Condensed Matter Physics in All the Cities: Online 2020
June 16 – 26, 2020

Website and Registration: https://bit.ly/CMPC2020

Conference schedule given in BST (London: UK Summer Time)
Japan: +8h; USA (east coast) -5h USA west coast: -8h

Wk 1: (Tues 16th—Fri 19th June 2020)

Tues 16th June 2020

2:00-3:30 Hidenori Takagi (MPI Stuttgart, Tokyo)
Electron correlations and spin-orbit coupling [Rec]
abstract:
The exploration of novel phases of interacting electrons (correlated electrons) has long been a major stream of condensed-matter research. Many-body interactions among electrons give rise to a huge variety of phases, grouped into electron-solid, -liquid-crystal, -liquid and -gas states. The wealth of possibilities arises from a complicated interplay of lattice geometry, quantum effects and the multiple degrees of freedom of the electron (charge, spin and orbital). In the past, the two dominant areas of exploration have been the 3d transition-metal (TM) oxides and the 4f intermetallic compounds but recently 5d TM oxides and related compounds have emerged as the next arena of correlated-electron physics. Significant new physics is expected due to the presence of a large spin-orbit coupling in heavy 5d elements, tying together the otherwise independent spin and orbital degrees of freedom. This can be of order 0.5eV and is often larger than the crystal-field splitting of the orbital states, resulting in a spin-orbital-entangled state of correlated electrons. The nature of the spin-orbital entanglement depends significantly on the d-electron number and the chemical bonding, and it is anticipated that, in combination with electron correlations, a rich variety of novel electronic phases are waiting to be discovered. In this talk, I will present the concept of such phases and our effort in materializing them.
(I) Spin-orbital Mott insulator1
(II) Correlated topological semimetals2
(III) Spin-orbital quantum liquid on honeycomb lattice3.
(IV) Excitonic magnetism4.
(V) Multipolar ordering5.
References
[1] B. J. Kim et al., Phys. Rev. Lett. 101, 076402 (2008); Science 323, 1329 (2009).
[2] J. Matsuno et al. , Phys. Rev. Lett. 114 240749 (2015).
[3] H. Takagi, T. Takayama, G. Jackeli, G. Khaliullin, and S. N. Nagler, Nature Reviews Physics 1, 264 - 280 (2019).
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and H. Takagi, Phys. Rev. B100, 045142 (2019)..

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4:00-5:30 Miles Stoudenmire (Flatiron Institute) 1: Introduction to Tensor **Networks for Machine Learning** [Rec]

Talk 1: Introduction to Tensor Networks for Machine Learning

Abstract:
Tensor networks are a tool to store and compute with tensors having many indices, which would otherwise be exponentially costly. While in physics the prototypical use of tensor networks is for approximating many-body wavefunctions, it has been appreciated over the last decade that tensor networks such as matrix product states (MPS) are much more general tools. One emerging application of tensor networks is for machine learning, where they can be used for a variety of tasks such as supervised learning, generative modeling, and compression of neural network parameters. Compared to other machine learning approaches, tensor networks offer advantages such as scalability, more sophisticated training algorithms, and theoretical clarity. After reviewing the basics of tensor networks, I will introduce the setting of machine learning and explain how tensor networks can be used for machine learning tasks, showing exemplary results for both classical (non-physics) applications and physics applications.

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Research Scientist, Flatiron Institute
Center for Computational Quantum Physics (CCQ)

[no constraint on date]

Weds 17th June 2020

2:00-3:30 Claudio Castelnovo (Cambridge)

1: a brief introduction to quasiparticles in frustrated magnets

Abstract:
Conventional magnets typically undergo a phase transition as temperature crosses the characteristic interaction energy scale, separating a disordered paramagnetic phase from an ordered one. The resulting behaviour has been the focus of attention and the setting of countless important discoveries over the past century in physics. Over the last few decades, an even richer plethora of phenomena has been uncovered in presence of frustration, when the competition between energy terms suppresses the transition temperature and opens the door to a new regime: A `spin liquid' where the magnetic degrees of freedom remain disordered and yet `strongly correlated', when the temperature becomes substantially smaller than the

characteristic interactions. These new phases of matter can give rise to unusual and interesting phenomena, encompassing emergent symmetries and topological order, and excitations that can fractionalise the properties of the very constituent elements that make up the system. In this talk we will review some of the basic concepts relating to frustrated magnets and spin liquids. We will focus in particular on how to model and understand their elementary excitations, both at the classical and quantum mechanical level.

Claudio Castelnovo cc726@cam.ac.uk

4:00-5:30 Senthil Todadri (MIT)

1: (Pedagogical): Neutral fermi surfaces in electronic matter

abstracts (for both talks):

A number of distinct electronic materials have been suggested to have Fermi surfaces of emergent neutral excitations. In these talks, I will present a general discussion of such a phase of matter. I will describe what it means to have a neutral fermi surface, what it takes for this phenomenon to happen, and its occurrence in models. I will discuss ideas in the literature on how to detect such a neutral fermi surface, and some of the suggested materials where it has been proposed to exist.

Senthil Todadri senthil@MIT.EDU
Professor, Department of Physics
Massachusetts Institute of Technology

Thurs 18th June 2020

2:00-3:30 Masaki Oshikawa (ISSP Tokyo)

1: "Applications of Adiabatic Flux Insertion to Quantum Many-Body Systems: A Pedagogical Introduction"

Abstract

A time-dependent magnetic field induces an electric field. While this has been known as Faraday's law
in classical electromagnetism, new aspects appear when applied to a quantum mechanical system.
Quantum mechanical systems couple to the magnetic field through the vector potential, and they can be affected
by the magnetic field even when the particles do not directly touch the magnetic field (Aharonov-Bohm effect).
A static magnetic field through a hole does not affect the outside particles only when the total magnetic flux
is an integral multiple of the unit flux quantum, which can be eliminated by a topologically nontrivial gauge
transformation. Considering an adiabatic insertion process of the magnetic flux, this ``periodicity'' leads to
various topological quantizations in quantum many-body systems, such as Quantum Hall Effects, Lieb-Schultz-Mattis

type theorems, and Luttinger's theorem.

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4:00-5:30 Premi Chandra (Rutgers)

1: Quantum Criticality in Polar Materials I [Rec]

abstract

In this pedagogical talk, I'll show how polar materials can bring new perspectives to the study of quantum criticality. The emergence of complex states of quantum matter in the vicinity of zero-temperature transitions suggests that such strongly correlated phenomena should be explored in a variety of settings. The connection between quantum criticality and polar materials is not obvious. Quantum phase transitions are typically studied in magnetic systems with links to novel metallic behavior whereas interest in polar materials, specifically insulating ferroelectrics, is often often motivated by room-temperature functionalities. There is much to be gained at the confluence of these two areas. Paraelectric materials in close proximity to ferroelectic quantum critical points can be viewed as "economy" quantum critical systems whose propagating dynamics and few degrees of freedom allow for detailed interplay between analytic approaches, first-principles calculations and laboratory measurements. Additional degrees of freedom like spin and charge can be added and characterized systematically. Unusual superconductivity in doped quantum paraelectrics remains to be understood.

References:

PC, G.G. Lonzarich, S.E. Rowley and J.F. Scott, "Prospects and Applications near Ferroelectric Quantum Phase Transitions: A Key Issues Review," Reports on the Progress in Physics 80, 112502 (2017)

PC, P. Coleman, M.A. Continentino and G.G. Lonzarich, "Quantum Annealed Criticality", arXiv: 1805.11771.

P .A. V olkov and PC, "Multiband Quantum Criticality of Polar Metals", arXiv: 2003.084191.

Premi Chandra pchandra@physics.rutgers.edu

Fri 19th June 2020

1:30-2:45 Senthil Todadri (MIT)

2: Possible realization and detection of neutral Fermi surfaces

abstracts (for both talks):

A number of distinct electronic materials have been suggested to have Fermi surfaces of emergent neutral excitations. In these talks, I will present a general discussion of such a phase of matter. I will describe what it means to have a neutral fermi surface, what it takes for this phenomenon to happen, and it's occurrence in models. I will discuss ideas in the literature on how to detect such a neutral fermi surface, and some of the suggested materials where it has been proposed to exist.

3:00-4:15 Qimiao Si (Rice University)
Iron-based Superconductivity after a Decade -- Progress and Prospect
abstract
Strongly correlated electron systems often feature multiple building blocks and competing interactions, which allow for plenty of surprises and ample opportunities for new physics. An important case study is provided by the iron-based superconductors, which have been the subject of extensive efforts during the past decade or so.

In this overview talk, I will survey some of the key issues about the physics of the iron-based superconductors and the progress that has been made in their understanding. For the normal state, the questions concern the degree of electron correlations and, relatedly, the electronic (magnetic and nematic) orders and their fluctuations. For the superconducting state, these include the amplitude and structure of the multiorbital superconducting pairing. Among the overarching themes are the role of bad metallicity, magnetic fluctuations, quantum criticality and orbital selectivity. I will close by touching upon the prospect for future advances in resolving some of the problems that remain outstanding.
Qimiao Si qmsi@rice.edu

4:30-5:45 Meigan Aronson (UBC)
Introduction to Quantum Criticality: an experimentalists perspective
abstract
Electrons in quantum materials are wavelike, displaying both tunneling and interference. They spontaneously fluctuate among states, and their wavefunctions can be entangled over macroscopic length scales. The quantum revolution will exploit these properties in new technologies as diverse as sensors with unprecedented sensitivity, logic gates enabling quantum computation, and new devices that transport heat and electricity very differently from conventional materials. Of central importance is the tension between quantum fluctuations that limit the stability of magnetically ordered states at T=0, and strong electronic interactions that favor moment formation and ordered phases. These novel phases host fundamental excitations that are wholly unlike those of conventional insulators and metals, and are themselves unstable to the formation of other phases, notably unconventional superconductivity. Investigating these wholly novel types of phase transitions requires the identification of new materials where different aspects can be isolated, as well as experimental tools that can probe the spatial and dynamic correlations in more powerful ways.
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Stewart Blusson Quantum Matter Institute
University of British Columbia
[Constraint: meetings on 18 June from 9-1030 PDT = 17-18:30 BST]

Wk 2: (Mon 22th—Fri 26th June 2020)

Mon 22nd June 2020

1:30-2:45 John Saunders (Royal Holloway)
Topological Quantum Materials in the Microkelvin Regime
abstract
The study of quantum materials, strongly correlated electron and helium systems, at the ultralow temperatures frontier is replete with scientific opportunities, and new technical challenges. Helium in two dimensions can be manipulated to realize: 2D Fermi liquids; Wigner-Mott-Hubbard transition; 2D frustrated magnetism with putative quantum spin liquid; heavy fermion Kondo-breakdown quantum criticality; intertwined density wave and superfluid order; many body localization [1,2]. Furthermore there is a renewed impetus to study p-wave superfluid 3He as the only firmly established topological “superconductor”. Technical innovations have enabled its study under precisely engineered nanoscale confinement, on length scales of order the superfluid coherence length. Using such confinement as a control parameter, allows sculpture of new superfluid states, and the engineering of hybrid nanostructures [2]. This opens the study of topological mesoscopic superfluid 3He and the characterization of the emergent excitations arising from bulk/surface/edge correspondence. New frontiers are also opening up in the area of strongly correlated electron systems. We have cooled a 2D electron gas to 1 mK and below, with the prospect to investigate correlation effects in semiconductor nanostructures, and FQHE. The study of quantum critical metallic systems to lower temperatures than hitherto explored is also of interest. Recent transport measurements on the heavy fermion metal YbRh2Si2 identify a superconductor with multiple phases, in which nuclear spin plays an important role. Ongoing work will establish whether this is a spin-triplet crystalline topological superconductor.
The main focus of this talk will be recent experiments on superfluid 3He confined in a nanofabricated cavity of height comparable to the superfluid coherence length. Such confinement is a powerful tool to modify the p-wave superfluid order parameter, and enables the creation of superfluid 3He hybrid nanostructures, with interfaces between two 3He material phases stabilized by a step in cavity height [2,3]. Measurements on the chiral A-phase, stabilized at low pressure in a 200 nm tall cavity, show that the order parameter suppression and the spectrum of surface bound states are fragile with respect to details of quasiparticle scattering at the cavity surfaces [4], which can be tuned in situ. We show that magnetic surface scattering leads to an unexpectedly large suppression of the transition temperature, corresponding to an increased density of low energy bound states. On the other hand with specular surface scattering gap suppression and surface states are eliminated, leaving edge states. The cavity height can then be shrunk to below the coherence length and towards the 2D limit, confirmed by experiments on an 80 nm high cavity, which find that the A-phase continues to be stable. In taller cavities an AB transition is observed; the 0.7 and 1.1 micron cavities show a universal phase boundary, with minute super-cooling, which is potential evidence for an intrinsic nucleation mechanism under confinement [5]. Near to the AB transition the confined B-phase is predicted to be unstable to spontaneous formation of domains, with a

predicted stripe phase. However our NMR measurements find a two-dimensional spatially modulated superfluid (pair density wave) [6]. The future holds: the prospect of new superfluid phases under stronger confinement, or sculpted by symmetry breaking confining geometries; superfluid meta-materials; studies of thermal transport in hybrid nanostructures and under rotation; the quest to identify and manipulate Majorana zero modes in the only firmly establish topological "superconductor".

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[6] L. V. Levitin et al. Phys. Rev. Lett. 122, 085301 (2019)
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3:00-4:15 Miles Stoudenmire (Flatiron Institute)

2: Tensor Networks for Machine Learning: Algorithms, Architectures, and Applications [Rec]

Abstract:
In this second talk, I will focus more on promising future directions for tensor network based machine learning, such as the use of other tensor networks besides matrix product states. One particularly promising direction is developing more sophisticated algorithms for training compared to basic gradient-descent algorithms. I will show how applying a density-matrix based, direct training algorithm to a synthetic data set of even-parity bit strings not only leads to state-of-the-art results, but also supports a theoretical explanation of how the model learns and an accurate prediction of how well it generalizes.

4:30-5:45 Johannes Lischner (Dept Materials, Imperial College)

1: How to construct effective Hamiltonians for Moiré materials

abstract
Since the discovery of correlated insulator states and unconventional superconductivity in twisted bilayer graphene in 2018, there has been an intense effort to understand the electronic properties of moiré materials. However, the combination of large supercells (containing more than 10,000 atoms for magic-angle twisted bilayer graphene) and strong electron correlations makes the theoretical description of this new class of materials highly challenging. Standard strong correlation techniques for real materials are often based on downfolded effective Hamiltonians where the number of degrees of freedom is greatly reduced compared to full first-principles models. Generating accurate effective Hamiltonians, however, is a difficult task even for materials

with few atoms in the unit cell. In this talk, I will try to give a pedagogical introduction into procedures for developing effective Hamiltonians from first-principles techniques and describe how these methods must be extended for the description of moiré materials.

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Senior Lecturer & Royal Society University Research Fellow
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Tues 23th June 2020

2:00-3:30 Frank Pollmann (TUM, Munich)
Far-from-equilibrium dynamics of systems with conservation laws
abstract:
Recent years have seen a great deal of effort to understand quantum thermalization: the question of whether closed quantum systems, evolving under unitary dynamics, reach a state of thermal equilibrium. In my talk, I will discuss how the presence of conservation laws affects the dynamics of thermalization. First, we investigate the dynamics of quantum entanglement after a global quench and uncover a qualitative difference between the behavior of the von Neumann entropy and higher Renyi entropies. We argue that the latter generically grow sub-ballistically in systems with diffusive transport. We provide strong evidence for this in both a U(1) symmetric random circuit model and in a paradigmatic non-integrable spin chain, where energy is the sole conserved quantity. Second, I will introduce the dissipation-assisted operator evolution (DAOE) method for calculating transport properties of strongly interacting lattice systems in the high temperature regime. DAOE is based on evolving observables in the Heisenberg picture, and applying an artificial dissipation that reduces the weight on non-local operators.
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4:00-5:30 Alix McCollam (Radboud University)
Heavy fermions in high magnetic fields
abstract:
High magnetic field is a powerful tool for the study of heavy fermion systems. The characteristics and behaviour of the f-electrons drive much of the physics in these materials, and magnetic field couples strongly to the relevant magnetic, Kondo, and other exchange interactions, thus serving as a relatively straightforward, and reversible, tuning parameter across the complex phase diagrams. Through experiments such as quantum oscillations, we are also able to directly determine the properties of the heavy quasiparticles and the Fermi surface, as magnetic, superconducting and Fermi liquid properties come and go.
In this talk, I will briefly describe some of the key experimental techniques that can be used to study heavy fermions in high magnetic fields, with an outline of the

information they yield. I will then focus on recent work we have carried out on the CenTmIn3n+2m family of materials (where T is a transition metal, and n = 1, 2, m = 0, 1, 2), looking specifically at the evolution of the Fermi surface and what it tells us, as the system is field-tuned through antiferromagnetic quantum phase transitions and Lifshitz transitions.

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Weds 24th June 2020

2:00-3:30 Roser Valenti (Frankfurt)

Kitaev models and materials: where are we now?

abstract:

"In the search for novel materials’ properties, the generation and manipulation of highly entangled quantum states is a grand challenge of solid state research. Among the most entangled proposed states are quantum spin liquids. In this context, the exactly solvable Kitaev Z2 spin-liquid model, for which finely tuned anisotropic interactions exactly fractionalize spins into fermionic Majorana spinons and gauge fluxes has activated an enormous amount of interest. Most specially since possible realizations may be achieved in octahedral coordinated spin-orbit-coupled transition-metal-based insulators. However, the low symmetry environment of the known Kitaev materials also allows interactions beyond the Kitaev model that open possible new routes for further exotic excitations.

In this talk I will first provide an overview and, based on ab initio and many-body simulations and comparison to experimental observations, I will discuss the challenges that one facesin designing such materials and in identifying the origin of their excitations. I will further present recent results on possible field- and pressure-induced phases in relation to the candidate alpha-RuCl3."

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Institut für Theoretische Physik

Goethe-Universität Frankfurt am Main

4:00-5:30 Johannes Lischner (Dept Materials, Imperial College)

2: Modelling electronic properties of twisted bilayer materials

Abstract

Twisted bilayer materials are an attractive emerging platform for studying electron correlations. For example, the phase diagram of twisted bilayer graphene contains correlated insulator states in the vicinity of superconducting domes and is thus reminiscent of the cuprate high-temperature superconductors. However, the two-dimensional nature of this system allows for new ways to study electron correlations which are not accessible in the cuprates. For example, it is possible to modify the effective interaction between electrons by device engineering, i.e. by changing the dielectric environment and controlling the distance to the metallic

gates. In my talk, I will show how the screened interaction between electrons in twisted bilayer graphene depends on the dielectric environment and how this results in profound changes to the phase diagram. I will also discuss the role of internal screening which could potentially give rise to superconductivity mediated by a polarization glue.

Thurs 25th June 2020

1:30-2:45 Dai Aoki (Tohoku University)

Field reentrant superconductivity and multiple phases in UTe2

abstract

There are many exotic superconductors which contains uranium atom. This is due to the characteristic properties of 5f electrons in uranium atom, which show the dual nature (itinerant and localized) and the strong spin-orbit coupling. For instance, the microscopic coexistence of ferromagnetism and superconductivity is known in uranium compounds, though they are usually antagonistic on the basis of the conventional BCS theory. The spin-triplet superconductivity is realized with the ferromagnetic fluctuations as a “glue” of superconducting pairing.

In this talk I will present an overview of ferromagnetic superconductivity and the spin-triplet state in uranium compounds. In particular, I will focus on the new spin-triplet superconductor UTe2 and its pressure and field response. A spectacular field-reentrant superconductivity, multiple superconducting phases, and the pressure-induced magnetism are reported in UTe2. I will further present our recent results and perspectives on UTe2.

Dai Aoki aoki@imr.tohoku.ac.jp

Institute for Materials Research, Tohoku Univ.

3:00-4:15 Premi Chandra (Rutgers)

2: Quantum Criticality in Polar Materials II [Rec]

abstract

Next I’ll give you a flavor for two of my current research projects in this area. Experimentally there exist several insulating ferroelectric materials that have classical first-order transitions that display quantum criticality. Because their electromechanical coupling is strong, it is natural to reexamine the emergence of first-order transitions in compressible systems due to strain-energy density coupling. Generalizing this Larkin-Pikin criterion, I’ll show you that a line of classical first-order transitions can end in quantum criticality where the quantum fluctuations toughen the system against macroscopic instabilities.

It is well known that metals close to quantum critical points can exhibit novel phases including non-Fermi liquid behavior and unconventional superconductivity. Motivated by recent discoveries of polar metals that undergo inversion symmetry-breaking transitions I’ll present a systematic exploration of the emergence of strong correlations driven by criticality when the polar transition is tuned to zero. Several novel interacting phases will be discussed with experimental signatures.

I’ll end with many open questions for further theoretical and experimental explorations.

References:
PC, G.G. Lonzarich, S.E. Rowley and J.F. Scott, "Prospects and Applications near Ferroelectric Quantum Phase Transitions: A Key Issues Review," Reports on the Progress in Physics 80, 112502 (2017)
PC, P. Coleman, M.A. Continentino and G.G. Lonzarich, "Quantum Annealed Criticality", arXiv: 1805.11771.
P .A. V olkov and PC, "Multiband Quantum Criticality of Polar Metals", arXiv: 2003.084191.

4:30-5:45 Claudio Castelnovo (Cambridge)
2: dynamics and localisation in spin liquids
Abstracts:
Quantum spin liquids (QSLs) are an interesting and often enigmatic phase of matter that exhibits some of the most exciting phenomena uncovered in modern condensed matter physics over the last few decades, from emergent symmetries and topological order, to fractionalised excitations and fractional statistics. QSLs remained for a long time largely the remit of theoretical physics. However, in recent years more and more candidate materials are being proposed and investigated, with a shift in focus to characterise and diagnose them to definitively confirm their spin liquid behaviour. Correspondingly, a theoretical interest has arisen to understand their finite temperature behaviour, both as an experimental inevitability, but also as an effort to look for possible finite temperature precursor properties that may tell the tale of a QSL at lower, more difficult to access, temperatures. In this talk we explore this intermediate temperature regime in a class of QSLs that are characterised by a large (classical) projective energy scale and weaker quantum fluctuations -- as is the case in model systems such as the six or eight vertex models in a transverse field, closely related respectively to quantum spin ice and the toric code. Whereas a general framework to understand the finite temperature behaviour of these systems remains a tall order, we illustrate the rich range of phenomena that one may expect -- encompassing configurational localisation, compact localised states, and statistics-driven phase separation -- in a few model systems. Furthermore, we discuss how these phenomena may be used to diagnose and understand QSL response and thermodynamic properties in real materials.

5:45-6:30 Student presentation and prize ceremony

Fri 26th June 2020

2:00-3:30 Masaki Oshikawa (ISSP Tokyo)
2: "Adiabatic vs Sudden Flux Insertion and Nonlinear Electric Conduction"
Abstract
The adiabatic insertion of the magnetic flux can be regarded as an application of an infinitesimal uniform electric field
over a long period of time. This can induce a ``persistent current'' which does not decay in the ideal limit. The coefficient
of proportionality is called Drude weight. On the other hand, we can

consider the limit of instantaneous flux insertion,
which produces a delta-function pulse of the electric field. This may be also regarded as a particular type of a quantum quench process. These two limits are quite different but still share many topological properties in common.
By considering these two limits, we can understand the Kohn formula for the Drude weight and the f-sum rule of the AC conductivity in a unified manner. Furthermore, both the Kohn formula and the f-sum rule can be naturally extended to nonlinear electric conduction at all orders.

4:00-5:30 Qimiao Si (Rice University)

2: Bad Metals and Electronic Orders: Nematicity in Iron Pnictides and Moire Systems

5:45-6:30 Closing remarks