulk superconducting transition T_C at 8.0 K. $H_{C2}(0)$ calculated from above mentioned measurements exceed the Pauli paramagnetic limit (14.7 T), indicating that the superconducting properties of $Re_{5.5}Ta$ are probably unconventional in nature. However, low-temperature specific heat and transverse-field muon spin rotation/relaxation (µSR) measurements suggest a surprising nodeless isotropic superconducting gap, although with strong electron-phonon coupling. Zero-field µSR suggest a probable presence of spin fluctuation over TRSB.

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Magnetic adatoms on conventional superconductor surfaces

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Keywords: 11. Topological superconductors/ hybrids (FM-SC)/Semiconductor - SC; 12. Superconductivity in 2D and interface superconductivity;

We derive the solution to the fully relativistic Dirac-Bogoliubov-de Gennes equations for embedded clusters with band structure methods. Such a method has an advantage that spin-orbit coupling, magnetism and the underlying electronic structure is treated on the same footing while the superconducting order parameter is handled as an adjustable parameter. We apply the theory to study the so called Yu-Shiba-Rusinov (YSR) states in simple magnetic impurity systems, like single ad-atoms, dimers and chains of of Mn, Fe and Co on (100) and (110) facets of substrates of s-wave superconductors like Nb and Pb We also compare our results with recent STM experiments and show the spatial behaviour of the YSR states both parallel and perpendicular to the surface. We clarify the role of the induced magnetic moments and analyse the symmetry of the states and the order parameter.

Acknowledgements: Work is supported by OTKA K 131938

METAMORPHOSIS OF D-LINES AND RECTIFICATION OF MAGNETIC FLUX AVALANCHES IN THE PRESENCE OF NON-CENTROSYMMETRIC PINNING FORCES

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Keywords: Vortex dynamics, magneto-optical imaging, anisotropic pinning, ratchet effect, time-dependent Landau Ginzburg model, continuous electrodynamics, magnetic flux avalanches.

Considering a non-centrosymmetric pinning texture composed of a square array of triangular holes, the magnetic flux penetration and evacuation is investigated experimentally and theoretically. A direct visualization of the magnetic landscape obtained by magneto-optical technique on an Nb film is complemented by a multi-scale numerical modeling. This combined approach allows the magnetic flux dynamics to be identified from the single flux quantum limit up to the macroscopic electromagnetic response. Within the theoretical framework provided by time-dependent Ginzburg-Landau simulations, an estimation of the in-plane current anisotropy is obtained and its dependence with the radius of curvature of the triangular hole vertices is addressed. These simulations show that current crowding plays an important role in channeling the flux motion, favoring hole to hole flux hopping rather than promoting interstitial flux displacement in between the holes. The resulting anisotropy of the critical current density gives rise to a distinct pattern of discontinuity lines for increasing and decreasing magnetic fields, in sharp contrast to the invariable patterns reported for centrosymmetric pinning potentials. This observation is partially accounted for by the rectification effect, as demonstrated by finite element modelling. At low temperatures, where magnetic field penetration is dominated by thermomagnetic instabilities, highly directional magnetic flux avalanches of finger-like shape are observed to propagate along the easy axis of the pinning potential. This morphology is reproduced by numerical simulations. Our findings demonstrate that anisotropic pinning landscapes and in particular ratchet potentials produce subtle modifications to the critical state field profile that are reflected in the distribution of discontinuity lines.

Scaling of I-V curves and identification of non-equilibrium phase transitions at two unique depinning thresholds in $2H$-NbS_2 single crystals

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Keywords: Non-equilibrium (NEQ) phase transitions, Vortex dynamics, Scaling analysis

By measuring the current (I)- voltage (V) characteristics at various magnetic fields (B) and temperatures (T) in layered $2H$-NbS_2 superconductor (T_c = 5.8 K), we have uncovered two depinning thresholds: one with lower critical current (I_c^l) associated with depinning from usual pristine vortex state and another having higher depinning threshold (I_c^h) related to depinning from a non-trivial drive-induced zero-velocity state [1,2]. We show that I-V characteristics above I_c^l satisfy a general scaling ansatz (see Fig. 1(a)) which relates vortex velocity ($u \propto V$), drive ($F \propto I$) and T [2,3]. Our scaling analysis [2] shows a concave rounding of I-V curves above I_c^l due to thermally activated vortex flow which exists upto a break in curvature (I_{cr}) in I-V curves. We identify I_{cr} as a crossover regime of NEQ phase transition from thermally activated flow to free flow motion. Using this scaling analysis, we also determine the pinning potential (U_c) across I_c^l. On the contrary, depinning characteristics above I_c^h scale obeying the NEQ scaling relation (see Fig. 1(b)) proposed by D. S. Fisher, $u \propto (1-\frac{F_{c0}}{F})^\beta$ (where F_{c0}: critical depinning force at 0 K and β: critical exponent) [4], suggesting depinning of vortices at I_c^h occurs abruptly and vortex motion at $I > I_c^h$ is coherent in nature and is unaffected by thermal fluctuations [2].

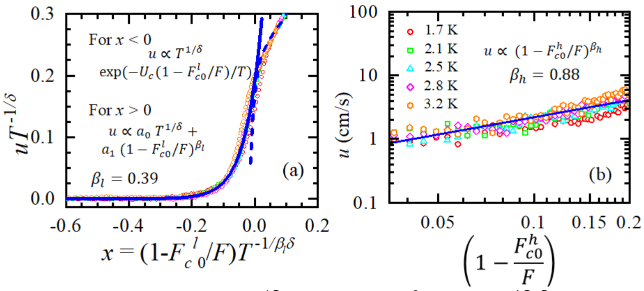

Figure 1: (a) $uT^{-1/\delta}$ vs $(1-F_{c0}^l/F)T^{-1/\beta_l\delta}$ curves estimated from I-V curves at I_c^l for various T and (b) u vs $(1-F_{c0}^h/F)$ curves (in log-log scale) derived from I-V curves at I_c^h for various T. I-V curves are recorded at 0.7 T. The T-legends shown in (b) are same for (a).The lines are fitting to the corresponding scaling form.

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NbRe nitride films for potential application as superconducting nanowire single photon detector

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Keywords: Novel superconducting materials and heterostructures; superconducting devices and applications

Superconducting Nanowire Single Photon Detectors (SNSPDs) are the core elements of many devices finding application in the emerging field of quantum technologies [1]. Since their performances are closely linked to the material properties on which they are based, the search for innovative superconductors to be used in this field has recently received great attention. In this work a new superconductor, NbReN, is successfully synthesized in form of thin films by reactive UHV dc-sputtering starting from a NbRe target and its potential as a constituent of SNSPDs is evaluated. The deposition conditions are systematically varied to optimize the superconducting and electrical properties of the resulting samples. Films with well established superconducting ordering are obtained. The results of the electrical transport properties are studied and interpreted in the framework of different theoretical models. The analysis of the estimated microscopical parameters supports the possibility that NbReN thin films are good candidates for the realization of superconducting nanowires single photon detectors in the frequency range useful for quantum applications.

Acknowledgements: The authors are grateful to Iman Esmaeil Zadeh for useful discussions.

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Interplay between magnetism and superconductivity in $EuFe_2(As_{1-x}P_x)_2$ single crystals

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids

The interplay between superconductivity and magnetism is currently one of the most intriguing topics in condensed matter physics. In this respect, $EuFe_2As_2$-based systems are particularly interesting due to the proximity of superconducting and ferromagnetic transition temperatures, where the latter is connected to the Eu^{2+} local magnetic moments.
We report on a microwave analysis of the interplay between magnetism and superconductivity in single crystals of $EuFe_2(As_{1-x}P_x)_2$, accomplished by means of a coplanar waveguide resonator technique, through a cavity perturbation approach [1]. The bulk complex magnetic susceptibility $\chi_m=\chi'_m+i\chi''_m$ – extracted from the high-frequency characterization – is demonstrated to be highly sensitive to the magnetic structure and dynamics, revealing two distinct magnetic transitions below the superconducting critical temperature [2]. A comparison with the similar but non-magnetic $BaFe_2(As_{1-x}P_x)_2$ [3] and with other quasi-static measurement techniques helps in identifying these transitions and in understanding the underlying mechanisms. In particular, a comparison with magnetic force microscopy maps of $EuFe_2(As_{1-x}P_x)_2$ allows to ascribe the χ''_m peak observed at about 17 K to the transition from the ferromagnetic domain Meissner phase to the domain vortex-antivortex state, with the subsequent evolution of the domain structure at lower temperatures. The second χ''_m peak observed at 11 K reflects a specific high-frequency feature, connected to vortex/antivortex dynamics. The two peaks merge and vanish upon application of an in-plane magnetic field, which is compatible with the presence of a quantum critical point below 1 T. Moreover, we studied the relative strength of the two collective phenomena by analyzing the dependence of their onset temperatures on different perturbations: magnetic fields and structural disorder. Results suggest that superconductivity and magnetism in this material are two competing orders: as the former is suppressed by irradiation or by excess P doping, the latter reinforces and manifests itself at higher temperatures [4].

Acknowledgements:
This work was partially supported by the Italian Ministry of Education, University and Research (Project PRIN HIBiSCUS, Grant No. 201785KWLE)

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Decreasing the flux front penetration depth in a Nb thin film under inhomogeneous magnetic field

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Keywords: Vortices in meso- and nanoscale systems, vortex pinning and its applications.

There is an intimate relationship between the penetration depth of the flux front developed in the smooth Bean envelope in a type-II superconductor and its effective current density. Thin films decorated with arrays of artificial pinning centers can successfully increase the pinning capacity and more effectively shield the magnetic flux, resulting in a shorter flux penetration depth when compared to plain samples [1]. Moreover, a gradient distribution of pinning centers can further enhance the effect [2], pronouncedly in the case of a conformal crystal arrangement [3].

Alternatively, it has been shown by numerical simulations within the Ginzburg-Landau formalism that a superconducting thin film cooled under an inhomogeneous magnetic field presents vortex distributions equivalent to conformal crystals [4]. Such a finding can be achievable experimentally by using a current loop concentric with the sample to generate the inhomogeneous field. This approach, therefore, stands to have a significant impact on the depth of flux penetration front.

Bearing this in mind, we have fabricated a superconducting device composed of a square 200 nm thick Nb film surrounded by a thin Nb loop with contact pads allowing current to flow through. Qualitative and quantitative analysis of magnetic-optical images of our device under critical state conditions reveal the influence of different cooling routes on the flux penetration. The results point to a hierarchy on the film's screening capacity directly influenced by interactions among vortices and/or anti-vortices, with the presence of vortices previously pinned during cooling under an inhomogeneous field with the same orientation as the applied field presenting the shortest flux front penetration depth, even when compared to a homogenous field cooling condition.

Acknowledgements: The authors would like to acknowledge financial support from Brazilian agencies Capes, CNPq, and FAPESP.

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CAN COOPER-PAIRS TUNNEL AS BOSONIC PARTICLES? THEORY AND RESULTS

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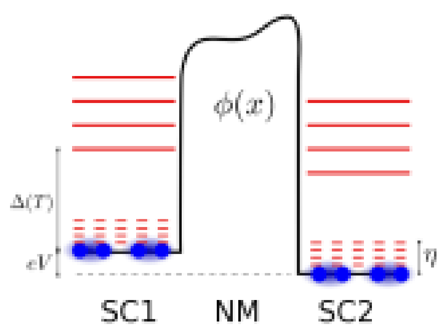
Keywords: Quantum tunnelling, S/I/S junctions, zero bias conductance peak, bosonic particles

We propose a simple phenomenological theory for quantum tunneling of Cooper pairs, in superconductor/insulator/superconductor tunnel junctions, for a regime where the system can be modeled as bosonic particles. Provided there is an absence of quasiparticle excitations (fermions), our model reveals a rapid increase in tunneling current, around zero bias voltage, which rapidly saturates. This manifests as a zero-bias conductance peak that strongly depends on the temperature of the superconductor in a non-monotonic way. This low energy tunneling of Cooper pairs could serve as an alternative explanation for some tunneling experiments where a zero-bias conductance peak has been observed.

Conference Topics: Josephson phenomena



Insulating potential barrier between two superconductors (boson reservoirs). Here Cooper pairs remain as bound particles in the ground state at energies below the energy gap Δ(T) and barrier height ϕo..

Acknowledgements: We would like to acknowledge D. Chevallier and N. Kelkar for useful discussions. This work was partially funded by Banco de la República No. 4.527, Convocatoria Programas 2012 Vicerrectoría de Investigaciones and Facultad de Ciencias No. INV-2020-105-2036 - PROGRAMA 2021-2022 of Universidad de los Andes Bogotá, Colombia.

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MAGNETIC FLUX AVALANCHES IN NANOSCALE WEDGE-SHAPED SUPERCONDUCTING THIN FILMS

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Keywords: Vortices in nanoscale systems, Vortex dynamics, Vortex pinning

Vortex matter in superconductors has been the focus of research by theoretical and experimental groups around the world (1). When developing superconducting devices patterned on thin films, it should be borne in mind that flux avalanches can occur for some materials in a certain range of applied fields and temperatures. Technological applications of thin films can be threatened by the occurrence of magnetic flux avalanches of thermomagnetic origin appearing in a large part of the superconducting phase (2). Using a quantitative magneto-optical imaging technique, this work deals with thin films of Pb in the distinctive form of a wedge. The thicknesses of the wedge-shaped samples decrease almost linearly to a non-zero minimum value at the opposite edge. AC and DC magnetometry measurements were conducted to characterize the superconducting properties of the thin wedge films. Magneto-optical images revealed interesting features of the dendritic flux avalanches in the films. Wedge-shaped systems open up a new way of tuning the critical current in the film, allowing one to study the resulting changes in the flux penetration patterns throughout the films. The observation of flux avalanches reported here implies that, as usual, attention should be paid to this feature when films with variable thickness are considered for possible applications.

Acknowledgements: This work was partially supported by the São Paulo Research Foundation (FAPESP), the National Council for Scientific and Technological Development (CNPq), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

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Imaging the magnetic landscape of chiral superconductor candidate 4Hb-TaS2

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Keywords: Vortex Imaging, Multi component superconductivity, Topological superconductors.

In chiral superconductors, time reversal symmetry breaking is expected to generate magnetic signals which onset at the superconducting critical temperature. Although the magnetic fields expected at the edges of the sample, and at chiral domain walls should be considerable, their detection in chiral superconductor candidates has been challenging. A promising candidate system is 4Hb-TaS2, where muon spin relaxation recently revealed time reversal symmetry breaking [1]. In my poster, I will show scanning SQUID microscopy measurements of 4Hb-TaS2, which reveal magnetic signals below Tc. I will show how these signals depend on temperature and external fields.

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Effects of creep on the linear ac magnetic response in type II superconductors

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Keywords: **1.** Vortex phase diagram; **2.** Vortex dynamics in bulk/nano/heterostructures/hybrid; **7.** Vortex pinning and its applications.

We study the effect of thermal fluctuations (or creep) [1] on the penetration of an ac magnetic field into the mixed state of a type II superconductor within the strong pinning formalism, where vortices get pinned by individual defects and jumps in the energy (Δe_{pin}) and force (Δf_{pin}) between pinned and free states characterize the pinning process. The ac linear magnetic response is quantified by the so-called Campbell length $\lambda_C(t)$ [2], whose evolution as a function of time t is the result of two competing effects, the change in the force jumps Δf_{pin} (t) and a change in the trapping distance $t_{trap}(t)$ of vortices; the latter describes the distance from the defect where a nearby vortex gets trapped. During the decay of the critical state in a zero-field cooled (ZFC) experiment, the Campbell length $\lambda_C(t)$ behaves nonmonotonically, contrary to what happens in a measurement of the persistent current. The Campbell length always decreases at short times, and then increases for longer waiting times, at least for very strong pinning, and its relative change is parametrically smaller than that of the persistent current [3]. Once thermal equilibrium is reached, the magnetic field is distributed homogeneously inside the superconductor, leading to vanishing persistent current, while the Campbell length remains finite and similar to the one without relaxation. Measuring the Campbell length $\lambda_C(t)$ for different states, zero-field cooled, field cooled, and relaxed along closed temperature loops, we obtain different results, dependent on the state preparation, the temperatures and the waiting times. In this way, important information on the pinning mechanism is obtained and the pinning potential of the defects can be quantitatively characterized [4].

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Interplay between nematicity and superconductivity in strained pnictides superconductors

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Keywords: Unconventional Superconductors.

The electronic phase diagrams of a variety of non-conventional superconductors have been described in the context of coupling of multiple orders [1]. A cutting edge topic has emerged from the observation of a true nematic phase [2] where the electronic and structural anisotropies are coupled, and the response is strongly influenced by the formation of nematic domains delimited by twin boundaries. In this context, the relationship between nematic and superconducting orders has attracted abundant interest in the last years. In particular, superconductivity in $Ba(Fe_{1-x}Co_x)_2As_2$ has been shown to compete with nematicity, evidenced by the suppression of orthorhombic distortion as the system undergoes the superconducting transition, and by the observed repulsion between vortices and twin boundaries. On the other hand, a quantum critical nematic point is found near the optimal doping [2].

In this work [3] we show evidence of nematic effects in the mixed superconducting phase of slightly underdoped $Ba(Fe_{1-x}Co_x)_2As_2$. Elasto-resistivity measurements [4] were done under a rotating magnetic field and the analysis of the angular dependence in the mixed superconducting state allows identify single domain detwinned samples. Our results show that although nematicity contributes in a decisive way in the conduction properties in the mixed state, its contributions to the anisotropy properties of the stiffness of the superconducting order parameter is not as significant in these samples. The dependence of T_c with strain and resistive anisotropy is also discussed.

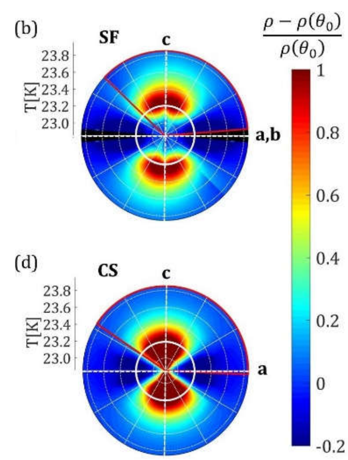

Figure: The anomaly observed in the angular dependence of the resistive superconducting transition in strain-free twinned samples (SF), related with the presence of domains, is absent under strong compressive strain (CS) [3].

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Two-step ac screening and non-local effects in the vortex lattice on $Bi_2Sr_2CaCu_2O_{8+\delta}$ samples

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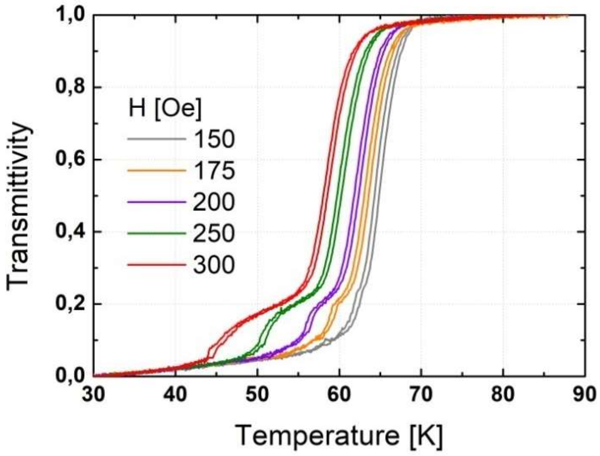
Keywords: Vortex phase diagram, Vortex dynamics

The screening of an ac field by vortex matter can be used as a tool to probe the dynamics of the vortex lattice and to detect the first order transition [1, 2]. In this work we report the presence of a two-step screening of a ripple magnetic field from vortex matter nucleated in bulk $Bi_2Sr_2CaCu_2O_{8+\delta}$ samples. At low fields (<150 Oe), an ordinary one-step screening of the in-phase component of the B field follows on cooling the first-order transition, signaled by a paramagnetic peak. However, for higher fields, the paramagnetic peak is no longer observed and the screening occurs in two steps. Experiments with a localized magnetic excitation and Hall-probe measurements arranged in different configurations allowed us to investigate non-local effects associated with this two-step screening process, revealing a correlation between direct and cross transmittivity measurements. We interpret this two-step screening as a result of the crossover between a surface-barrier dominated screening and the continuation of the first order transition observed at higher temperatures.



Transmittivity curves as a function of temperature for different applied fields. Over H=150 Oe the screening happens in two steps separated by a plateau.

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Symmetry reorientation transition in the vortex lattice and flux jumps in single crystals of V_3Si superconductor

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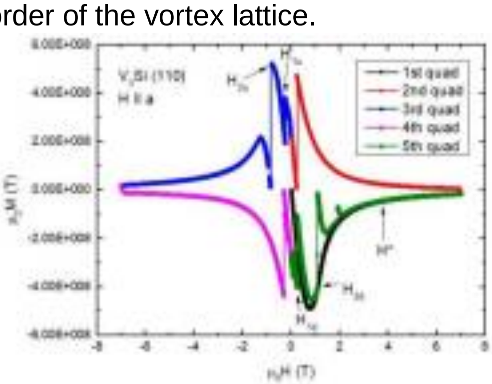
Keywords: Vortex phase diagram, symmetry reorientation transition, V_3Si superconductor

Abrikosov predicted the vortex state of a Type-II superconductor to exist in a triangular lattice [1]. However, defects in the underlying crystalline lattice can induce symmetry transitions from triangular to square or vice-versa. Such transitions have, in fact, been observed in the vortex lattice (VL) of low temperature superconductors like borocarbides [2]. Through small angle neutron scattering measurements on a conventional superconductor V_3Si that grows in a simple cubic crystal structure, a low field first-order symmetry reorientation transition has been observed from triangular to square at a field of ~ 1T for H || a [3]. By systematic temperature and field dependent magnetisation measurements performed on a vibrating sample magnetometer, we have observed flux jumps at similar field values of ~ 1T. The flux jumps are found to be consistently two in number. These flux jumps are expected to capture the symmetry reorientation transition in the VL of the superconductor [4]. In this work, we provide the details of the model proposed earlier where domains of vortices and anti-vortices lying in juxtaposition to each other at the centre of the sample, get annihilated due to a sudden symmetry reorientation transition resulting in a flux jump. We have made suitable Bean's profile to construct the details of first order transition and the resultant flux jumps caused. Through a series of temperature dependent M-H measurements, we have constructed a VL phase diagram describing the field and temperature variation of the two jumps where a demarcation of the two symmetry dominant phases has been done. Very surprisingly, we find both the lower as well as the upper field boundary to have a non-monotonic variation with field and temperature. Our study has important implications for investigations of correlations between symmetry reorientation transitions of vortex lattice, its underlying crystalline lattice and the state of order of the vortex lattice.



1 Magnetization hysterisis of V_3Si at 1.8K

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The impact of kinetic inductance on the critical current oscillations of nanobridge SQUIDs

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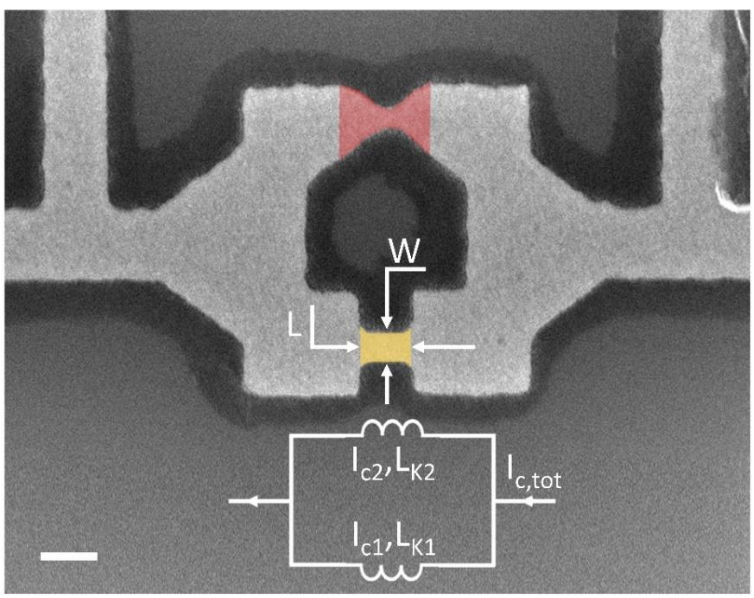
Keywords: Superconducting devices and applications; Quantum Computation/Devices/Superconducting circuits;

We study the current phase relation (CΦR) of lithographically fabricated molybdenum germanium (MoGe) nanobridges, which is intimately linked to the nanobridge kinetic inductance. We do this by imbedding the nanobridges in a SQUID. We observe that for temperatures far below T_c, the CΦR is linear as long as the condensate is not weakened by the presence of supercurrent. We demonstrate lithographic control over the nanobridge kinetic inductance, which scales with the nanobridge aspect ratio. This allows to tune the SQUID $I_c(B)$ characteristic. The SQUID properties that can be controlled in this way include the SQUID sensitivity and the positions of the critical current maxima. These observations can be of use for the design and operation of future superconducting devices such as memory devices or flux qubits.



Scanning electron microscopy (SEM) image of a typical SQUID studied in this work. The top junction (indicated in red) is a Dayem bridge. The bottom junction is a nanobridge (shown in yellow) with width W and length L. The white scale bar represents 200 nm. The white circuit diagram presents an equivalent electronic circuit of the SQUID: L_{K1} and L_{K2} represent the inductances of each branch, while I_{c1} and I_{c2} represent the two critical currents of each branch. $I_{c,tot}$ is the total critical current of the SQUID.

Acknowledgements: This work has been supported by the Research Foundation - Flanders (FWO, Belgium), with grant number G0B5315N.

Interplay of spin waves and vortices in the two-dimensional XY model at small vortex-core energy

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Keywords: Vortex phase diagram.

The Berezinskii-Kosterlitz-Thouless (BKT) [1-3] phase transition is the key to understand the physical properties of a wide class of two-dimensional (2D) systems, ranging from cold atoms in 2D harmonic traps to thin superconducting (SC) films. Albeit the BKT universal scaling is solely due to the vortex unbinding mechanism, nonuniversal thermodynamic quantities such as the critical temperature or the superfluid density crucially depend on the interplay between vortices and the other noncritical excitations resulting from the microscopic nature of the system itself. This issue may be overcome by suitably modifying the initial conditions of the BKT flow equations to account for noncritical fluctuations at small length scales.

In this work, we perform a systematic study of the validity and limits of the two-step approach by constructing optimised initial conditions for the BKT flow of the classical 2D XY model. We find that the two-step approach can accurately reproduce the results of Monte-Carlo simulations. To systematically study the interplay between vortices and spin-wave excitations, we introduce a modified XY model with increased vortex fugacity. We present large-scale Monte-Carlo simulations of the spin stiffness and vortex density for this modified XY model and show that even at large vortex fugacity, vortex unbinding is accurately described by the nonperturbative functional renormalisation group.

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Panoramics of vortex matter in FeSe and FeSeS at low fields

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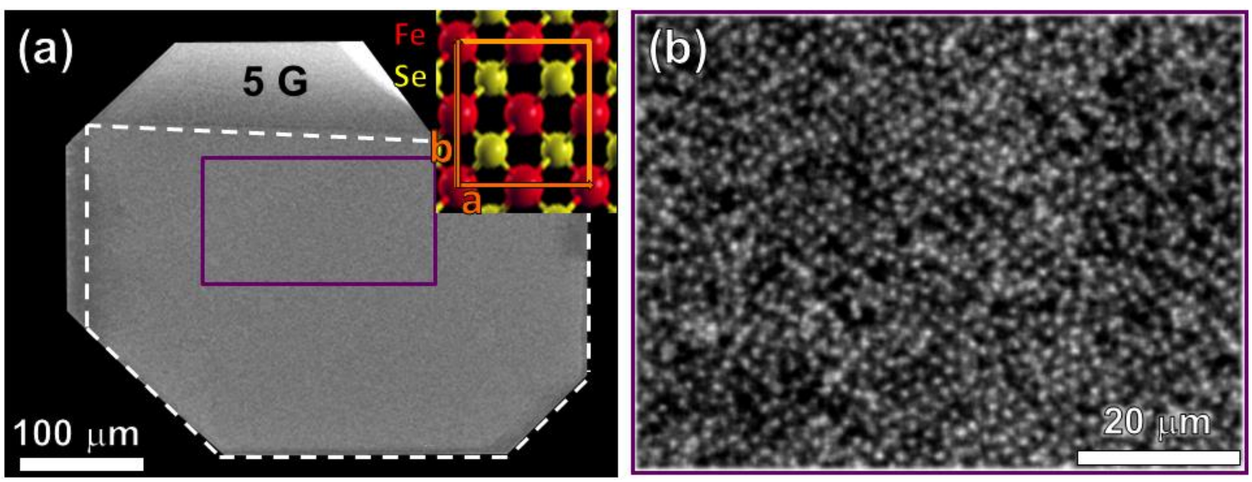
Keywords: Vortex imaging; Emergent flux patterns in unconventional SC or hydrids/novel HTSC superconductors; Novel superconducting materials and heterostructures.

We apply magnetic decoration to obtain large field-of-view images of the vortex matter nucleated at the surface of FeSe and FeSeS single crystals at low fields (5-15 Oe). We analyse the structural properties in thousands-vortices fields-of-view and found that the non hyperuniform structure is composed by a mixture of isotropic and distorted hexagonal domains. Structure factor and Delaunay triangulation analysis indicate that the latter domains correspond to an oblique structure obtained by expanding or compressing the hexagon along the Fe-Fe bond crystallographic direction (*a* or *b* axis). Nevertheless, at the edge of the sample few vortex rows are aligned at 45° from the *a* and *b* axis, mimicking the sample geometry.



Magnetic decoration images of the vortex structure (white dots) nucleated in FeSe sample at B=5 G and 2.3 K. (a) Image of the full decorated sample. The white dashed line indicates the zone where vortices are individually distinguishable. Insert: Orthorhombic crystal structure of the FeSe at the surface of the sample, yellow and red circles correspond to Se and Fe atoms, respectively. The corresponding crystallographic vectors a and b are indicated with orange arrows. The orange frame indicated the unit cell. Orientation of crystallographic axes in the scheme corresponds to the real orientation of the sample. (b) Vortex structure nucleated at the centre of the sample.

Bridges in micron-sized type-II superconducting samples act as converging lenses for vortices

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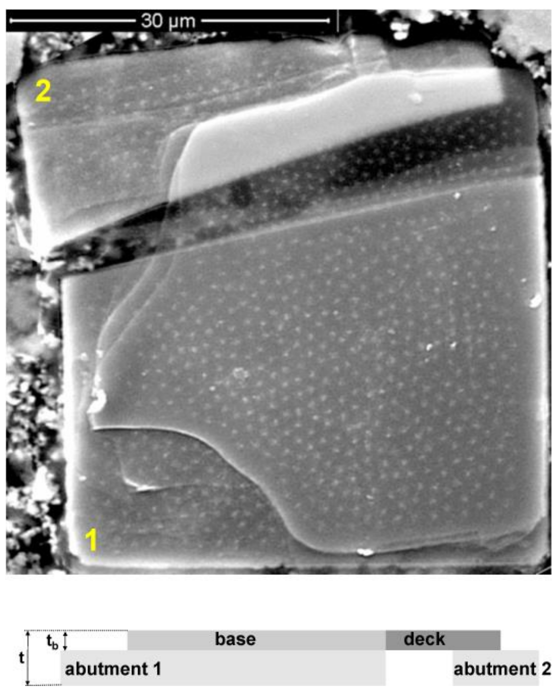
Keywords: Vortex imaging; Vortices in meso- and nanoscale systems.

We report on direct imaging of vortex nanocrystals nucleated in micron-sized $Bi_2Sr_2CaCu_2O_{8+y}$ superconducting samples that incidentally present a bridge structure. We find that when nucleating vortices in a field-cooling condition the deck of the bridge acts as a converging lens for vortices. By means of Bitter decoration images allowing us to quantify the enhancement of vortex-vortex interaction energy per unit length in the deck of the bridge, we are able to estimate that the deck is thinner than ~0.6 µm. We show that the structural properties of the vortex nanocrystals are not significantly affected by sample-thickness variations of the order of half a micron, an important information for micron-sized type-II superconductors-based technological devices.



Scannig electron microscope image of the field-cooling magnetic decoration performed at 12 Oe and 4.2 K in a micron-sized cuboid of Bi2Sr2CaCu2O8+y presenting a bridge structure. Fe clusters (white dots) decorate vortices as they impinge at the sample surface. The cuboid has a nominal size of ~40 µm side and 2 µm thickness. Bottom: schematic lateral representation of the bridge structure indicating the parts of the sample that act as deck, base and abutments of the bridge. The abutments 1 and 2 are also labelled with yellow numbers in the top picture. The thickness of the deck is indicated as t_b.

RESISTIVE SWITCHING IN NANOSTRUCTURED YBCO THIN FILMS

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Keywords: Vortex pinning, superconducting devices and applications, heterostructures, resistive switching.

Modulation of carrier concentration in strongly correlated oxides offers the unique opportunity to induce different phases in the same material which dramatically change their physical properties, providing novel concepts in oxide electronic devices with engineered functionalities [1]. This work reports on the local electric manipulation of the superconducting to insulator phase transition in $YBa_2Cu_3O_{7-d}$ thin films by electrochemical oxygen doping. The normal state resistance, the superconducting critical temperature (T_c) and the critical current density (J_c) can be reversibly manipulated in confined active volumes of the film by gate-tunable oxygen vacancy diffusion (Fig. 1 (a,b)). We specifically modify the geometry of contact patterns as dots with circular or triangle shape, lines or other features (Fig. 1 (c)), in order to infer on trapped magnetic fields and vortex dynamics, and thus engineer reversible pinning centers. Local oxygen diffusion may be finely modulated, at the micro-and nano-scale, by tuning the applied bias voltage and operating temperature thus providing the basis for the design of homogeneous and flexible transistor-like devices with loss-less superconducting drain-source channels.

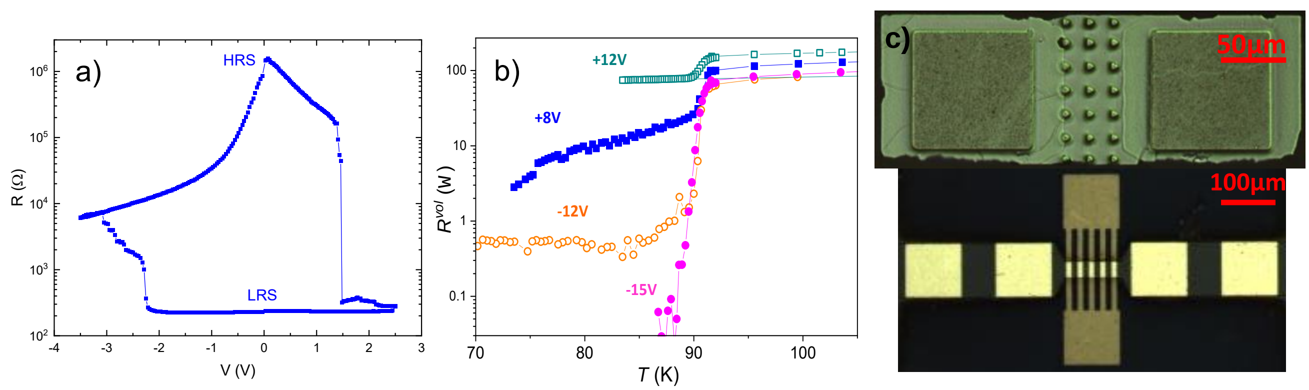

Figure 1: (a) Normal state resistance and **(b)** T_c modulation through voltage pulses, **(c)** Different nanostructured contacts patterned in our YBCO track.

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Reference: [1] A. Palau et al. *ACS Appl. Mater. Interfaces. 10, 30522,* 2018

Superconducting Properties of α-Mn High Entropy Alloy Superconductors

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Keywords: Novel superconducting materials and heterostructures

High entropy alloys are an uncommon class of materials and currently receive interest from theoretical and experimental prospects. These alloys contain at least five chemical elements in either equimolar ratio or atomic percentage of a constituent element should lie between 5 to 35 [1], which differs from conventional alloys, consisting of only one or hardly two principal elements [2]. These alloys are the high entropy of mixing, which stabilizes the disordered solid solution and crystallizes in body-centered, face-centered, and hexagonal closed-packed structures [3]. They are also termed amorphous glasses on the perfectly ordered lattice. These unusual alloys have highly tunable properties such as high mechanical strength, ductility, thermal stability [4], and applications in thermoelectrics, soft magnet, and radiation tolerance [5]. Bulk Superconductivity was firstly observed in a HEA $Ta_{34}Nb_{33}Zr_8Hf_{14}Ti_{11}$ at 7.2 K [6] and survived the extreme application of pressure up to 190 GPa [7], which enhanced the application spectrum range of HEAs. Most HEA superconductor's work is focused on discovering new superconducting HEA, whereas the superconducting pairing mechanism for these HEAs largely unexplored. Due to its multi-component nature and disorders, HEA offers a unique opportunity to understand the role of spin-orbital coupling and disorder on the superconducting ground state. We have studied non-centrosymmetric α-Mn HEA $(HfNb)_{0.10}(MoReRu)_{0.90}$ and $(ZrNb)_{0.10}(MoReRu)_{0.90,}$ [8] having superconducting transition temperature 5.9(1) K and 5.8(1) K, respectively. Combined bulk (magnetic, transport, heat capacity) and muon spin rotation/relaxation (µSR) measurements suggest isotropic s-wave superconducting ground state with preserved time-reversal symmetry, even in the presence of a high amount of disorder in their crystal structure.

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Zero-energy peak induced by a magnetic impurity in a conventional superconductor: first-principles based study

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Keywords: 11. Topological superconductors/ hybrids (FM-SC)/Semiconductor-SC; 12.Superconductivity in 2D and interface superconductivity

Topological superconductivity has emerged a promising platform for fault-tolerant quantum computing using braiding of Majorana modes. Considering that intrinsic topological superconductors are rare, various heterostructures including s-wave superconductors have been proposed to realize topological superconductivity. One of the viable heterostructures consists of ferromagnetic chains on conventional superconductors. Here we present our first-principles based study of a single magnetic impurity at and under the surface of an s-wave superconductor by solving the Bogoliubov-de Gennes equations for embedded impurity clusters within the screened Korringa-Kohn-Rostoker method in the framework of density-functional theory. We investigate the local density of states or bound Yu-Shiba-Rusinov states within the superconducting gap by varying the location of the magnetic impurity, the magnitude and direction of the magnetic moment, and spin-orbit coupling. Interestingly, we find a zero-energy peak near the single magnetic impurity with a judicious choice of environmental factors which may be observable in experiment. We also analyze the characteristics of the zero-energy peak and pairing potential.

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The Resistive State of Two-Band Superconductors

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Vortices in meso- and nanoscale systems; Multi-component superconductivity

Within the framework of the time-dependent Ginzburg-Landau theory, we study the resistive state of a two-band superconducting strip driven by an external current. In this case, the system leaves the Meissner state at a threshold current j_c, at which flux penetrates the sample in the form of fractional vortex/anti-vortex pairs in each condensate. At a higher current j_{c2}, where the dissipation caused by the fractional vortices motion is sufficiently strong, superconductivity is completely destroyed and the system goes to the normal state. Due to the external current, the resistive state between j_c and j_{c2} is characterized by the periodic nucleation of the fractional vortex/anti-vortex pairs at the edges of the sample and their annihilation at the center of the superconductor. Once the vortex cores in each band are spatially displaced, we also have the existence of two phase solitons which are created and annihilated together with the vortex/anti-vortex pairs. As it is shown here, the ratio between the diffusion coefficients of each band significantly influences the resistive state behavior, quantitative and qualitatively. On the quantitative side, we find that the resistance and the output voltage of the resistive state, as well as the frequency at which the fractional vortex/anti-vortex pairs are created and annihilated, depends on this ratio. This is linked to the normal conductivity dependence on the ratio of the diffusion coefficients, once the normal conductivity directly influences how much viscous the superconducting medium is to the motion of vortices, thus quantitatively affecting the above cited quantities. Qualitatively, the ratio of the diffusion coefficients affects the amount and the rate of destruction of the supercurrent carried by each band. We show that this dependence has detectable consequences in the shape of the current-voltage characteristics of the system, such as its concavity and the appearance of an extra peak in the differential resistance for some values of the ratio, which is shown to be linked to a maximum destruction rate of the supercurrents. Finally, we also investigate how a weak interband coupling affects the properties of the resistive state. As it is shown, the coupling between the bands is responsible for a significant enhancement of some superconducting properties when compared to the same values obtained for each band in the decoupled limit. For instance, we find that, in the presence of a weak coupling between the bands, the system displays critical currents two times as large as the obtained in the decoupled limit, also displaying a smaller resistance. We argue that the last enhancement is caused by an increase in the ratio between the coherence length and electric field relaxation length, which emerges from the weak coupling between the bands.

Acknowledgements: LRC and ES thank the Brazilian agency FAPESP for financial support (process numbers 20/03947-2 and 12/04388-0).

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HEAT HUNTING IN A FREEZER: DIRECT MEASUREMENT OF QUASIPARTICLE DIFFUSION IN SUPERCONDUCTING NANOWIRE

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Keywords: Josephson phenomena, Superconducting devices and applications.

Propagation and relaxation of nonequilibrium quasiparticles (QPs) in superconductors are fundamental for functioning of numerous nanoscale devices, enabling operation of some of them, and limiting the performance of others. The QPs heated above lattice temperature may relax locally via phonon or photon-emission channels, or diffuse over appreciable distances in a nanostructure altering the functionality of their remote components. Tracing QPs experimentally in real-time domain has remained a challenging task owing to their rapid dynamics. With electronic nanothermometry, based on probing of the temperature-dependent switching current of a superconducting nanobridge, we monitor heat pulse carried by a flux of nonequilibrium QPs as it passes by our detector with a noise-equivalent temperature of 10 mK/$(N)^{0.5}$, where N is the number of pulses probing the bridge (typically N = 10 000), and temporal resolution of a single nanosecond (Fig. 1). The measurement provides the picture of QP diffusion in a superconducting aluminum strip and direct determination of the diffusion constant D equal to 100 cm^2/s with no energy dependence visible [1].

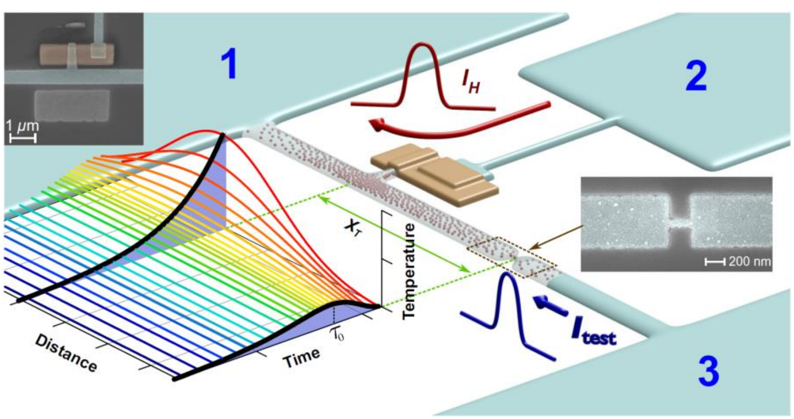

Fig. 1: Hot electrons are created in the heater by applying short current pulse I_H (approximately 10 ns long) flowing between ports 1 and 2. QPs start diffusing along the nanowire. Qualitatively, their population at the bridge location is derived from the time-evolving Gaussian profile. The testing pulse I_{test}, flowing between ports 1 and 3 is used to test the bridge temperature. The insets show the SEM images of the copper heater and the aluminum nanobridge of the measured nanostucture.

Acknowledgements: The work is financed by Foundation for Polish Science (First TEAM/2016-1/10).

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Study of the Flux Pinning Properties of YBCO: NaNbO3 Nanorods Composite Superconductor

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Abstract

In this work, we are reporting the impact of addition of NaNbO3 nanorods (NRs) on the flux pinning properties of YBCO compound. YBCO: NaNbO3 composite samples were synthesized via two step method i.e. hydrothermal and solid-state reaction method. All the composite samples were characterized using various techniques to investigate the structural, electrical, and magnetic properties of the composite samples. XRD studies indicated that the orthorhombic crystal structure of YBCO compound remain unchanged in the composite samples also. The transport electrical measurement of YBCO: NaNbO3 composite samples showed that there is decrement in the superconducting transition temperature from 92 K to 90 K with increase in the amount of NaNbO3 up to 2 wt% concentration. The magnetic hysteresis loop measurement was conducted using PPMS technique. An enhancement in the value of critical current density and pinning force for YBCO:0.5 NaNbO3 composite sample was observed which is attributed to the generation of sufficient no. of defects with NRs addition to pin the motion of the vortices. Further, the pinning mechanism was investigated by fitting the critical current density vs temperature curve using various theoretical models for strength of weak and strong pinning centres. It was observed that T=30 K is the de-pinning temperature where the thermal energy dominates over the pinning energy barrier in all the composite samples.

Superconductivity in Chemically Doped Type-II Weyl Semimetal

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Keywords: Novel superconducting materials and heterostructures, Topological superconductors

The discovery of superconductivity in layered topological semimetals offers a fascinating opportunity to explore superconductivity and topological states by tuning the local structural distortion or manipulating chemical pressure [1]. We have studied exotic type-II Weyl semimetal $MoTe_2$ and $NiTe_2$ systems. Re substitution in Mo-site in $MoTe_2$ is doping electrons and facilitates superconductivity by increasing the electron-phonon coupling and density of states at the Fermi level [2]. Apart from this, superconductivity coexists with the strain-induced pseudo magnetic field and charge density wave in Re-doped $MoTe_2$ [3-4]. Re-doped $NiTe_2$ shows the emergence of superconductivity at 2.4 K at ambient pressure [5]. We are performing further experiments to understand the effect of topological states on superconducting properties in these exotic materials.

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SENSING SUPERCONDUCTING VORTICES WITH DAYEM NANOBRIDGE

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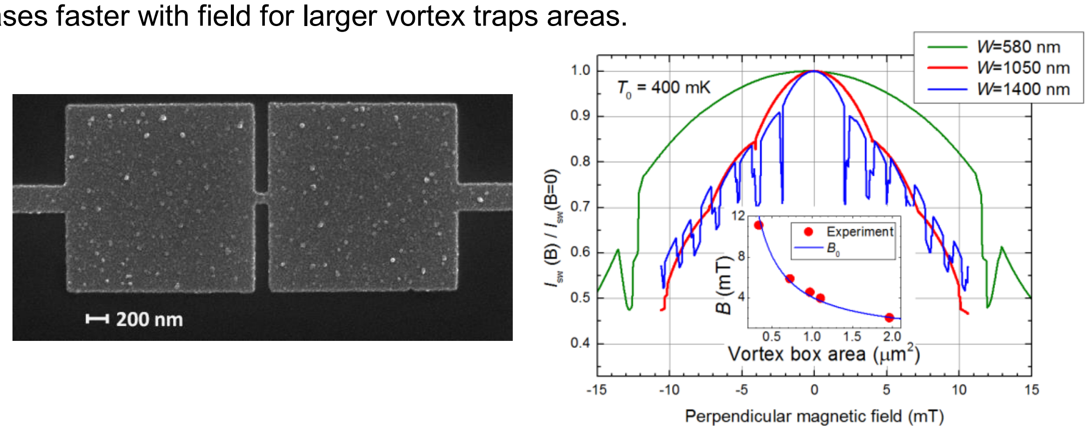
Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Josephson phenomena; Vortices in meso- and nanoscale systems.

Superconducting Dayem nanobridges find many interesting applications in scientific and engineering disciplines. Switching currents I_{SW} of such bridges are very sensitive to small electric currents, temperature or tiny changes of the magnetic flux. The superconducting structure prevents the penetration of the externally applied magnetic field by creating the screening currents. For a superconducting nanowire with a width W and the thickness less than the coherence length, at perpendicular magnetic field equal to a critical value $B_0=\pi\Phi_0/4W^2$, where $\Phi_0=h/2e$, one can expect entry of vortices into the nanowire. The equation was validated for superconducting strips where the two edge Meissner currents push the vortex into the superconductor [1]. Here we fabricate series of structures consisting of the vortex traps in a form of squares connected directly to the Dayem nanobridge (Fig. 1a). For low applied fields we see monotonous lowering of the I_{SW}, which we associate with influence of the Meissner screening currents on the superconducting order parameter. At higher fields we observe a step-like changes of the bridge I_{SW}. They are caused by the vortices that enter into squares and disturb the pattern of screening currents in the vicinity of the bridge. We see clear relation between the magnetic field at which first vortex enters, and trap area (Fig. 1b). Our experimental data seem to obey the same equation for vortex stability. We also see that at Meissner state I_{SW} decreases faster with field for larger vortex traps areas.

(a)



(b)

Fig. 1: (a) A typical SEM photo of the vortex traps connected directly to the aluminium Dayem nanobridge. (b) The normalized I_{SW} vs. perpendicular magnetic field for different vortex trap sizes. Inset: Theoretical and experimental critical fields B_0 vs. vortex trap area.

Acknowledgements: The work is financed by Foundation for Polish Science (First TEAM/2016-1/10).

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NON-MAGNETIC IMPURITY EFFECTS IN VORTEX STATES OF NEMATIC SUPERCONDUCTORS

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Keywords: Vortex imaging, Vortex matter vs. pairing symmetry.

Non-magnetic impurity scattering effect on the vortex core states are studied by the Eilenberger theory in nematic superconductors which has two-fold symmetric pairing function [1]. Calculating spatial structure of the pair potential and the local electronic states around a vortex in the vortex lattice, we examine the differences between anisotropic superconductors with (p_x-wave pairing) and without (anisotropic s-wave) sign-change of the pairing function. And we find how two-fold symmetric shape of the vortex core changes with increasing the impurity scattering rate both in the Born and the unitary limits. For example, two-fold symmetric vortex core image of zero-energy local density of states changes the orientation of the two-fold symmetry with increasing the scattering rate when the sign change occurs in the pairing function, as shown in Fig.1. Without the sign change, the vortex core shape reduces to circular one with approaching dirty cases. These results clarify the contributions from the sign-change of the pairing function in the impurity effects on the vortex state. These results are helpful to identify the pairing symmetry in unconventional superconductors, in relation to the STM vortex core observation. The nonmagnetic impurity effects in vortex states of chiral superconductors are studied in Ref. [2].

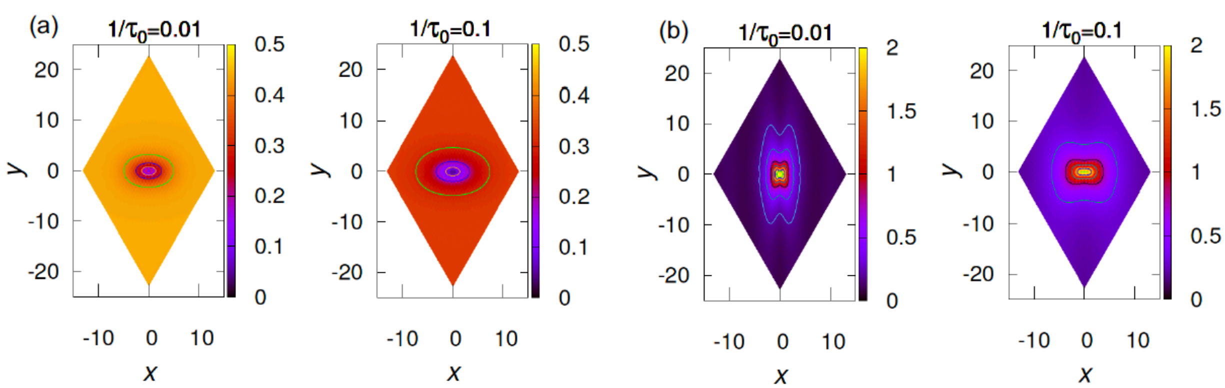

Fig. 1. (a) Pair potential $|\Delta(\mathbf{r})|$ and (b) zero-energy local density of states $N(E=0,\mathbf{r})$ around a vortex in a p_x-wave superconductor for scattering rates $1/\tau_0$ =0.01 and 0.1 in the Born limit. We show a region within a unit cell of triangular vortex lattice.

Acknowledgements:

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Superconducting phase diagram of magnetically ordered superconductor pristine $RbEuFe_4As_4$ and $RbEu(Fe1-_xNi_x)_4As_4$ for x ≤ 0.04 in large pulsed fields

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Keywords:.13. Novel superconducting materials and heterostructures

We present a study of H_{c2} in single crystals of the ferromagnetic pnictide superconductor $RbEuFe_4As_4$ in large pulsed magnetic fields, without and with low Ni-for-Fe doping. Doping progressively lowers T_c from 36.5 K while the bulk Eu magnetic ordering temperature (15 K) is not affected. Doping slightly lowers the superconducting anisotropy, but the curvature of the phase boundaries for both H || [110] and H || [001] remain remarkably consistent. This suggests T_c suppression is doping driven and not disorder driven in our crystals. The strong curvature in H_{c2} for the in-plane field orientation is consistent with Pauli paramagnetic limiting with a high Maki parameter α. Recent results and implications for possible formation of a Fulde-Ferrell-Larkin-Ovchinnikov state at high field / low temperature will be discussed.

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Widening the range of applicability of superconducting NbN thin films by suppressing flux avalanches

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids, Vortex pinning and its applications.

Technological applications of NbN thin films may be threatened by the occurrence of magnetic flux avalanches emerging in a large portion of the magnetic field-temperature diagram [1]. These avalanches appear due to thermomagnetic instabilities and consist of abrupt bursts of magnetic flux rushing into the sample, usually assuming the form of dendrite-like structures. An efficient manner to reduce the avalanche activity consists in coating a superconducting film with a normal metal [2]. In this case, an electromagnetic drag force, due to eddy currents, is induced in the metal layer, even when it is not in close contact with the superconducting film [3].

In this work, we describe an approach to substantially suppress the magnetic flux avalanche regime, without compromising the upper critical field. This procedure consists of depositing a thin Nb layer before the reactive deposition of NbN, thus forming a bi-layered system. We have studied such hybrid systems, where NbN is in intimate contact with other superconducting layer [4]. Ac susceptibility and dc magnetometry were used to characterize both the single layer films, Nb and NbN, and the bi-layered specimen, as well as calibrated magneto-optical imaging to map the instability regime of the studied samples. Magnetic flux imaging reveals interesting features of the dendritic flux avalanches in the bi-layer system, including halolike patterns and crossing avalanches [4].

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A prototype of Superconducting Fault Current Limiter with three dimensional current mapping ability

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Keywords: Vortex dynamics in bulk, vortex pinning and its applications, superconducting devices and applications

We have developed and tested a prototype of unique Smart Superconducting Fault Current Limiter (SFCLsm) [1]. Conventional Superconducting Fault Current Limiters (SFCL) are used in the power network to limit the fault current due to its advantages of negligible loss during normal operation and limitation of fault current in the first cycle of the fault current. But a disadvantage of SFCL is that during normal operation sometimes SFCL fails due to instability generated in the superconductor. We also require multiple SFCL with different rating as voltage rating of the power networks changes. Furthermore, in conventional SFCL as it starts its action when fault current crosses the critical current threshold, hence the fault current operation only occurs close to the critical current value. This is a limitation; as early detection of faults becomes difficult. Here a prototype of a SFCLsm is developed using array of hall sensors placed around the superconductor. The superconductor with hall arrays is in parallel with a shunt around which hall sensors are placed. Using the hall sensors array placed around the superconductor, we obtain a unique three dimensional map of the surface current density of the superconductor. We can generate such maps for macroscopic superconducting elements. Using the map, the current through the superconductor is continuously monitored and mapped via a computer interface. Using the measured current values being monitored across the superconductor, one can trigger switching of current path between superconductor and shunt. Thus unlike conventional fixed rating SFCL, our multipurpose SFCLsm can limit the current at any desired value which can be less than the critical current. These three dimensional maps are also used for the detection of any instability generated in the superconductor as well as detect when a fault is going to occur as the increasing current passing through the superconductor is detected by hall sensors. All of this imparts a smart aspect to conventional SFCL.

Acknowledgments: We would like to thank IIT Kanpur and Department of Science & Technology, Government of India for funding the project.

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SKYRMION-AFFECTED VORTEX DYNAMICS IN A MAGNET-SUPERCONDUCTOR HETEROSTRUCTURE

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Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Novel superconducting materials and heterostructures; Skyrmions / Soft matter systems and similarities with vortex physics.

We show the results of time-dependent Ginzburg-Landau simulations of vortex statics and dynamics in a superconducting film coupled to a chiral magnet in a hybrid heterostructure. We discuss the conditions on the stray field of skyrmions to nucleate vortex-antivortex structures in the superconductor, and how those interact with externally applied homogeneous magnetic field – changing simultaneously both skyrmion and vortex(-antivortex) configuration. Correspondingly, in applied current simulated vortex dynamics reveals rich features due to the presence of skyrmion background. This includes successive vortex-antivortex pair creations and annihilations at the skyrmion domain walls, interacting non-trivially with other moving vortices under applied drive, and changing strongly with inverted polarity of the applied current and/or applied magnetic field. Our results are in agreement with recent experiments conducted on similar hybrids [1], and offer insights into the underlying mechanisms of measurable quantities, be it static magnetization or transport I-V characteristics. Such realizations of a strongly interacting skyrmion-vortex system could open a path towards controllable topological hybrid materials, unattainable to date.

Acknowledgements: This work was supported by Research Foundation – Flanders (FWO)

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Effect of heavy ion irradiation on Mo_8Ga_{41} superconductor

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Keywords: Superconductivity, Flux pinning,

The endohedral gallide clusters involving transition metals provides a structural motif that supports theoccurrence of superconductivity[1-2]. We have grown polycrystalline samples of $Mo_8Ga_{41}$where the reported transition temperature is in the range of Nb-Ti. Towards studying its vortex dynamics properties, the samples were heavy ion beam irradiated with 950MeV Xe ions offluence 5 $\times10^{11}$ (S2), 1×10^{12}(S3),5 $\times10^{12}$ (S4), and 1×10^{13}(S5) ions per cm^2 at GANIL (France). Both unirradiated (S1) and irradiated samples were characterised by magneto-resistance and magnetization protocols. The calculated $J_c$at 2K by using Bean's model is found to be of order of $6\times10^5 A/cm^2$. In the heavy- ion (Xe) irradiated Mo_8Ga_{41} samples, the T_c decreases while the $J_c$increased gradually on increasing the fluence of the ion beam. The enhancement inJ_c can be attributed to the increment in the flux pinning centers in the compound due to irradiation. Similar enhancement in $J_c$is also observed on application of pressure[3]. The pinning property is analyzed using Kramer's formula that indicate the combined effect of point, surface and volume pinning in the irradiated samples.

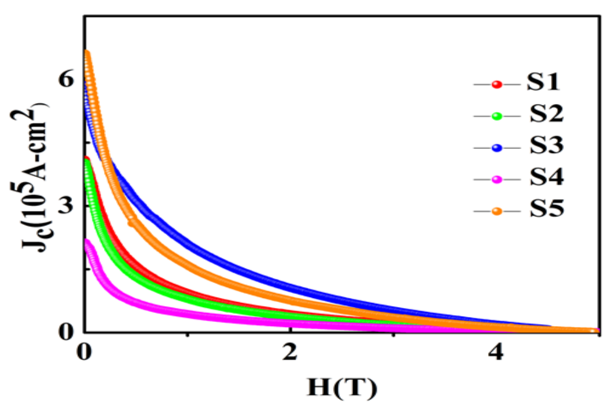

Figure1: Enhancement in critical current density on increasing the ion (Xe) fluence.

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Visualization by scanning SQUID microscopy of the intermediate state in the superconducting Dirac semimetal $PdTe_2$

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Keywords: Vortex phase diagram, Vortex imaging, Emergent flux patterns in unconventional SC or hydrids

The Dirac semimetal $PdTe_2$ becomes superconducting at a temperature T_c = 1.6 K. Thermodynamic and muon spin rotation experiments support type-I superconductivity, which is unusual for a binary compound. A key property of a type-I superconductor is the intermediate state which presents a coexistence of superconducting and normal domains at magnetic fields lower than the thermodynamic critical field Hc. We present Scanning SQUID microscopy (SSM) studies of $PdTe_2$ [1,2] revealing coexisting superconducting and normal domains of tubular and laminar shape as the magnetic field is more and more increased thus confirming type-I superconductivity in $PdTe_2$. Values for the domain wall width in the intermediate state have been derived. The field amplitudes measured at the surface indicate bending of the domain walls separating normal and the superconducting domains.

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Superconducting properties of in-plane W-C nanowires grown by He^+ focused ion beam induced deposition

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Keywords: superconducting devices and applications

Precise nanopatterning of functional nanostructures may be achieved making use of the Focused Ion Beam Induced Deposition technique (FIBID), which employs a focused beam of energetic ions to induce the decomposition of a gaseous precursor. While FIBID of the $W(CO)_6$ precursor using Ga^+ ions is known to yield a type-II superconducting material with T_c around 4.5 K [1,2], its growth using He^+ ions still remains relatively unexplored [3], with most reported results referring to 3D hollow nanopillars [4] and nanohelices [5]. The lighter nature of the ions used in He^+ FIBID allows for much higher lateral patterning resolution than that of Ga^+ FIBID, while keeping its flexibility and convenience for the growth of nanodevices [6]. Here, we explore the superconducting properties of in-plane W-C nanowires grown in this manner, achieving lateral patterning resolution down to 10 nm, virtually unattainable using Ga^+ FIBID. In addition, by perpendicularly injecting a driving current through one end of the nanowire, a Lorentz force is induced in the vortices therein, which in turn push their neighbours along the nanowire, eventually reaching the other end. As they move, they generate a finite resistance in areas depleted of current, which is then measured at the other end [7]. Exhibiting a comparable behaviour to that observed in nanowires grown by Ga^+ FIBID [8], this long-range non-local vortex transport effect is observed in He^+ FIBID W-C nanowires for the first time.

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STRUCTURAL TRANSFORMATION OF VORTEX LATTICE IN LOW-K SUPERCONDUCTORS

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Keywords: Vortex phase diagram.

We show that in s-wave superconductor with parameter k close to $1/\sqrt{2}$. equilibrium vortex lattice structure undergoes structural phase transition from hexagonal one in high magnetic field to vortex chains in low fields. Structural transformation of vortex lattice is macroscopic manifestation of attractive vortex-vortex interaction in low-k superconductors. Energy of various vortex configurations is calculated by numerical solving of Eilenberger equations.

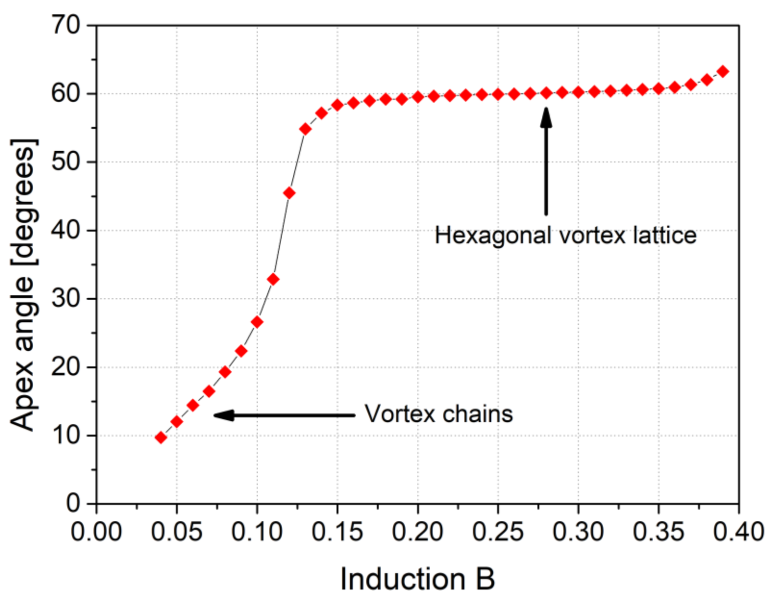

Fig: Equilibrium vortex lattice structure (described by apex angle between primitive vectors of vortex lattice unit cell) as function of magnetic induction B for $T = 0.5T_c$ and parameter $k = 0.8$. Magnetic field is in units $\Phi_0/2\pi R^2$ where $R = v_F/2\pi T_c$.

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MONODISPERSE CARBON SPHERES AS PINNING CENTERS FOR ENHANCED PROPERTIES OF MgB_2 SUPERCONDUCTOR CABLES

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Keywords: Vortex pinning and its applications.

It has been observed in superconductivity, that C impurities improve properties of MgB_2 samples at working conditions ($H > 1$ T).[1] The substitution of B with C distorts crystal structure and generates local fluctuations of the superconductor order parameter. On the other side, it has also been observed that nanoparticles generate 3D vortex pinning centres, independents of the direction of the applied magnetic field.[2]

In this work, we study properties of MgB_2 samples with monodisperse C spheres impurities acting as pinning centres.[3] Structural properties as well as superconducting properties are measured. Results are compared with samples of MgB_2 in concordance with superconductor cables of this material. Even no Mg substitution are expected in the MgB_2 lattice, results are in the order of those obtained using addition of SiC as controlled spherical impurities.

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This research is partially supported by ANPCyT throw PICT-2017-2898.

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Hall Effect for Dirac Electrons in Graphene Exposed to an Abrikosov Flux lattice

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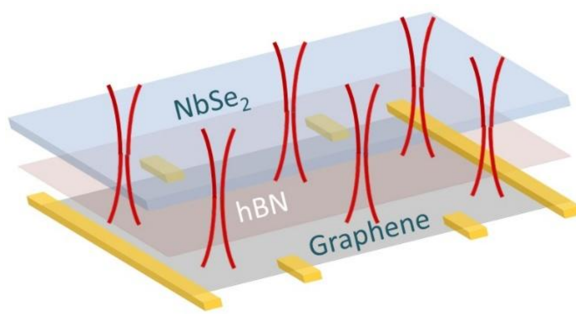
Keywords: Novel superconducting materials and heterostructures

The proposals for realizing exotic particles through coupling of quantum Hall effect to superconductivity involve spatially non-uniform magnetic fields [1-3]. As a step toward that goal, we study, both theoretically and experimentally, a system of Dirac electrons exposed to an Abrikosov flux lattice. We theoretically find that non-uniform magnetic field causes a carrier-density dependent reduction of the Hall conductivity. Our studies show that this reduction originates from a rather subtle effect: a levitation of the Berry curvature within Landau levels broadened by the non-uniform magnetic field. Experimentally, we measure the magneto-transport in a mono- layer graphene-hexagonal boron nitride - niobium di selenide ($NbSe_2$) heterostructure, and find a density-dependent reduction of the Hall resistivity of graphene as the temperature is lowered from above the superconducting critical temperature of $NbSe_2$,when the magnetic field is uniform, to below, where the magnetic field bunches into an Abrikosov flux lattice.



Device schematic: Abrikosov vortices (red color) are formed in the 40 nm thick NbSe2 flake and threaded into graphene layer residing at 10 nm (hBN thickness) below the NbSe2.

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A topological flux trap: Majorana bound states at screw dislocations

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Keywords: giant vortices, Caroli-de Gennes-Matricon states, screw dislocation

We study the electronic Caroli-de Gennes-Matricon states arising in the core of a giant vortex aligned with a screw dislocation. The breaking of inversion symmetry at the crystallographic defect, the parity (even/odd) of flux vorticity, and the Zeeman effect imprinted by the carried flux reveal a rich phenomenology of in-gap states. In particular, we find the possibility that this system hosts Majorana bound states at the sample termination. Most naturally the findings may be tested in weak type-I superconductors–where the sample thickness can tune the flux vorticity–and imaged in local probe experiments.

Conference Topics:
3. Vortex imaging; **11.** Topological superconductors/ hybrids (FM-SC)/Semiconductor – SC; **14.** Quantum Computation / Devices / Superconducting circuits;

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ENHANCEMENT IN THE μ-SQUID'S FLUX SENSITIVITY THROUGH STOCHASTIC RESONANCE

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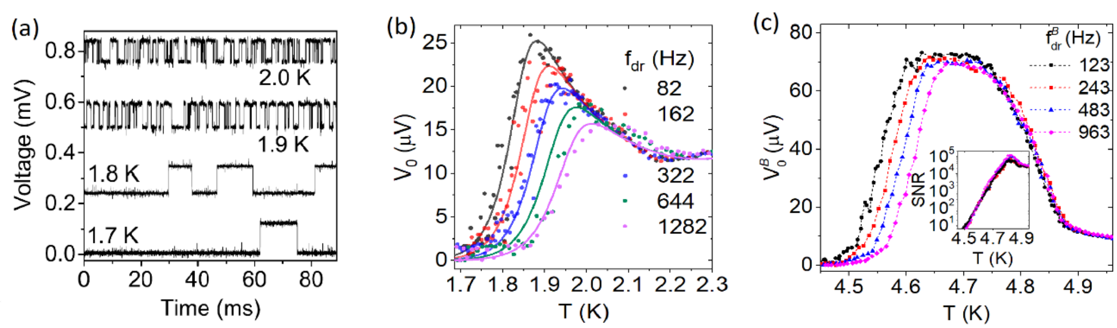
Keywords: Josephson phenomena, Superconducting devices and applications

Periodically driven bistable systems show an enhanced response when the noise-induced stochastic transition rate between the two states matches with the drive frequency. The random telegraphic noise (RTN) in response also gets synchronized with the drive. This is known as the phenomenon of stochastic resonance (SR). This was first invoked for explaining the periodic occurrence of "ice ages'' on earth [1] and has been studied in several bistable systems [2]. Constriction-based Josephson weak links (WL) display a thermal bistability between two states exhibiting zero and finite voltages. This manifests in experiments either as hysteresis in the current-voltage characteristics of weak links or as a RTN in voltage. In the latter case, a noise-driven amplification of a sinusoidal excitation of the device by an oscillating current is observed, at frequencies matching the characteristic switching frequency in the telegraphic signal. The observed behaviour is understood using a two-state model of SR, generalized for an asymmetric double well potential. In a μ-SQUID consisting of two weak links in parallel, the phenomenon of SR in its thermally bistable weak links has been exploited to improve magnetometry performance. An oscillating magnetic field, instead of an oscillating current, is used as a driving signal in a μ-SQUID. An enhanced signal to noise ratio, for an oscillating (driving) magnetic field, observed within the bistable region opens new perspective of noise induced improvement of the μ-SQUID flux sensitivity [3].



(a) RTN in WL voltage at symmetric bias, (b) Voltage response V_0 (T) for WL at different drive frequencies fitted to two state model of SR, (c) V^B_0 (T) for μ-SQUID showing SR with inset showing enhancement of SNR.

Acknowledgements: This work is supported by CEFIPRA, SERB-DST of the Govt. of India.

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Probing superconducting gap structure in La*M*Si(*M*=Ni, Pt) using muon spin rotation and relaxation

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Keywords: Novel superconducting materials and heterostructures

Systems with strong spin-orbit coupling have been a topic of fundamental interest in condensed matter physics due to the exotic topological phases and the unconventional phenomenon they exhibit [1]. In particular, noncentrosymmetric materials have garnered much attention due to the appearance of unconventional superconductivity. The lack of an inversion center in these systems induces an antisymmetric spin-orbit coupling (ASOC), favoring a mixed state of spin-singlet and triplet [2]. Such an admixed state is beyond the conventional understanding of superconductivity, as explained by BCS theory [3]. We have investigated the superconductivity in the transition-metal ternary noncentrosymmetric compounds La*M*Si (*M*=Ni, Pt). A theoretical study on similarly structured materials showed splitting of Fermi surface, depending on the atomic number Z of the constituent atoms [4]. Hence, La*M*Si (*M*=Ni, Pt) with heavy Pt and light Ni is a potential candidate to look for the effects of ASOC. Transverse-field muon spin rotation and relaxation measurements made in the vortex state indicate that the superconductivity in both materials is fully gapped, with a conventional *s*-wave pairing symmetry and BCS-like magnitudes for the zero-temperature gap energies. Zero-field measurements suggest a time-reversal symmetry preserved superconductivity in both the systems, though a small gradual increase in muon depolarization is observed upon decreasing temperature. This behavior can be attributed to quasistatic electronic fluctuations. However, the presence of electronic fluctuations in the superconducting state can be an indication of novel superconductivity, which needs to be further studied [5].

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Probing vortex dynamics in YBCO nanowire using RF illumination

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Keywords: Vortex motion, YBCO, nanowire, Shapiro steps.

Physics of moving vortices plays a crucial role in superconducting properties of such HTS as YBCO. It affects transport properties as moving vortex forms 2pi-phase slip that leads to voltage signal. Thus, the understanding of vortex movement is also important for applications of devices based on YBCO. We fabricated thin (30 nm thick) YBCO nanowire with length and width 500 nm and 200 nm correspondingly. We studied transport properties of it in dependency of temperature. Under constant current vortex experienced three different forces: the Lorenz force, the pinning force and the thermal force due to thermal fluctuations. Superposition of three of them defines vortex behaviour. We also added external microwave source with certain photon power to probe the value and interplay between pinning energy and thermal energy. We obtained Shapiro-like curves on current-voltage dependencies as it was approached by Likharev [1] using concept of synchronized vortex moving. In contrast with ordinary Shapiro steps in Josephson junctions we found that there are fractional steps in YBCO nanowire at low temperature and at some fixed microwave frequency and fixed temperature critical current is not fully suppress.

Conference Topics:
2. Vortex dynamics in bulk/nano/heterostructures/hybrids; **6.** Vortices in meso- and nanoscale systems; **7.** Vortex pinning and its applications; **8.** Superconducting devices and applications

Acknowledgements:

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Magneto-optical imaging and manipulation of Abrikosov vortices trapped in high-T_c superconductor

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Keywords: Vortex imaging

Visualisation of Abrikosov vortices in superconductors has given way to their manipulation for use in superconducting electronics as control bits [1,2]. Several techniques exist to simultaneously image and manipulate vortices but magneto-optical imaging (MOI) coupled with optical tweezers [3] offers the imaging speed required for real-time manipulation. While MOI performs well with low-T_c superconductors like niobium (Nb), the technique does not transfer to high-T_c superconductors like YBCO due to the background subtraction scheme required above and below T_c. Here we report for the first-time magneto-optical imaging of vortices in a high-T_c superconductor (YBCO) using a low-T_c superconductor (Nb) as proxy. The vortices initially trapped in YBCO undergo flux-retrapping [4] in Nb and are then imaged using the conventional MOI method. Displacement of vortices in Nb reveals the underlying YBCO vortices, shown in Figure 1. This method opens avenues for optical control of vortices in high-T_c superconducting devices and the possibility of interesting topological vortex physics [5].

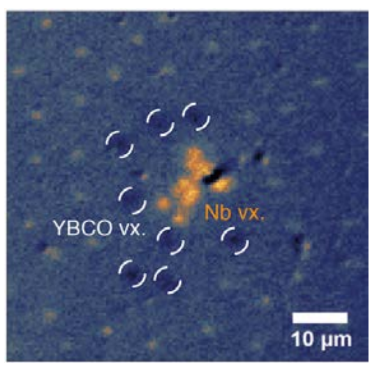

Figure 1. Magneto-optical image of displaced vortices in the niobium film revealing the underlying YBCO vortices

References:

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Nb-based nanoscale superconducting quantum interference devices tuned by electroannealing

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Keywords: Josephson phenomena, Superconducting devices and applications

In this work [1], we show that targeted and controlled modifications of the Josephson junction properties of a bridge-type Nb nanoSQUID can be achieved by an electroannealing process allowing to tune and tailor the response of a single device. The electroannealing consists in substantial Joule heating produced by large current densities followed by a rapid temperature quench. We report on a highly non-trivial evolution of the material properties when performing subsequent electroannealing steps. As the current density is increased, an initial stage characterized by a modest improvement of the superconducting critical temperature and normal-state conductivity of the bridges, is observed. This is followed by a rapid deterioration of the junction properties, i.e. decrease of critical temperature and conductivity. Strikingly, further electroannealing leads to a noteworthy recovery before irreversible damage is produced. Within the electroannealing regime where this remarkable resurrection of the superconducting properties are observed, the nanoSQUID can be operated in nonhysteretic mode in the whole temperature range and without compromising the critical temperature of the device. The proposed postprocessing is particularly appealing in view of its simplicity and robustness.

Reference:

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Confinement-engineered superconductor to correlated-insulator transition in a van der Waals monolayer

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Keywords: Superconductivity in 2D and interface superconductivity.

Transition metal dichalcogenides (TMDC) are a rich family of two-dimensional (2D) materials displaying a multitude of different quantum ground states with broken symmetry such as charge density waves (CDW), superconductivity, and magnetism. Among this family, $NbSe_2$ is a paradigmatic CDW and superconducting 2D material and it realizes Ising superconductivity at the monolayer limit. $NbSe_2$ has long been considered to be a metal where Coulomb repulsions play a marginal role, and the superconducting state arises from conventional electron-phonon coupling. The emergence of CDW states is usually attributed to soft-phonon modes, so that symmetry broken states are not related with strong Coulomb interactions. However, related compounds in the TMDC family such as VSe_2 and $TaSe_2$ are known to be strongly correlated materials with competing correlated states including magnetic Mott insulating state. Also, theoretical calculations have shown that $NbSe_2$ is close to a Mott insulating transition to a ferromagnetic state. In this work, we experimentally demonstrate that $NbSe_2$ is in proximity to a correlated insulating state, by controlling the strength of the electronic interactions by quantum confinement effects. We grow a crystalline sub-monolayer (ML) $NbSe_2$ with a wide variety of island sizes and their relative separations. Employing low-temperature scanning tunnelling microscopy and spectroscopy, we show that for ML-$NbSe_2$ of size several times the coherence length, repulsive electronic interactions create a phase transition from a superconducting to a correlated insulating state. This transition is rationalized from enhanced repulsive Coulomb interactions, which dramatically change the nature of the ground state in $NbSe_2$. We finally showed that for correlated ML-$NbSe_2$ islands close to the phase transition, superconducting proximity effect strongly impacts the ground state, pushing the system through the superconductor-correlated phase boundary. Our results emphasize the role of Coulomb interactions for the emergence of both CDW and superconductivity besides the typical electron-phonon driven scenarios in 2D TMDC's.

Acknowledgements: This research made use of the Aalto Nanomicroscopy Center (Aalto NMC) facilities and was supported by the European Research Council (ERC-2017-AdG no. 788185 "Artificial Designer Materials") and Academy of Finland (Academy professor funding nos. 318995 and 320555, Academy postdoctoral researcher no. 309975, Academy research fellow nos. 331342 and 336243).

Reference:

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Mechanisms of vortex-induced Josephson phase shift

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Keywords: Vortices in meso- and nanoscale systems, Superconducting devices and applications, Josephson phenomena.

Abrikosov vortices contain magnetic fields and circulating currents that decay at a short range lambda ~ 100 nm. However, vortices can induce Josephson phase shifts at a long range r >> lambda. Mechanisms of this phenomenon are not clearly understood. Here we present a systematic study of vortex-induced phase shifts in planar Josephson junctions. We make two key observations: (i) The cutoff effect: Although vortex-induced phase shift is a long-range phenomenon, it is terminated by the junction and does not persist beyond it. (ii) A linear to superlinear crossover with a rapid upturn of the phase shift occurs upon approaching a vortex to a junction. The crossover occurs at a vortex junction distance comparable to the penetration depth. This allows identification of two distinct and independent mechanisms. The short range mechanism is due to circulating vortex currents inside a superconducting electrode without involvement of magnetic fields. The long range mechanism is due to stray magnetic fields outside electrodes without circulating vortex currents. We argue that understanding of controlling parameters of vortex-induced Josephson phase shift can be used for development of novel compact cryoelectronic devices.

Observation of distinct spatial distributions of the zero- and non-zero energy vortex modes in $(Li_{0.84}Fe_{0.16})OHFeSe$

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Keywords: Vortex imaging; Vortices in meso- and nanoscale systems; Vortex matter vs. pairing symmetry; Topological superconductors/ hybrids (FM-SC)/Semiconductor – SC; Superconductivity in 2D and interface superconductivity

The energy and spatial distributions of vortex bound state in superconductors carry important information about superconducting pairing and the electronic structure. Although discrete vortex states, and sometimes a zero-energy mode, had been observed in several iron-based superconductors, their spatial properties are rarely explored. In this study, we used low-temperature scanning tunneling microscopy (STM) to measure the vortex state of (Li, Fe)OHFeSe with high spatial resolution. We found that the non-zero energy states display clear spatial oscillations with a period corresponding to bulk Fermi wavelength; while the zero-energy mode doesn't show such oscillation, which suggests its distinct electronic origin. Furthermore, the oscillations of positive and negative energy states near E_F are found to be clearly out-of-phase. Based on a two-band model calculation, we show that our observation is mostly consistent with an s_{++} wave pairing in the bulk of (Li, Fe)OHFeSe, and superconducting topological states on the surface.

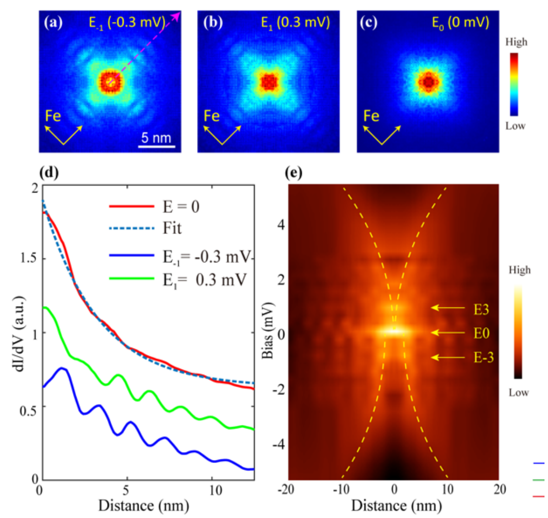

Fig.1(a,b,c) Four-fold symmetrized dI/dV maps of the E_{-1}, E_1 , E_0 states, respectively. (d) Vortex state profile: Line cuts taken along the Fe-Fe direction of the dI/dV maps of E_1, E_0, E_{-1} states. (e) Color plot of the symmetrized dI/dV line cuts taken at various energies.

Reference:

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Intrinsic Josephson junction $Bi_2Sr_2CaCu_2O_8$ terahertz sources: Achieving high power output above 77 K

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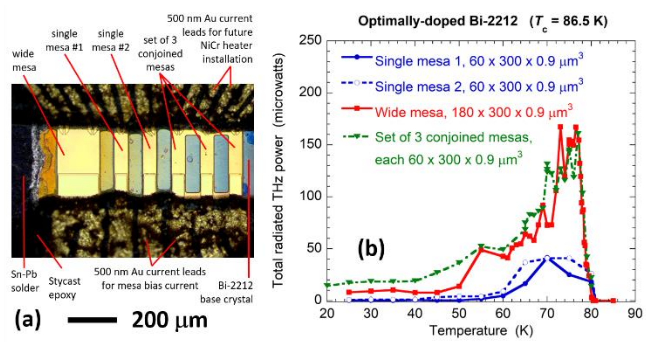
Keywords: Josephson phenomena, Superconducting devices and applications

The high-temperature superconductor $Bi_2Sr_2CaCu_2O_8$ contains stacked 'intrinsic' Josephson junctions, with very high packing density and a large superconducting gap energy. Rectangular ‘mesa’ devices constructed from this material are consequently a promising technology for coherent, continuous-wave radiation in the 'terahertz gap' range, spanning from approximately 0.3 – 1.5 THz. A key issue for technological applications of such devices is their cryocooling requirements, and it is therefore highly desirable to optimize their performance at temperatures that can be achieved while using liquid nitrogen cryogenics, or by using highly compact Stirling micro-cryocoolers. Here we report 0.13 milliwatts of coherent emission power at 0.5 THz, at a bath temperature of 77 Kelvin. We achieved this by exciting the (3, 0) cavity mode of a stack containing 580 junctions. In order to minimize self-heating, the THz source was mounted on a copper substrate using PbSn solder. We will discuss the choice of mesa dimensions and cavity mode, and future strategies for the design of $Bi_2Sr_2CaCu_2O_8$ THz devices that are intended to operate at 77 Kelvin or above.



(a) BSCCO THz sources tested in this work. (b) Maximum THz emission as a function of temperature [1].

Acknowledgements: This research is supported by PSC-CUNY Award 60792-00-48; and by the US Department of Energy, Office of Sciences, Materials Sciences and Engineering Division.

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VORTEX-ANTIVORTEX DYNAMICS BEYOND THE BKT STATE IN ION-GATED MoS_2

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Keywords: Vortex phase diagram; Vortex dynamics in bulk/nano/heterostructures/hybrids; Superconductivity in 2D and interface superconductivity.

In conventional 2D superconductor films, it is known that the true superconducting state is achieved at the Berezinskii–Kosterlitz–Thouless (BKT) transition in the low-current limit. However, the vortex and antivortex (V-AV) dynamics beyond the low-current region remains not fully understood, probably because of the effect of disorder on vortices. We tackled this issue using a gate-induced 2D superconductor, MoS_2, with minimal disorder by measuring the current-voltage (*I*-*V*) characteristics [1].

In the low-current region, we obtained the power law behavior $V \propto I^{\alpha}$ below the mean-field transition temperature T_{c0} = 7.6 K, which is followed by the BKT transition with the clear universal jump of α from 1 to 3 at T_{BKT} = 6.0 K. With increasing *I*, on the other hand, we found successive step-like increases in *V*(*I*) at the characteristic currents I_{c1}, I_{c2}, and I_{c3}; and in the *T*-dependence of the nonlinear resistance R_{NL} at T_1 and T_2, respectively. Eventually, we obtained the *I*-*T* dynamical phase diagram as shown in Fig. 1. Based on the calculation of the vortex velocity v_f, the anomaly at I_{c1} and T_1 can be ascribed to the dynamic transition of the V-AV pairs from the BKT state with $v_f \sim 10^3$ m/s (Abrikosov vortex flow) to the ultrafast dynamical state with $v_f \sim 10^5$ to 10^6 m/s (Josephson-like vortex flow) accompanying the phase-slip line across the conducting plane. I_3 and T_2 correspond to the transition to the partially normal region. The unexpected richness of the dynamical vortex diagram of Fig. 1 originates from the combination of the weak pinning force, low resistance, and enhanced fluctuations at the 2D limit in our high-crystallinity gated superconductors.

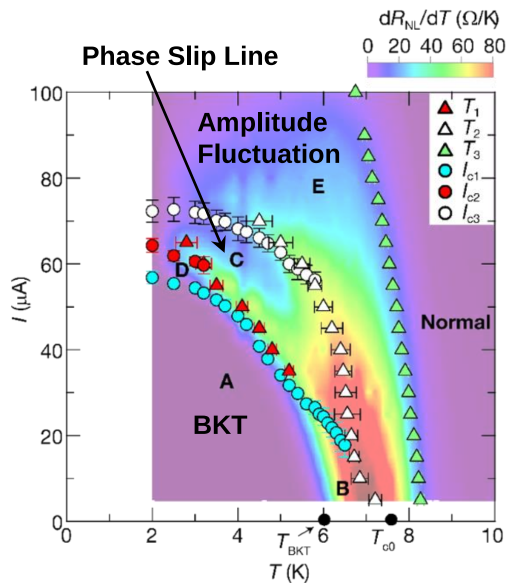

Fig.1 I-T phase diagram of ion-gated MoS_2 at zero magnetic field [1]. I_{c1}, I_{c2} and I_{c3}, or T_1 and T_2 are characteristic currents or temperatures at which the step-like increase in I-V or R_{NL} are observed. T_3 is the onset temperature of R_{NL}.

Reference:

[1] Y. Saito, Y. M. Itahashi, T. Nojima, Y. Iwasa, Phys. Rev. Mater. 4, 074003 (2020).

INTERPLAY BETWEEN KIBBLE-ZUREK MECHANISM AND INVERSE FARADAY EFFECT FOR ABRIKOSOV VORTEX GENERATION

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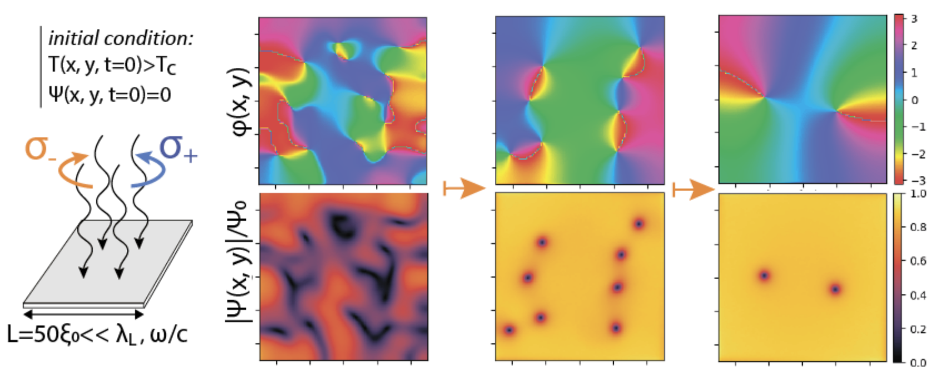
Keywords: Vortex dynamics in bulk/nano/heterostructures/hybrids; Vortices in meso- and nanoscale systems; Vortex pinning and its applications.

We found that the circularly polarized light can affect the Kibble-Zurek mechanism of the vortex-antivortex pair formation in a superconductor driven through the T_c point and expels the vortices of a certain polarity depending on the polarization sign. As a consequence one can create a nonzero vorticity and corresponding magnetic moment in a superconducting system using the polarized light realizing, thus, the Inverse Faraday Effect (IFE). We present the results of numerical simulation of the vortex generation due to the rapid thermal quench in a quasi-two dimensional superconductor exposed to the circularly polarized external electromagnetic field. Our calculations are based on the time dependent Ginzburg-Landau (TDGL) equation and we demonstrate that the described effect is related to the imaginary part of the relaxation time in the TDGL equation. This is in accordance with the recent theoretical studies of the IFE in superconductors [Mironov et al PRL 2021].



Time evolution of the modulus and phase of the order parameter Ψ(x,y,t) in a two-dimensional superconductor exposed to an external polarized light with the frequency ω. At t=0 the order parameter is equal to zero at each point, so superconductivity is recovered in the presence of an external homogeneous electromagnetic field with σ- polarization. The sign of polarization determines the sign of vortices remaining in the superconductor.

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Magnetic Field Penetration and Magnetizations in Nb, N-doped Nb and NbTi Plates

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Keywords: Vortex dynamics in bulk, Vortex pinning and its applications, Novel superconducting materials and heterostructures.

Magnetization hysteresis loops have been measured for Nb, N-doped Nb and NbTi plates with magnetic field parallel to the plane. It is found that the N-doped Nb has a full penetration field of about $H_f \approx 1610$ Oe which is higher than that of the pure Nb plate ($H_f \approx 1510$ Oe). This indicates that the N-doping effect in Nb can improve the performance of cavity with radio-frequency electromagnetic field. In contrast, the NbTi plate has a full penetration field of about 620 Oe, although a critical current persists to a high magnetic field due to the bulk pinning. A modified model for the critical state was proposed, which combines both the surface screening current and the bulk pinning in a self-consistent way. The model can be used to fit the experimental data of three kinds of samples fairly well and thus may be extended to a general case for studying the magnetization hysteresis in other type-II superconductors.

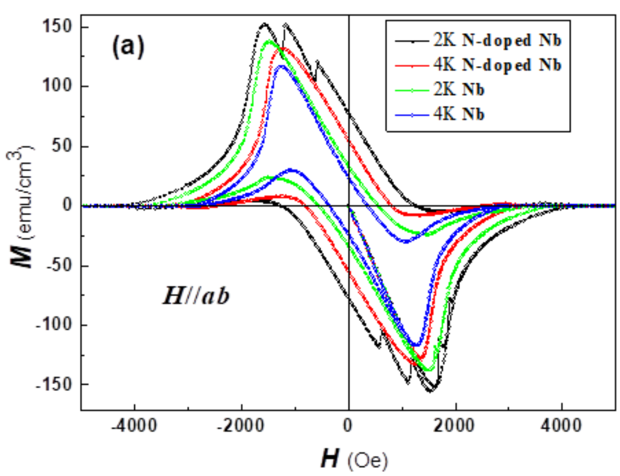

Fig.4(a). Magnetization hysteresis loops (MHLs) of N-doped Nb and pure Nb, with temperatures at 2K, 4K. The applied field H_a is parallel to the plane.

Acknowledgements:
This work was supported by the National Key R & D Program of China (Grant nos. 2016YFA0300401 and 2016YFA0401704) and National Natural Science Foundation of China (Grants: A0402/13001167, A0402/11534005 and A0402/11674164), and the Strategic Priority Research Program of Chinese Academy of Sciences (Grant No.XDB25000000).

Critical current and magnetic interference effects in topological superconducting arrays of Nb islands coupled through Bi_2Se_3 epitaxial films

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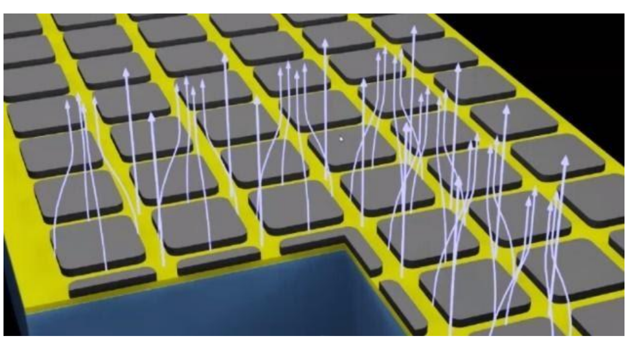
Keywords: Topological superconductors/ hybrids (FM-SC)/Semiconductor - SC; Emergent flux patterns in unconventional SC or hybrids

Placing an ordinary superconductor in a direct contact with a topological insulator (TI) enables topological superconductivity due to the proximity effect. Such systems have been predicted to harbor non-Abelian excitations, namely Majorana zero modes. Here we study matching fields and the critical current of a square array of superconducting Nb islands placed onto a topological insulator epitaxial film of Bi2Se3. The critical current temperature dependence is in agreement with the Eilenberger theory, indicating ballistic transport and the existence of a global topological superconducting state induced in the TI film. If the number of flux quanta per unit cell, *f*, is an integer, the critical current exhibits a sharp local maximum. The effect is analogous to the Little-Parks effect: If *f* is an integer then each unit cell can accept *f* vortices, thus minimizing the circulating currents globally and reducing the energy to the level of the ground state at zero field. Unexpectedly, the expected critical current peak at *f*=2 is missing in our arrays. This fact is remarkable since similar non-topological arrays did not show such peak disappearance [1]. Thus, at *f*=2 the usual 2π invariance of the array Hamiltonian breaks down, although the array remains superconducting globally. Interestingly, the value of the critical current at *f*=2 matches the estimated current carried by Majorana zero modes. We propose that such topological superconducting arrays can be used as sources of Majorana topological currents.



Schematic of the sample: Nb square islands (grey) form a periodic square lattice (the array). The applied magnetic field penetrates mostly in the gaps between the islands. The Nb islands are placed over a topological insulator film (green) sitting on c-plane sapphire (blue).

Acknowledgements: This work was supported by NSF DMR 18-36710.

Reference:

[1] C. G. L. Bøttcher, F. Nichele, M. Kjaergaard, H. J. Suominen, J. Shabani, C. J. Palmstrøm, and C. M. Marcus, Nat. Phys. 14, 1138 (2018).

Microscopic theory for disorder and anisotropy enhanced superconductivity in atomic layer crystalline materials

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Keywords: microscopic theory, noncentrosymmetric superconductivity, atomic layer crystalline materials, in-plane critical magnetic field, quasiparticle density of states

In the last decade, rapid progress in microfabrication technology and atomic layer materials research, as well as the integration and development of measurement technology in multiple extreme environments such as ultra-low temperature and ultra-high vacuum, has led to the measurement of the physical properties of a completely new material phase, namely, superconductivity in highly-crystalline atomic layers. Because of the highly-crystalline surface superconductivity, direct spectroscopic measurement of the superconducting state is possible, and experimental verification of the two-dimensional superconductivity, the hybridization effect of the wave function parity due to the spontaneous spatial inversion symmetry breaking on the surface, and the giant spin-orbit energy splitting due to the Rashba or generic anti-symmetric spin-orbit coupling effect are in full progress.

The subject of this study is superconductivity in In metal atomic layers and monatomic layer Tl-Pb alloys on a Si(111) substrate surface. Since these systems are not amorphous films but highly crystalline metal (alloy) atomic layers, the Fermi surfaces are well defined. Most of the previous theoretical studies have assumed an isotropic electronic structure plausible to amorphous films. However, we believe that the existence of a material-specific Fermi surface due to the highly crystalline atomic layer and the fact that it is highly anisotropic are important factors in understanding the superconducting properties of highly crystalline atomic layers. By constructing a microscopic theory incorporating information on the Fermi surface, we can discuss for the first time phenomena unique to highly crystalline atomic layers, such as giant in-plane critical fields and helical superconductivity, which cannot be obtained in amorphous thin films. In the presentation, we will discuss the effects of disorders and Fermi surface anisotropy on the in-plane critical field and quasiparticle density of states.

Vortices in $^3P_2$ Superfluid: Majorana fermion and non-Abelian half-quantum vortex

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Keywords: multicomponent superfluidity, Majorana zero modes, half quantum vortex.

Neutron stars are the largest topological materials in our Universe[1]. In their outer core region, the spin triplet superfluidity with the total angular momentum J=2 is expected to be realized, and it is called the $^3P_2$ superfluid. In addition, there must exist a huge number of quantized vortices as neutron stars rotate rapidly, analogous to rotating liquid helium superfluid. The possibility of the fractional vortices are pointed out in such a superfluid phase by the earlier works[2,3]. It may be an important issue to seek for the Majorana fermions known as a non-Abelian anyon in the fractional vortices.

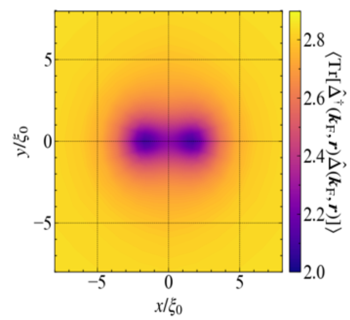

Figure 1 double core vortex at zero magnetic field

The authors perform the microscopic calculations of quantized vortices in nematic phases of the $^3P_2$ superfluid. There are rich vortex structures in the nematic phase because it is a multicomponent superfluid with discrete symmetry. The order parameter is determined self-consistently using the quasiclassical Eilenberger equation, and its energy stability is studied on the basis of the Luttinger-Ward energy functional. We also study the fermionic bound states in terms of whether the Majorana fermions exist or not using the Bogoliubov--de Gennes equation. We have found that the double core vortex without Majorana fermions are stable in the low magnetic field (Fig.1). In the D_4 biaxial nematic phase in the high magnetic field, the integer vortex is found to split into two half quantum vortices (HQVs) as indicated by their interaction energy (Fig.2). We have also clarified that each HQV has a Majorana fermion. Such a high magnetic field may be realized in a so-called magnetar.

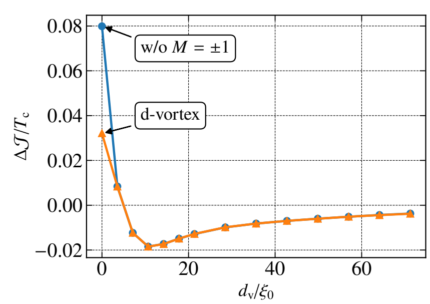

Figure 2 interaction energy of two HQVs

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Transport characterization and pinning analysis of $BaFe_{1.9}Ni_{0.1}As_{2.05}$ thin films

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We report on the vortex-glass transition and superconducting performance of $BaFe_{1.9}Ni_{0.1}As_{2.05}$ thin films with T_c = 17.8 K on CaF_2(00l) single crystals by pulsed laser deposition. Atomic force microscopy characterization indicates the volumes of droplets appearing on the film surface increase with thickness and Magneto-optical imaging proves slight inhomogeneities in the current flow within the *ab*-plane of thin film. The thin films show a transport current density J_c of ~1.14 MA cm^{-2} in self-field, and 0.34 and 0.28 MA cm^{-2} for *H//c* and *H//ab* up to 9 T at 4.2 K. Pinning mechanism associated with the fluctuations in the mean free path of the charge carriers is found to be dominant in the thin films. The vortex-glass (VG) to vortex-liquid phase transition is identified in terms of the plots of the logarithmic derivative of the resistivity curves under different fields, allowing us to deduce the values of the VG transition temperature T_g, and the critical exponent *s*. The ρ–T curves are well scaled by VG theory. A phase diagram combining the VG transition temperature, irreversibility field and upper critical field is constructed.

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