Abstracts: Condensed Matter Physics in the City 2023

"Quantum Materials, Information and Technology"

Monday 10 July

10:00 Shuqiu Wang (Oxford University)
"Visualizing the Surface States of the Spin-Triplet Superconductor UTe_2"

Although topological spin-triplet superconductivity appears probable in UTe_2, the superconductive order-parameter of this material has not yet been established. Many diverse forms for are physically possible including a pair density wave [1] exhibiting spatially modulating superconductive order-parameter. To search for a PDW, we visualize the pairing energy-gap with energy-resolution using superconductive STM tips. We detect three PDWs modulating at and at incommensurate wavevectors [2]. Concurrent visualization of the UTe_2 superconductive PDWs and the non-superconductive CDWs reveals a relative spatial phase. Given UTe_2 as a spin-triplet superconductor, this PDW state should be a spintriplet pair density wave, an unprecedented state of quantum matter.

A spin-triplet superconductor should also have odd parity so that and, in addition, may also break time-reversal symmetry into a chiral state. A distinctive identifier of all odd-parity superconductors is the ubiquitous appearance of a zeroenergy surface Andreev bound state (SABS). Moreover, theory shows that specific SABS characteristics observable in tunnelling to an *s*-wave superconductor distinguish between chiral and non-chiral. To search for such phenomena in UTe_2 we employ *s*-wave superconductive scan-tip imaging to discover a powerful zero-energy SABS [3]. Atomic-resolution visualization of this SABS yields quasiparticle scattering interference signatures of two nodes aligned with the crystal *a*-axis. Most critically, development of two finite-energy conductance maxima as the tunnel barrier is reduced, demonstrates that UTe_2 superconductivity is non-chiral. Overall, this combination of a zero-energy SABS, internodal scattering along the *a*-axis, and splitting of Andreev conductance maxima with diminishing tunnel barrier identifies spectroscopically of UTe_2 as the odd-parity non-chiral B_{3u} state.

[1] Yu, *et al*. *Phys. Rev. B* 105, 174520(2022).
[2] ***Nature*,** 618, 921–927 (2023)
[3] Gu, Wang, *et al*. (2023).

11:40 Ashvin Vishwanath (Harvard U)
“Non-Abelian topological order in synthetic quantum systems .”

Non abelian topological orders are remarkable quantum states of matter, which host “non-Abelions”, particle excitations that display a significant generalization of quantum statistics. The unambiguous experimental realization of these states is challenging but highly desirable, not just for their possible application to fault tolerant quantum computing, but equally for the unique physical properties they display. I will describe a newly discovered route to efficiently creating non-Abelian topological order which utilizes measurements in an essential way. We leverage this theoretical proposal in collaboration with Quantinuum’s trapped ion platform to create a nonAbelian topological phase whose exotic braiding statistics could be unambiguously demonstrated for the first time. I will highlight some unique features of non-Abelions that came to the fore during this exploration and the power of measurements in preparing quantum states.

14.30 Roopayan Ghosh
"*Separability criterion using one observable for special states: Entanglement detection via quantum quench"*

Detecting entanglement in many-body quantum systems is crucial but challenging, typically requiring multiple measurements. Here, we establish the class of states where measuring connected correlations in just {\em one} basis is sufficient and necessary to detect separability, provided the appropriate basis and observables are chosen. This methodology leverages prior information about the state, which, although insufficient to reveal the complete state or its entanglement, enables our one basis approach to be effective. We discuss the possibility of one observable entanglement detection in a variety of systems, including those without conserved charges, such as the Transverse Ising model, reaching the appropriate basis via quantum quench. This provides a much simpler pathway of detection than previous works. It also shows improved sensitivity from Pearson Correlation detection techniques.

15:00 Alex Nico-Katz
"*An entanglement-complexity geometric measure"*

By exploiting the matrix product state formalism we propose a new geometric measure of entanglement for pure state. These measures are completely divested from the notion of separability and can be freely tuned to target states which vary in entanglement complexity. This allows us to unravel the properties of many-body quantum systems in which the conventional geometric entanglement fails. We demonstrate this by probing the ground state phase diagram of several widely-known condensed matter systems, namely the J1-J2 model, the AKLT model, and a general anisotropic Haldane chain. This investigation reveals that our measure can successfully detect all phase boundaries and critical points; all of which are invisible to the conventional geometric entanglement. Thus, our measure may provide a striking new way to investigate phase transitions without appealing to specific order parameters.

15:50 Aline Ramires (Paul Scherrer Inst, Zurich)
"Unconventional properties of unconventional superconductors: the odd, the dirty, and the driven"

The apparently contradicting responses of complex superconductors to different experimental probes poses fundamental difficulties that hinder our understanding of their full potential. In this context, the concept of superconducting fitness emerges as a tool that quantifies the unusual effects of external symmetry breaking fields and allows us to engineer the normal state electronic structure towards the optimization and stabilization of desirable superconducting phases [1,2]. This concept was applied to several families of materials, and in this talk I cover three cases. First, Sr2RuO4 has been considered an ODD superconductor with contracting phenomenology. I discuss how a chiral d-wave order parameter can resolve this conundrum anyhow it can be stabilized using as guide the superconducting fitness measure [3-5]. Second, the DIRTY doped topological insulators in the family of Bi2Se3 are unconventional superconductors which seem to be extremely robust against disorder. In this context, I discuss how the superconducting fitness measure appears in a Generalized version of Anderson's theorem [6,7]. Third, we move to DRIVEN systems, and explore how the superconducting fitness structures manifest. I discuss how the superconducting critical temperature can be significantly enhanced within flatband superconductors [8].

[1] Aline Ramires and Manfred Sigrist, Phys. Rev. B **94**, 104501 (2016).
[2] Aline Ramires, Daniel F. Agterberg and Manfred Sigrist, Phys. Rev. B **98**, 024501 (2018).
[3] Han Gyeol Suh, Henri Menke, P. M. R. Brydon, Carsten Tim, Aline Ramires and Daniel F. Agterberg, Phys. Rev. Research **2**, 032023(R) (2020).
[4] Aline Ramires, J. Phys.: Conf. Ser. **2164**, 012002 (2022).
[5] Sophie Beck, Alexander Hampel, Manuel Zingl, Carsten Timm, and Aline Ramires Phys. Rev. Research **4**, 023060 (2022)
[6] Lionel Andersen*, Aline Ramires*, Zhiwei Wang, Thomas Lorenz, Yoichi Ando Science Advances **6**, eaaY6502 (2020).
[7] Bastian Zinkl and Aline Ramires, Phys. Rev. B **106**, 014515 (2022).
[8] Rui Lin, Aline Ramires, Chitra Ramasubramanian, arXiv.2306.02861

Tuesday 11 July

10:00 Vidya Madhavan (Univ. Illinois Urbana Champaign):
“The strange case of magnetic field sensitive charge density waves”

UTe2 is a heavy fermion superconductor with strong evidence for spin-triplet pairing. Recent work from our group has revealed the presence of an intriguing charge density wave (CDW) phase which is sensitive to magnetic fields and disappears close to the superconducting H_{c2}. A possible explanation for this unique CDW involves the presence of an intertwined pair-density wave (PDW) which is a density wave of cooper pairs. The PDW scenario suggests that any vortex in the uniform superconducting phase or the PDW phase will result in topological defects i.e., dislocations in the CDW where the CDW order parameter also winds by 2π. In this work we employ scanning tunneling microscopy (STM) to visualize the magnetic field induced melting of this unconventional CDW order. We use the amplitude and phase information present in the Fourier transforms of the CDW to detect the presence of topological defects. We show that the phase around these topological defects winds by $\pm 2\pi$, while the amplitude goes to zero at the center of the defect. The data show that as the magnetic field increases, the CDW melts by the proliferation of vortexanti-vortex pairs consistent with the PDW scenario.

11:40 Sasha Balatsky (Nordita/University of Connecticut)
“*Rectified Quantum Orders*”

Quantum matter out of equilibrium emerge as an important platform to induce correlations and transient orders. Modern techniques of coherent and fast light sources developed recently enable this evolution. Broad basic questions about orders that emerge dynamically have been addressed in the context of driven cold atoms, spins, magnetism and superconductivity. I will discuss new orders that emerge in quantum matter where quantum coherence and entanglement matter and discuss the concept of rectified quantum orders. I will illustrate with old and new examples of dynamically induced quantum states.

14.30 Gaurav Chaudhary
"*Superconductivity from polar fluctuations in multi-orbital systems*"

Motivated by the superconductivity near paraelectric (PE) to ferroelectric (FE) quantum critical point (QCP) in polar metals, we study polar fluctuation mediated superconductivity in multi-orbital systems. The PE to FE QCP is approached by softening of a transverse optical (TO) phonon that is odd under inversion. Previously, it has been shown that in the presence of spin-orbit (SO) coupling, electron-phonon coupling to such TO modes can lead to superconductivity. We show that for the multi-orbital systems, coupling to the polar fluctuations (such as TO modes) can generally lead to superconductivity irrespective of the SO coupling. In the absence of the SO coupling, the electron-phonon coupling and the resultant

superconducting instability also does not require multiband physics, such as multiple bands at the Fermi or vicinity to Dirac nodes or nodal lines.
The electron-phonon vertex has strong k-dependence. We also show that irrespective of the strong k-dependence of the electron-electron interaction in the BCS channel, quite generally the spin-singlet even-parity channel leads to the highest critical temperature. In the presence of additional repulsive electron-electron interactions, an odd-parity spin-triplet channel can become the leading BCS instability. Finally, we discuss our results in the context of the superconductivity in SrTiO3 and KTaO3 that highlights the importance of the underlying multi-orbital physics if the superconductivity is mediated by the polar fluctuations.

15:00 Steffen Bollmann
"*Time-reversal invariant topological superconductor in the Coulomb blockade regime*"

Floating topological superconductors coupled to conduction electrons can realize unconventional O(N), Sp(2N), or multi-channel Kondo effects. Here, we introduce a new topological superconducting mesoscopic device, a timereversal invariant version of the Majorana Cooper pair box in the Coulomb blockade regime. In this setup of Cartan-Altland-Zirnbauer class DIII, spinful Majorana zero modes appear at the edges of a topological triplet superconductor with fluctuating Cooper pair spin and charge. We study the Kondo effect in the limit of dominating charging energy and in the limit of both small and large spin fluctuations. Beyond its value in the context of exotic mesoscopic Kondo effects, our study sheds light on the intricate interplay of band topology and strong quantum fluctuations of non-Abelian order parameter fields.

15:50 Tony Carrington (Bristol University)
"Magneto-transport in cuprate superconductors"

I will talk about recent results concerning the transport properties of cuprate superconductors in high magnetic fields, including quantum oscillations, the Hall effect and the longitudinal magnetoresistance. The motivation is that these properties can give us insight into the unusual normal state of the cuprates which is likely linked to the high temperature superconductivity. We have made a long-term study of the over-doped regime of the cuprates $Tl_2Ba_2CuO_{6+x}$ (Tl- 2201) and $Bi_2Sr_2CuO_{6+x}$ (Bi-2201).. In very overdoped Tl-2201, quantum oscillations and angledependent-c-axis-magnetoresistance measurements have mapped out the Fermi surface in remarkable detail and seem to be well described by a conventional, strongly correlated metallic state. However, in this overdoped regime the Hall number (n_H) shows a broad crossover from n_H = p, to n_H = 1+p in a regime where there appears to be no pseudogap [1]. Recently, there has been evidence for a charge density wave (CDW) in Tl-2201, with a remarkably long coherence length (up to 200Å) for p<0.265, which provides a possible explanation for the evolution of n_H[2]. However, in this same regime the longitudinal magnetoresistance displays a quadrature scaling form: $\rho(T, H) = F(T) +([\alpha T]^2+[\beta H]^2)^{0.5}$ [3], which does not seem to be explained easily by conventional transport theory – even allowing for strong scattering anisotropy. This latter result suggests a universal correlation between the magneto-transport and the ubiquitous linear-in-T resistivity which has been suggested to originate from maximal ‘Planckian’ dissipation.

[1] C. Putzke et al, Nature Physics 17, 826 (2021).
[2] C.C. Tam et al, Nature Comms 13, 570 (2022).
[3] J. Ayres *et al*, Nature 595, 661 (2021).

Wednesday 12 July

10:00 Joaquín Fernández Rossier (INL, Portugal)
"*Bottom-up design of quantum matter with nanographenes"*

In this talk I will discuss a new route to engineer non-trivial electronic collective quantum states using nanographenes as building blocks in a bottom-up manner. I will first review the state of the art in this research field, that includes the recent realization of Haldane spin chains [1] with linear and non-linear exchange. I will also discuss how spin excitations can be probed with inelastic electron tunnel spectroscopy with STM. I will make the case that this general class of systems can be understood in terms of the Hubbard model at half filling [2,3,4], from which S=1 AKLT-type model can be derived [5]. I will then discuss the electronic properties of a variety of different nanographene 2D crystals[6,7], showing the gigantic potential of the bottom-up approach to generate exotic electronic states and explore quantum magnetism, leveraging on the enormous advances in on-surface synthesis, organic chemistry and STM spectroscopy.

[1] Observation of fractional edge excitations in nanographene spin chains
S. Mishra, G. Catarina, F. Wu, R. Ortiz, D. Jacob, K. Eimre, J. Ma, C. A. Pignedoli, X. Feng, P. Ruffieux, J. Fernández-Rossier, R.Fasel, Nature **598**, 287 (2021)
[2] Magnetism in graphene nano-islands J. Fernández-Rossier, J. J. Palacios, Phys. Rev. Lett. 99, 177204 (2007).
[3] Exchange rules for diradical Pi-conjugated hydrocarbons
R. Ortiz, R. A. Boto, N. García-Martínez, J. C. Sancho-García, M. Melle-Franco and J. Fernández- Rossier, Nano Letters 19, 5991 (2019).
[4] Hubbard model for spin-1 Haldane chains, G. Catarina and J. Fernández-Rossier, Phys. Rev. B 105, L081116 (2022).
[5] Anatomy of linear and non-linear intermolecular exchange in S=1 nanographenes, J. C. G. Henriques, J. Fernández-Rossier, arXiv 2023 (in prep)
[6] Theory of triangulene two-dimensional crystals R Ortiz, G. Catarina, J. Fernández Rossier, 2023 2D Mater. 10 015015.
[7] Broken-symmetry magnetic phases in two-dimensional triangulene crystals, G. Catarina, J. C. G. Henriques, A. Molina-Sánchez, A. T. Costa, J. Fernández Rossier, arXiv 2023 (in prep)

11:40 Frank Schindler (Imperial College, London):
"Hermitian Bulk — Non-Hermitian Boundary Correspondence"

Non-Hermitian topology offers a fresh perspective on open quantum systems, but identifying suitable physical realizations remains a challenge. In my talk, I will demonstrate that the lossless edge states of Hermitian topological insulators acquire nontrivial non-Hermitian topological invariants upon exposure to minor perturbations. This discovery expands the range of potential materials for non-Hermitian topology to encompass all known topological insulators. I will provide a comprehensive characterization of the emergent higher-order non-Hermitian skin effects and edge states, which act as distinctive experimental signatures for the correspondence between Hermitian and non-Hermitian topology.

14.30 Nilotpal Chakraborty

"*Magnon transport in quantum Hall heterojunctions probes the interplay of symmetry breaking, topology and entanglement*"

Magnon transport in graphene quantum Hall heterojunctions has been a remarkable recent experimental development to identify spin structure of ground states at various Landau level fillings. Inspired by experiment, we introduce a theoretical model to study magnon scattering in skyrmion crystals, sandwiched between quantum Hall ferromagnets which act as the source and sink of magnons. Skyrmions are topological objects while skyrmion crystals break internal and translational symmetries, thus our setup allows us to study the interplay of topology and symmetry breaking. Starting from a basis of holomorphic theta functions, we construct an analytical ansatz for such a junction with finite spatially modulating topological charge density in the central region and vanishing in the leads. Using analytical techniques, field theory, heuristic models and microscopic recursive transfer-matrix numerics, we calculate the spectra and magnon transmission properties of the skyrmion crystal. We find that magnon transmission can be understood via a combination of low-energy Goldstone modes and effective emergent Landau levels at higher energies. The former manifests in discrete low-energy peaks in the transmission spectrum which reflect the nature of the Goldstone modes arising from symmetry breaking. The latter, which reflect the topology, lead to band-like transmission features, from the structure of which further details of the excitation spectrum of the skyrmion crystal can be inferred. Such characteristic transmission features are absent in competing phases of the quantum Hall phase diagram, and hence provide direct signatures of skyrmion crystal phases and their spectra [1]. Our results directly apply to quantum Hall heterojunction experiments in monolayer graphene with the central region doped slightly away from unit filling, and are also relevant to junctions formed by metallic magnets or in junctions with artificial gauge fields. Besides, purely SU(2) spin skyrmion crystals, we also study crystals of SU(4) entanglement skyrmions [2], in which the spin and valley degrees of freedom are entangled. We show how non-local transport signatures of magnons in such junction experiments can detect and quantify this entanglement [3], thereby establishing magnon transport as a concrete route to probe such entanglement in multicomponent quantum Hall systems.

[1] Nilotpal Chakraborty, Roderich Moessner, and Benoit Douçot. “Riemann meets Goldstone: magnon scattering off quantum Hall skyrmion crystals probes interplay of symmetry break- ing and topology”: arXiv:2304.13049 (2023).

[2] Benoit Douçot et al. “Entanglement skyrmions in multicomponent quantum Hall systems”, PRB 78, 195327 (2008)

[3] Nilotpal Chakraborty, Roderich Moessner, and Benoit Douçot: In Prep

15:00 Li Ern Chern

"*Topological phase diagrams of in-plane field polarized Kitaev magnets"*

While the existence of a magnetic field induced quantum spin liquid in Kitaev magnets remains under debate, its topological properties often extend to proximal phases where they can lead to unusual behaviors of both fundamental and applied interests. Subjecting a generic nearest neighbor spin model of Kitaev magnets to a sufficiently strong in-plane magnetic field, we study the resulting polarized phase and the associated magnon excitations. In contrast to the case of an out-of-plane magnetic field where the magnon band topology is enforced by symmetry, we find that it is possible for topologically trivial and nontrivial parameter regimes to coexist under in-plane magnetic fields. We map out the topological phase diagrams of the magnon bands, revealing a rich pattern of variation of the Chern number over the parameter space and the field angle. We further compute the magnon thermal Hall conductivity as a weighted summation of Berry curvatures, and discuss experimental implications of our results to planar thermal Hall effects in Kitaev magnets. [arXiv:2303.16222

15:50 Erez Berg (Weizmann Institute):

“Programmable adiabatic demagnetization: State preparation by simulated cooling”

How can one prepare the ground state of a given many-body Hamiltonian using a "programmable quantum simulator", capable of applying unitary gates and measurements? We propose a simple, robust protocol to achieve this goal. The protocol is inspired by the adiabatic demagnetization technique, used to cool solidstate systems to extremely low temperatures. A fraction of the qubits (or spins) is used to model a spin bath that is coupled to the system. By an adiabatic ramp down of a simulated Zeeman field acting on the bath spins, energy and entropy are extracted from the system. The bath spins are then measured and reset to the polarized state, and the process is repeated until convergence to a low-energy steady state is achieved. We discuss the advantages and shortcomings of this protocol, and how it can be adapted to simulate systems with topological (non-local) excitations or systems of fermions using bosonic physical qubits.

19:00 Oliver Dial (IBM) Public lecture (Clore Lecture Theatre, Huxley Building, Imperial College) *“The future of quantum computing” (note: separate registration required!)*

Thursday 13 July

10:00 Pablo Jarillo-Herrero (MIT)
I *"Magic-Angle Multilayer Graphene: A Robust Family of Moiré Superconductors"*

The understanding of strongly-interacting quantum matter has challenged physicists for decades. The discovery five years ago of correlated phases and superconductivity in magic angle twisted bilayer graphene has led to the emergence of a new materials platform to investigate strongly interacting physics, namely moiré quantum matter. These systems exhibit a plethora of quantum phases, such as correlated insulators, superconductivity, magnetism, ferroelectricity, and more. In this talk I will review some of the recent advances in the field, focusing on the newest generation of moiré quantum systems, where correlated physics, superconductivity, and other fascinating phases can be studied with unprecedented tunability. I will end the talk with an outlook of some exciting directions in this emerging field.

11:40 Oliver Dial (IBM)
"*An error-mitigated path to quantum utility"*

In the past decade, the scale, speed, and quality of quantum computers has advanced considerably. Although there is interest in using these machines to simulate condensed matter systems, it is still speculative when and how they will begin to be able to contribute useful computational power by simulating a system more complex than is practical using classical computers. A common school of thought is that useful computation will not be possible without large, fault tolerant quantum systems. However, using simulating time evolution of a toy condensed matter system as an example, I will show evidence that techniques like error mitigation are bringing us near to quantum utility.

14.30 Alexander Tyner "*AI guided topological materials design and discovery"*
Recent years have seen multiple high-throughput studies reveal an immense number of topological materials through use of symmetry indicators. Despite this success, two-dimensional TIs admitting a band gap larger than bilayer bismuth, remain extremely rare. Simultaneously, a significant effort has been made to understand and identify topological phases "invisible" to symmetry indicators. Such phases offer a unique opportunity to expand the search for a large band-gap TI, however their identification requires sophisticated probes of bulk topology. Magnetic flux tubes or vortices have emerged as one such probe in two-dimensions when inserted into the bulk. We develop an automated workflow to perform vortex insertion and apply it to a current database of high-quality, experimentally realized, two-dimensional insulators. The results are combined with existing databases to train a neural network (NN) capable of diagnosing non-trivial topology of all orders in two-dimensional systems. The resulting NN represents a significant step towards the construction of designer topological materials for future quantum devices.

15:00 Yu-Chin Tzeng "*General properties of fidelity in non-Hermitian quantum systems with PT symmetry*"

There are various definitions of fidelity in non-Hermitian systems, leading to confusion among researchers on which definition to use and the potential for different results. The present study proposes metricized fidelity, which has many desirable general properties. In PT-symmetric non-Hermitian systems, the PT-unbroken state is characterized by a real fidelity, while for PT-broken states, the real part of the fidelity susceptibility approaches negative infinity as the parameter approaches the exceptional point. Furthermore, the study proves that the real part of the fidelity between PT-unbroken and PT-broken states is always 1/2 at the second-order exceptional point. This definition provides clarity and consistency in the study of non-Hermitian systems, potentially enabling more accurate and comprehensive investigations of non Hermitian systems in the future.

15:50 Amalia Coldea (Oxford University)
“Fermi surfaces and quasiparticle behaviour of ironchalcogenide superconductors”

Iron-based superconductors display a plethora of competing electronic phases and offer a unique platform to explore unconventional superconductivity [1]. The electronic structure originating mainly from Fe layers has a multi-band character stabilized by orbitally-dependent electronic correlations and band shifts. The magnetic moments are often strongly fluctuating and can provide the exchange for superconducting pairing. The family of iron-chalcogenide superconductors displays electronic nematic orders and spin-density wave phases which are often intertwined but their importance on superconducting pairing remains to be understood [2,3]. Tuning parameters, like applied and chemical pressure, are versatile tools to explore their relative importance. In this talk, I will present experimental progress made in understanding the electronic behaviour of iron chalcogenide $FeSe_{1-x}S_x$ and $FeSe_{1-x}Te_x$ [3,4]. Firstly, I will describe the generic signatures of the multi-band electronic structure inside the nematic electronic state and in the tetragonal phase probed by angle-resolved photoemission spectroscopy. Secondly, I will present quantum oscillations and how they evolve across the nematic end point in $FeSe_{1-x}S_x$, tuned both by pressure and chemical pressure [5,6,7]. Thirdly, I will focus on the magnetotransport behaviour inside the nematic and tetragonal phases of these materials and discuss the role of disorder, spin fluctuations and critical fluctuations close to a nematic phase transition [8,9,10].

*This work was supported by the EPSRC, UK and the Oxford Centre for Applied Superconductivity.

[1] R. M. Fernandes, A. I. Coldea et al., *Nature* **601**, 35 (2022).
[2] A. I. Coldea, M. D. Watson, *Ann. Rev. Cond. Matt. Phys.*, **9**, 125 (2018).
[3] A. I. Coldea, *Frontiers in Phys*. **8**, 594500 (2021).
[4] A. Morfoot et al, AIC, submitted (2023).
[5] A. I. Coldea et al., *npj Quantum Materials*, 4, 2 (2019).
[6] P. Reiss et al, *Nature Physics*, 16, 89 (2020).

[7] Pascal Reiss, et al., *Phys. Rev. Lett.* 127, 246402 (2021).
[8] L. Farrar et al. AIC, *PNAS* 119 No.43 e2200405119 (2022).
[9] Z. Zajicek, et al., Phys. Rev. B 105, 115130 (2022).
[10] M. Bristow, et al., Phys. Rev. Research 2, 013309 (2020).

Friday 14 July

10:00 Pablo Jarillo-Herrero II (MIT)
"*Next Generation Moiré Quantum Matter"*

Abstract: In this second talk I will review recent experiments on next generation moiré quantum matter, both twisted multilayer graphene systems as well as dual (or asymmetric) moiré systems. In particular, first I will briefly discussed our experiments on magic-angle twisted multilayer graphene as a family of robust moiré superconductors. Second, I will discuss the engineering of moiré quasicrystals and a new type of unconventional ferroelectricity and electron ratchet in asymmetric moiré systems.

11:40 Je-Geun Park (Seoul National University)
"Emerging new opportunities of van der Waals magnets"

Two-dimensional (2D) systems hold an exceptional place in the development of condensed matter physics. Without exaggeration, the modern understanding of condensed matter physics has been shaped by three fundamental models: Ising, XY, and Heisenberg models in 2D. These models revolve around a fundamental question: Can a phase transition be stable within the given models at a finite temperature? Although theorists have extensively studied these models, progress in experimental investigations has been relatively slow. However, the landscape drastically changed with the recent discovery of new 2D van der Waals (vdW) materials with antiferromagnetism in 2016 and ferromagnetism in 2017. With several 2D magnets reported to exhibit stable orders down to single atomic layers, a door is wide open for entirely new research directions. In this talk, I will highlight two particular cases: magnetic exciton and spintronic applications.

14.30 Raffaele Mazzilli
"*Electrical transport probes of quantum spin liquids"*

Quantum spin liquids are an exotic phase of matter characterized by the presence of fractionalized excitation(spinons) and emergent gauge fields. One of the difficulties in probing experimentally a QSL phase comes from the fact that the spinons do not carry an electric charge, ruling out the possibility of using conventional electrical probes. Going beyond conventional transport, we propose two setups of electric probes to characterize a QSL phase. First, we analyze a setup in which a QSL layer is interposed between two metallic layers. In this setup, we apply a current in the first metallic layer and measure the induced voltage on the second one. The momentum transfer is affected by the non-trivial behavior of momentum-carrying spinons and results in a response that will potentially be helpful for the future characterization of candidate QSL materials.
The second probe we propose is an STM experiment on a Kondo lattice in which the local moments have non-trivial dynamics (hence forming a QSL phase). We provide the STM response in each of the phase configurations of this system allowing also

for the possibility for the conduction electrons and for the spinons to form a superconducting phase. This last setup might find a concrete realization in materials such as TaS2, TaSe2 and NbSe2 in the 1T, 2H and in the 4Hb crystallographic phases.

15:00 Ewan Scott
"*Hard axis ordering in Kondo magnets* "

We present a mechanism for hard-axis magnetic ordering that is observed in many Kondo magnets. We go beyond the recently proposed single-impurity mechanism by including the full Kondo lattice and the associated collective effects. Motivated by the work of Perkins et al. (Phys. Rev. B 76, 125101, 2007) we employ an under-screened Kondo lattice model of anisotropic spin-1 impurities and fractionalise each impurity into two spin-1/2s such that one spin-1/2 is screened and the other is uncoupled in the Kondo channel. The Kondo channel is treated using large-N mean-field theory. Moment reorientation and hard-axis order is shown to occur for a wide range of anisotropy and electron filling in the strong Kondo coupling regime when $T_K \gtrsim T_{RKKY}$. When $T_K \lesssim T_{RKKY}$ conventional easy-axis magnetic order takes place. Deep in the under-screened Kondo regime, the single-ion anisotropy is effectively replaced by anisotropic exchange between conduction electrons and the unscreened impurity component. We demonstrate that this anisotropic exchange drives moment re-orientation. We find that the effect to be symmetric: moment re-orientation can take place from easy-axis to easy-plane and vice-versa.

15:50 Steve Simon (Oxford U)
"*Kekule spirals in twisted bilayer graphene*"

Abstract: I review some of the puzzles of the phase diagram of magic angle twisted bilayer graphene. I discuss first the so-called "strong coupling" or "flat band limit". While this describes some of the experiments, we find that there are still a number of experimental features that are not obtained correctly. In a more realistic calculation, keeping some experimentally relevant deviations from the flat-band limit, we find a new type of order which we dub "Incommensurate Kekule Spiral." This result appears to be in agreement with a very large number of experimental observations and has now been directly observed in STM experiment.