Peter Armitage

Johns Hopkins University, Baltimore, USA

On the nature of below-gap dissipation in disordered superconductors

It has been noticed for a number of years that in highly disordered superconductors, anomalous absorption and spectral weight develops in the superconducting gap. This has been observed in many different systems including granular superconductors, amorphous superconducting thin films, and high temperature superconductors with intrinsic disorder. The ubiquity of this observation points to the possibility of a universal explanation, but there is as of yet no accepted explanation for this phenomena. In this work we investigated the subgap spectral weight in disordered superconducting NbN thin films with time-domain terahertz spectroscopy. Various explanations for this anomalous dissipation will be discussed in the context of existing theories.

Emilio Artacho

University of Cambridge, UK

On the origin of the two-dimensional electron gas at the interface between insulating perovskites

There is considerable interest in the two-dimensional electron gas obtained at the interface between perovskite oxides such as lanthanum aluminate and strontium titanate. In addition to foreseeable applications for devices, the interest is also fundamental, due to interesting observed behaviour: superconductivity, magnetism, and possibly their coexistence, among others. We will discuss some ideas about the origin of the gas and the character of the metal to insulator transition when it forms, either with film thickness or with external applied electric field.

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Paola Barbara

Georgetown University, Washington D.C., USA

Electronic transport and superconductivity at van Hove singularities in carbon nanotubes

The connection between VHSs and superconductivity has been discussed since the discovery of the cuprate superconductors, when a van Hove scenario was proposed as a route to superconductivity. However, a clear experimental demonstration of a direct link between superconductivity and VHSs is still lacking.

Here I will report our observation of an anomalous increase of conductance (zero bias anomaly or ZBA) below 30 K, in carbon nanotubes that are gated in proximity of a van Hove singularity. I will argue that intrinsic superconductivity in the carbon nanotube is a plausible explanation and present a theoretical model to fit the experimental data. Although we previously reported the observation of ZBAs in carbon nanotubes at high values of gate voltage [1, 2], more recent data provide the experimental evidence that such a feature appears in proximity to the van Hove singularity in carbon nanotubes [3].

Nicolas Bergeal

ESPCI, Paris, France

Quantum phase transitions at oxide interfaces

At the interface between insulating oxides such as $SrTiO_3/LaAlO_3$ or $LaTiO_3/SrTiO_3$, a superconducting two-dimensional electron gas (2DEG) has been discovered [1-3], whose carrier density can be tuned by applying a gate voltage. Within the quantum well, a strong (a few meV) Spin Orbit Coupling has been measured. Using back and top gating, we recently showed that it is directly proportional to the electric field, as expected for a Rashba mechanism [4]. The unique possibility of modulating the superfluid density easily and continuously opens new perspectives to tackle fundamental issues in condensed matter physics, such as the Superconductor to Insulator Quantum Phase Transition (QPT) in a two-dimensional system. Using two different external parameters, the magnetic field and the electric field, we explored the phase diagram of the 2DEG. As proposed theoretically [5], we point out that the system can be described as a disordered array of coupled superconducting puddles. Depending on the conductance, the observed critical behaviour is single (corresponding to the long-range phase coherence in the whole array) or double (one at intermediate distances belonging to the (2+1)D clean XY universality class related to local phase coherence, the other one to the array of puddles)[6]. Moreover, by retrieving the coherence-length critical exponent ν, we show that the quantum critical behaviour can be clean or dirty, depending on whether the phase-coherence length is smaller or larger than the size of the puddles. Finally, the electric-field driven QPT reveals an anomalous critical behavior. It can be understood if we assume that the dynamics in the Cooper pair channel is dominated by (nearly critical dynamical) density fluctuations in the low doping regime. This shades a new light on unexplained critical exponents found in the literature.

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Mark Blamire

University of Cambridge, UK

Superconducting tunneling through spin filter barriers

A tunnel current through a ferromagnetic insulator (FI) is strongly spin polarised because the exchange splitting of the FI density of states (DOS) results in spin-dependent barrier heights. In the case that the electrodes are superconducting pair and quasiparticle tunneling are affected by both by the spin filtering effect of the barrier and by the exchange field of the FI which can Zeeman split the superconductor DOS. We have shown that we can create NbN/GdN/NbN spin filter Josephson junctions[1,2] and that the current-phase relation of these devices is highly unconventional[3]. This talk will cover recent result relating to Zeeman splitting and the role of spin-triplet pairs in the tunneling process.

Sangita Bose

Centre for Excellence in Basic Sciences, Mumbai, India

Superconducting Nanostructures

Superconducting properties are expected to show significant modifications when the system dimensions become smaller than the characteristic length scales for bulk superconductors. Lately, the rapid improvements in experimental methods related to the fabrication and feasibility of studying low dimensional superconductors have led to the study of new and exotic effects in these nanoscale systems. In this talk, I will review the studies on superconducting nanostructures from ensembles to single, isolated particles to arrays of superconducting islands. I will present the results of “parity effects”, “shell effects” and “giant vortices” observed in these systems. The effect of quantum and thermal fluctuations on different superconducting properties in nanostructures will also be discussed. Finally, I will present how quantum confinement controls the size-evolution of the superconducting transition temperature which in some cases also leads to enhancement of superconductivity from the bulk limit.

Vincent Bouchiat

Institut NÉEL, CNRS, Grenoble, France

Field effect controlled superconductivity in metal decorated graphene

The easily accessible 2D electron gas offered by graphene provides an ideal platform on which to tune, via application of an electrostatic gate, the coupling between adsorbates deposited on its surface. This situation is particularly interesting when the network of adsorbates can induce some electronic order within the underlying graphene substrate, such as magnetic or superconducting correlations. We have experimentally studied the case of macroscopic graphene decorated with an array of superconducting tin clusters, which induce via percolation of proximity effect a global but tunable 2D superconducting state. By adjusting the graphene disorder and its charge carrier density on one side , the geometry and size of the superconducting dot network on the other side, the superconducting state can exhibit very different behaviors, allowing to test different regimes and quantum phase transition from a granular superconductor to either metallic or insulating states. We will show recent experimental results involving set of triangular arrays sparsely distributed on graphene, in which superconductivity is suddenly destroyed for a critical gate value due to quantum fluctuations of the phase giving rise to an intermediate metallic state .

Alexander Brinkman University of Twente, Enschede, The Netherland

Proximity induced topological superconductivity

New electronic phases emerge at the interface between 3D topological insulators (TI) and superconductors. The observability of a p-wave order parameter symmetry and Majorana bound states in these devices will be discussed. Our experimental efforts have concentrated on inducing superconductivity into Bi based TI by the proximity effect from superconducting Nb elecrodes. Josephson junction characteristics and dI/dV spectroscopy results provide insight into the prospects of using topological superconductivity towards Majorana detection and topological quantum computation.

Claudio Castellani Sapienza University of Rome, Italy

Intra-gap optical absorption in disordered superconductors

We study the disordered attractive Hubbard model by solving the BdG equations on two-dimensional finite clusters at zero temperature. By coupling the sample to an external field we find that the current density is strongly inhomogeneous, with almost one-dimensional patterns, in rough agreement with Ioffe and Mezard recent proposal of a low temperature glassy phase in disorder superconductors. The optical conductivity besides the quasi-particle contribution shows an intra-gap absorption due to collective modes. These excitations are related to the phase of the superconducting (SC) order parameter and for clean systems they are optically inactive. Here we show that for strongly disordered superconductors the phase modes acquire a dipole moment and appear as a subgap spectral feature in the optical conductivity. In the strongly disordered regime, where the system displays an effective granularity of the SC properties, the optically active dipoles are linked to the isolated SC islands, offering a new perspective for microwave measurements and optical devices.

Eduard Driessen IRAM, Grenoble, France

STM experiments on electrically connected superconducting TiN nanowires locally driven out of equilibrium

Superconducting materials with a large normal-state resistivity, such as TiN, exhibit a lot of interesting physics due to the proximity to the superconductor-insulator quantum phase transition. By now, the equilibrium properties of these materials have been extensively studied, and experimental evidence for e.g. phase fluctuations and an inhomogeneous superconducting state are abundant. The non-equilibrium properties of these materials remain however untraded territory.

I will present STM measurements on a single, electrically connected TiN nanowire close to the superconductor-insulator transition. I will show how a small tunneling current (< 1 nA) can be used as a local perturbation of the superconductor that is measured by its global consequence: a severe reduction of the critical current of the wire (from 1.2 uA to 250 nA). The magnitude of the effect is linked to the existing (equilibrium) electronic inhomogeneity in the material. The results underline that the inhomogeneity in strongly disordered superconductors has a strong impact on the performance of the superconducting state.

Stefano Gariglio

University of Geneva, Switzerland

Study of Superconductivity at LaAlO3/SrTiO3 Interfaces by Field Effect

The discovery of a superconducting 2D electron liquid at the interface between the two oxides LaAlO3 and SrTiO3 has provided a platform to study superconductivity in reduced dimensionality [1]. Moreover, the confinement between the two insulating materials offers a natural setting for field effect experiments [2]. In this presentation, I will discuss field effect experiments aimed at modulating the electron liquid properties [3], with particular emphasis on the tuning of the superconducting state.

Arindam Ghosh

Indian Institute of Science, Bangalore, India

Probing superconductivity in low-dimensional systems with conductivity noise

There is a recent surge of interest in low dimensional systems which are either superconductors themselves, or acts as unique hosts of proximity-induced superconductivity. The associated phenomenology is complex, where questions ranging from the nature of superconducting correlations to new modes of Andreev reflections are becoming important. Here we have adopted a novel route to probe superconductivity where we measure the low frequency fluctuations in conductivity, or noise, close to the superconducting transition. In the first part of the talk, I shall present evidence of long range correlations in the time dependent noise in ultra-thin NbN films close to normal-superconductor transition when the film thickness is reduced below the superconducting correlation length. In the second part of the presentation, noise (as a function of Fermi energy) in the conductivity of graphene with superconducting Al contacts will be presented, where we have observed a dramatic increase in noise possibly arising from new phase coherent Andreev modes at the superconductor-graphene interface.

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V. Kochat, K. Damle and A. Ghosh (To be published)

Marco Grilli

Sapienza University of Rome, Italy

Nanoscopic inhomogeneity, intrinsic charge instability, and novel metal-to-superconductor quantum

Experiments in oxide interfaces like LaAlO3/SrTiO3 or LaTiO3/SrTiO3 (LXO/STO) heterostructures, strongly indicate that the 2D electron gas and the resulting superconducting state at the interface is strongly inhomogeneous on the nanoscopic scale[1]. Microscopic mechanisms for *criticality in oxide heterostructures*

electronic phase separation (EPS) based on Rashba spin-orbit coupling (RSOC) [2] and/or electrostatic electron confinement at the interface [3] are investigated to establish a possible intrinsic origin for this inhomogeneous character of LAO/STO or LTO/STO superconductors. Both RSOC and electrostatic confinement not only provide an intrinsic mechanism for the observed inhomogeneity, but also open the way to new interpretations of the observed quantum critical behaviour of superconductivity in LXO/STO [4,5]. We investigate the effects of temperature, gating, and magnetic field on the charge instability finding a novel type of SC-to-metal quantum criticality related to the vanishing of the critical temperature of the EPS [5].

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Wanzheng Hu

MPI Hamburg, Germany

Light control of correlated electron systems

Light control is a new branch in time-resolved optical spectroscopy. It uses ultra-short infrared laser pulses to drive selected modes in the solids. In this way, highly unconventional states inaccessible under equilibrium conditions can be achieved. In this talk, I will show two examples: the light-induced transient superconductivity in cuprate superconductors, and the phonon-driven insulator to metal transition in nickelate heterostructures.

Harold Hwang

Stanford University, USA

Superconductivity in SrTiO3 Heterostructures

Shahal Ilani

Weizmann Institute, Rehovot, Israel

Attraction by Repulsion: Pairing electrons by electrons

I will describe recent experiments that test the fundamental concept proposed by William Little 50 years ago that electrons can pair up via only repulsive interactions with other electrons. The experiments demonstrate in highly controlled carbon nanotube devices that an two electrons in one nanotube attract each other via their repulsion to other electrons in an effective medium formed in a different, adjacent nanotube.,

Jienfeng Jia

Shanghai Jiao Tong University, China

Superconductivity in single-layer films of FeSe with a transition temperature above 100 K

Recent experiments on FeSe films grown on SrTiO3 (STO) suggest that interface effects can be used as a means to reach superconducting critical temperatures (Tc) of up to 80 K. This is nearly ten times the Tc of bulk FeSe and higher than the record value of 56 K for known bulk Fe-based superconductors. Together with recent studies of superconductivity at oxides heterostructure interfaces, these results rekindle the long-standing idea that electron pairing at interfaces between two different materials can be tailored to achieve high temperature superconductivity. Subsequent angle-resolved photoemission spectroscopy measurements of the FeSe/STO system revealed an electronic structure distinct from bulk FeSe, with an energy gap vanishing at around 65 K. However, ex situ electrical transport measurements have so far only detected zero-resistance - the key experimental signature of superconductivity - below 30 K. Here we report the observation of superconductivity with Tc above 100 K in the FeSe/STO system by means of in situ 4-point probe electrical transport measurements. This finding confirms FeSe/STO as an ideal material for studying high-Tc superconductivity.

Brigitte Leridon

ESPCI, Paris

Confinement of superconducting fluctuations due to emergent electronic inhomogeneities in ultrathin NbN

The question of homogeneity, granularity, or glassiness of materials on the verge of a superconductor/insulator transition is fundamental and hotly debated. It is also of particular relevance for applications such as single photon detectors built with ultra thin NbN stripes [1]. Here, by combining transport and scanning tunneling spectroscopy studies of superconducting ultrathin NbN films, we reveal some nanoscopic electronic inhomogeneities that emerge when the film thickness is reduced. STS measurements show that these inhomogeneities persist above the critical temperature Tc and their correlation length Li is the same below and above Tc. They are also shown to be independent from the structural inhomogeneities. While thicker films display a purely Aslamazov-Larkin [2] two-dimensional behavior in the fluctuation conductivity, we demonstrate an Aslamazov-Larkin zero-dimensional regime [3] in the superconducting thermal fluctuations for the thinner samples. Remarkably, the typical length scale, 20-40 nm, extracted from the fluctuation conductivity coincides with the correlation length of the electronic inhomogeneities revealed by local scanning tunneling spectroscopy. In addition, the critical exponents inferred from the study of the magnetic-field-tuned transition at low-temperature are consistent with a two-dimensional quantum XY model, suggesting that these inhomogeneities behave like an assembly of "supergrains" coupled by Josephson effect.

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Jainming Lu

Zernike Institute for Advanced Materials, Groningen, The Netherlands

Huge upper critical field of ionic gated MoS2

In superconductivity induced in layered transition metal dichalcogenides (TMD) by electric-double-layer (EDL) gating, the inversion symmetry breaking at the surface can dramatically modify the bulk energy band by establishing a direct gap between conduction and valence bands at the edge of Brillouin zone, where spin degeneracy is lifted in both bands by out-of-plane effective Zeeman type spin-orbit coupling (SOC). In ion-gated TMD flakes, this Zeeman type SOC exhibits strong protection of superconductivity, which manifests as significantly enhanced in-plane upper critical field in magnetotransport, an order of magnitude bigger compared to bulk superconducting phases where the same Zeeman type SOC is eliminated by interlayer coupling. Our observation highlights the multifaceted nature of ionic gating, which not only induces dense charge carriers but also change the electronic structure by breaking inversion symmetry, which together with spin-orbit couplings can develop novel intrinsic property in the interface superconductivity.

Pinaki Majumdar

Harish-Chandra Research Institute, Allahabad, India

Spatial textures and thermal fluctuations near the superconductor-insulator transition.

Scanning tunneling spectroscopy reveals the presence of superconducting nanoregions well past the bulk thermal transition in strongly disordered superconductors. We use a recent method to compute the spatially diffentiated fluctuations in such a material and establish spatial maps of the coherence peak as the superconductor is driven through the thermal transition. The local density of states reveals that superconducting regions shrink and fragment with increasing temperature, but survive in small clusters to a temperature T_clust much greater than T_c. The gap (or pseudogap) in the spectrum survives in general to another independent scale, Tg. This multiple scale description, we feel, defines the frame work for analysing strongly disordered superconductors.

Jochen Mannhart MPI, Stuttgart, Germany

Superconducting Phenomena in the Insulating Regime of the $LaAlO_3$–$SrTiO_3$ Interface

The electron liquid at the $LaAlO_3$-$SrTiO_3$ interface is a two-dimensional superconductor that simultaneously displays magnetic order. We explored this remarkable state using a planar tunnel junction technology that allows to measure the spectral density-of-states of the superconducting liquid while tuning its carrier density by electric fields [1]. These studies yield surprising results, as characteristic features of the interface superconductor are found to be analogous to features deemed characteristic for the high-T_c cuprates. Our studies show macroscopically phase-coherent Cooper pairs to be present in the insulating state of the system.

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Nadya Mason University of Illinois, Urbana, USA

Engineering Interactions in Arrays of Superconducting Islands

In this talk, I will discuss a “bottom-up” approach to studying collective effects in matter via nanostructured arrays of superconducting islands. We fabricate large arrays of superconducting islands patterned on normal metal films; by changing the size and configuration of the islands, we can to tune the parameters relevant to 2D superconductivity, such as disorder, dissipation, and phase separation. I will discuss electrical transport measurements of these systems, including characterization of the superconducting transitions, vortex dynamics in finite magnetic-fields, and evidence that the system approaches an unusual metallic ground state as the island spacing is increased. I will also discuss the mechanism behind the suppression of superconductivity in individual granular islands, even at large diameters.

Karen Michaeli Weizmann Institute, Rehovot, Israel

Superconductivity in the presence of spin-orbit coupling - old dog, new tricks

The coupling between the spin of an electron and its momentum is recognized to generate a variety of new phases in condensed matter systems. For example, in symmetry broken states, spin-orbit coupling permits exotic low energy excitations such as skyrmions in helimagnets. The interplay between superconductivity and spin-orbit effects gives rise to additional surprising features, which I will discuss in my talk. For instance, it stabilizes a condensate of Cooper pairs with finite momentum (a variant of the Fulde-Ferrel-Larkin-Ovchinikov state) up to high magnetic fields. More generally, in the presence of spin-orbit coupling a superconductor has a peculiar mixed state in which vortices resemble magnetic monopoles. I will discuss the consequence of this feature on various superconducting properties.

Uwe Pracht Physikalisches Institut, University of Stuttgart, Germany

Pairing enhancement versus phase disordering in coupled nanograins of a conventional superconductor

We performed optical spectroscopy on granular aluminum, i.e. thin films composed of coupled nanograins, in order to study the development of the relevant superconducting energy scales as a function of grain coupling. We report a striking enhancement of the superconducting gap as the sample resistivity increases, with a consequent increase of Tc. In contrast, in weakly-coupled grains the gap tends to saturates while Tc decreases, concomitantly with a sharp decline of the superfluid stiffness. The crossover to a phase-driven superconducting transition is accompanied by the emergence of a pseudogap-like optical gap. Our findings demonstrate that granular aluminum is an ideal playground to test the basic mechanisms involved in the formation of a phase-coherent superconductor out of an inhomogeneous state with large local pairing.

Goetz Seibold

Institut F□ur Physik, BTU Cottbus

Intrinsic spin Hall effect in systems with striped spin-orbit coupling

The Rashba spin-orbit coupling arising from structure inversion asymmetry couples spin and momentum degrees of freedom providing a suitable (and very intensively investigated) environment for spintronic effects and devices. In this framework, the spin-Hall effect is a crucial ingredient since it allows for the manipulation of spin degrees of freedom without magnetic fields. Here we show that, in the presence of disorder, a striped modulation of a two-dimensional electron gas, affecting both density and Rashba spin-orbit coupling, gives rise to a finite spin Hall conductivity in contrast with the corresponding homogeneous system. We suggest that this mechanism can be exploited for a practical realization of a spin-Hall device. This could be implemented at oxide interfaces with periodic top gating, leading to a large ratio between the induced spin and charge currents.

Dan Shahar

Weizmann Institute, Rehovot, Israel

The superconductor-insulator transition

In this talk I will review recent developments in the study of the superconductor-insulator transition. Special emphasis will be put on experiments probing high-frequency Higgs-like excitations, tunneling studies and other probes of the insulating state.

Mikhail Skvortsov

Skolkovo Institute of Science and Technology, Skolkovo, Russia

Superfluid density in inhomogeneous superconductors

A theory of electromagnetic response in disordered superconductors beyond the mean-field approximation is developed. It is shown that the Mattis-Bardeen theory breaks down due to imhomogeneities. Relation between reduction of the superfluid density and suppression of the coherence peak is discussed.

Daniela Stornaiuolo

University of Naple Federico II, Italy

Tunable superconductivity and spin polarization in an oxide two-dimensional system.

The control of individual atomic layers in oxide heterostructures paves the way to the creation of new structures with functionalities dominated by the interface physics. A notable example is the $LaAlO_3/SrTiO_3$ interface, where a 2 dimensional electron gas (2DEG) is created [1]. It exhibits a wide range of properties, including superconductivity and spin orbit coupling, both tunable using field effect. Here we show that robust ferromagnetism can be induced in this system by depositing few unit cells of delta-doping $EuTiO_3$ between $SrTiO_3$ and $LaAlO_3$ (LAO/ETO/STO)[2]. Polarization dependent x-ray absorption spectroscopy and magnetotransport studies give evidence of the creation of a spin-polarized 2DEG with spin orbit coupling, while ultra low temperature measurements show a superconducting transition. All these properties are fully tunable using field effect. The results are condensed in a rich phase diagram, showing how LAO/ETO/STO spans different ground states as function of the carrier density. The presence of a superconducting and of a ferromagnetic ground state in the same system, showing also spin orbit coupling, is of great interest for the emergence of novel quantum states in confined systems.

James Valles

Brown University, Providence, USA

TBA

Summary of the conference topics

Lili Wang

Tsinghua University, Bejing, China

The superconductivity in single-layer FeTe1-xSex films on SrTiO3

For bulk FeSe, the critical transition temperature Tc = 8 K has been observed for the composition with stoichiometry $Fe_{1.1}Se$. The tetragonal-orthorhombic structural transition observed in FeSe is suppressed with Te substitution and the superconducting transition temperature reaches a maximum of Tc =15.2 K at about 50% Te substitution.

We prepared single unit cell $FeTe_{1-x}Se_x$ films on $SrTiO_3$ by molecular beam epitaxy. *In situ* scanning tunneling microscopy revealed a superconducting gap as large as 20 meV in single unit-cell thick FeSe films [1]. By *ex situ* transport measurements on single unit-cell thick FeSe films protected with FeTe layer, we demonstrated an onset T_C above 40 K and a critical current density $J_C \sim 1.7\times10^6$ A/cm^2 at 2 K [2], which are much higher than $T_C \sim 8$ K and $J_C \sim 10^4$ A/cm^2 for bulk FeSe. We also found that Te substitution in the single-layer FeSe films doesn't induce further increase of the transition temperature Tc, which is in contrast to the results in the corresponding bulk materials. This implies that the $SrTiO_3$ substrates paly important role in the interfacial superconductivity.

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