Hong Kong Forum of Physics 2018: Recent Progress in Quantum Matter – Theories and Experiments

January 7 – 9, 2019

Lecture Theatre T7, 1/F, Meng Wah Complex

Poster Room
Rm. 522, 5/F, Chong Yuet Ming Physics Building, HKU

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Monday, January 7, 2019 (Day 1) 09:20 – 09:50

Topological Superfluid for 1D Spin-1 Bosons and Its Continuous Phase Transition

Prof. Xiao-Gang Wen
Massachusetts Institute of Technology

Spin-1 bosons on a 1-dimensional chain, with anti-ferromagnetic spin interaction between neighboring bosons, may form a spin-1 boson condensed state that contains both gapless charge and spin excitations. We argue that the spin-1 boson condensed state is unstable, and will become one of two superfluids by opening a spin gap. One superfluid must have spin-1 ground state on a ring if it contains an odd number of bosons and has no degenerate states at the chain end. The other superfluid has spin-0 ground state on a ring for any numbers of bosons and has a spin-1/2 degeneracy at the chain end. The two superfluids have the same symmetry and only differ by a spin-SO(3) symmetry protected topological order. Although Landau theory forbids a continuous phase transition between two phases with the same symmetry, the phase transition between the two superfluids can be generically continuous, which is described by a conformal field theory (CFT). Such a CFT has a spin fractionalization: a spin-1 excitation can decay into a spin-1/2 right mover and a spin-1/2 left mover.

Monday, January 7, 2019 (Day 1) 09:50 – 10:20

Superconductivity in Sr_2RuO_4: Theory vs Experiments

Prof. Qiang Hua Wang
Nanjing University

We use functional renormalization group method to study a three-orbital model for superconducting Sr_2RuO_4. The pairing symmetry is found to be chiral p-wave, but the atomic spin-orbit coupling induces near-nodes for quasiparticle excitations. The theory is compared to a variety of experimental data, with excellent agreements. In particular, the theory explains a major experimental puzzle between d-wave-like feature observed in thermal experiments and the chiral p-wave triplet pairing revealed in nuclear-magnetic-resonance and Kerr effect.

Other co-authors: Wan-Sheng Wang, Ningbo University, China; Fu-Chun Zhang, University of Chinese Academy of Science, China

Monday, January 7, 2019 (Day 1) 10:20 – 10:50

Chiral Magnetic Effect and Collective Modes in Topological Semimetals

Prof. Xi Dai
Hong Kong University of Science and Technology

Quasi-particles and collective modes are two fundamental aspects that characterize a quantum mater in additional to its ground state features. For example, the low energy physics for Fermi liquid phase in He-III was featured not only by Fermionic quasi-particles near the chemical potential, but also by fruitful collective modes in the long wave length limit, including several different sound waves that can propagate through it under different circumstances. On the other hand, it is very difficult for sound waves to be carried by the electron liquid in the ordinary metals, due to the fact that long range Coulomb interaction among electrons will generate plasmon gap for ordinary electron density waves and thus prohibits the propagation of sound waves through the electron liquid. In the present paper, we propose a unique type of acoustic collective modes formed by Weyl fermions under the magnetic field, which is called chiral zero sound (CZS). The CZS only exists and propagates along an external magnetic field for Weyl semi-metal systems containing multiple-pairs of Weyl points. The sound velocity of CZS is proportional to the field strength in the weak field limit, whereas oscillates dramatically in the strong field limit generating completely new mechanism for quantum oscillations through the dynamics of neutral Bosonic excitation, which may manifest itself in the thermal conductivity measurements under magnetic field.

Monday, January 7, 2019 (Day 1) 11:30 – 12:00

Daniel Tsui Fellowship Award Presentation

Emergent Quantum Criticality in Spin-1 Magnets and Some Thoughts on Thermal Hall Transports

Dr. Gang Chen
The University of Hong Kong

Monday, January 7, 2019 (Day 1) 14:00 – 14:30

Resonantly Enhanced Moiré Superlattice Coupling in Transition-Metal Dichalcogenide Bilayers with Almost Matching Band Edges

Prof. Vladimir Fal'ko
National Graphene Institute, UK

Atomically-thin layers of two-dimensional materials can be assembled in vertical stacks held together by relatively weak van der Waals forces, allowing for coupling between monolayer crystals with incommensurate lattices and arbitrary mutual rotation. A profound consequence of using these degrees of freedom is the emergence of a periodicity in the local atomic registry of the constituent crystal structures, known as a moiré superlattice. Here, we discuss how moiré superlattice effects on the electronic properties of almost aligned $MoSe_2/WS_2$ and $MoTe_2/MoSe_2$ heterobilayers get enhanced by resonant hybridization of conduction-band states in different layers, promoted by alignment of their band edges [1]. In particular, we find that in semiconducting heterostructures built of incommensurate $MoSe_2$ and WS_2 monolayers, A exciton undergoes an almost resonant interlayer hybridisation, resulting in the enhancement of the moiré superlattice effects, as an electron in the exciton explores efficiently the local arrangement of atoms in the two layer. $MoSe_2$ and WS_2 are specifically chosen for the near degeneracy of their conduction band edges to promote the hybridisation of intra- and interlayer excitons, which manifests itself in photoluminescence through a pronounced exciton energy shift as a periodic function of the interlayer rotation angle. This occurs as hybridised excitons (hX) are formed by holes residing in $MoSe_2$ bound to a twist-dependent superposition of electron states in the adjacent monolayers. For heterostructures with almost aligned pairs of monolayer crystals, resonant mixing of the electron states leads to pronounced effects of the heterostructure's geometrical moiré pattern on the hX dispersion and optical spectrum, including the appearance of new lines in their optical absorption spectra that correspond to the electron-photon umklapp processes. We also show that similar resonant hybridization is possible for B excitons in some TMD heterostructures, and that they should naturally appear in twisted homobilayers of various transition-metal dichalcogenides.

[1] D.A. Ruiz-Tijerina and V.I. Fal'ko, arXiv:1809.09257

Other co-authors: D.A. Ruiz-Tijerina, National Graphene Institute, University of Manchester, Booth St E, M13 9PL, Manchester, UK

Monday, January 7, 2019 (Day 1) 14:30 – 15:00

Probing and Tuning Interlayer Interactions to Control Electronic and Photonic Properties of 2D Heterostructures

Prof. Chih Kang Shih
The University of Texas at Austin

Atomically thin, single crystalline 2D electronic materials have recently emerged, offering a remarkably wide range of building blocks of nanostructures, ranging from metals (e.g. graphene), large gap insulators (BN), to semiconductors (transition metal dichalcogenides and black phosphorous). One key advantage of these van der Waals materials lies in the flexibility of stacking different types of materials to form heterostructures, providing a design platform for achieving novel device functionality. In vdW hetero-bilayers, the interface encompasses the whole heterostructure and interlalyer interactions become the controlling parameter for the electronic structure.

In this talk I will first discuss directly probing the inter-layer interactions through the "lens" of moiré patterns using scanning tunneling microscopy and spectroscopy (STM/S). I will show that the interlayer coupling is strongly dependent on the inter-atomic alignment of the constituent layers. Moreover, as a consequence of moiré pattern formation, the energy band structure of the hetero-bilayer also shows lateral modulation, forming a 2D electronic superlattice. The moiré pattern "lens" also provides us with a means to measure the 2D strain tensor with high precision and high spatial resolution. In addition, the strain profile shows a direct correlation with the band gap modification.

As the periodic potential modulation also provides lateral confinement for excitons, an intriguing scenario occurs – the 2D lateral superlattices also form 2D exciton quantum dot arrays. Recent reports of ultra-sharp atomic like spectra provide a direct confirmation of such a scenario. Finally, I will add another control knob and show evidence for valley spin mediated interlayer couplings, and their effect on excitonic states of the hetero-bilayer.

Monday, January 7, 2019 (Day 1) 15:00 – 15:30

Low-energy Moiré Band Formed by Dirac Zero Modes in Twisted Bilayer Graphene

Dr. Long Zhang
University of Chinese Academy of Sciences

An unconventional insulating phase and a superconducting phase were recently discovered in the twisted bilayer graphene [Y. Cao et al, Nature 556, 80; 556, 43 (2018)], but the relevant low-energy electronic states have not been clearly identified yet. In this work, I show that the interlayer hopping induces a spatially modulated Dirac mass term in the continuum Hamiltonian, and leads to a low-energy band formed by Dirac zero modes in the moire superlattice. This moire band becomes extremely flat and thus strongly correlated when the Dirac velocity vanishes approaching the magic angle, and enters a quantum disordered Mott insulating phase at 1/4 and 3/4 filling, i.e., +-2 excess electrons per moire supercell, which may account for the insulating phase discovered in experiments. This model should be a good starting point for studying the exotic superconducting phase in slightly doped twisted bilayer graphene.

Monday, January 7, 2019 (Day 1) 16:00 – 16:30

Hidden SU(2) Symmetries, the Symmetry Hierarchy and the Emergent Eight-Fold Way in Spin-1 Quantum Magnets

Prof. Yi Zhou
Zhejiang University

The largest allowed symmetry in a spin-1 quantum system is an SU(3) symmetry rather than the SO(3) spin rotation. We reveal some SU(2) symmetries as subgroups of SU(3) that, to the best of our knowledge, have not previously been recognized. Then, we construct SU(2) symmetric Hamiltonians and explore the ground-state phase diagram in accordance with the SU(3)xSU(2)xU(1) symmetry hierarchy. It is natural to treat the eight generators of the SU(3) symmetry on an equal footing; this approach is called the eight-fold way. We find that the spin spectral functions and spin quadrupole spectral functions share the same structure, provided that the elementary excitations are flavor waves at low energies, which serves as a clue to the eight-fold way. An emergent S=1/2 gapless quantum spin liquid is found to coexist with spin nematic order in one of the ground states.

Monday, January 7, 2019 (Day 1) 16:30 – 17:00

Hidden Order in a Triangular Lattice Magnet

Prof. Jun Zhao
Fudan University

Certain magnetic materials exhibit exotic hidden-ordered phases which are inaccessible to conventional magnetic probes. Thus, experimental identification and theoretical understanding of a hidden order are difficult. In this work, we combine neutron scattering and thermodynamic probes to study a rare-earth triangular-lattice magnet. We find that the observed sharp and highly dispersive spin excitations cannot be explained by a conventional dipolar order, but instead is the direct consequence of the preformed multipolar order that is “hidden” in the neutron diffraction measurements. We show that the unusual static and dynamic responses can be accurately described by a transverse field Ising model on the triangular lattice with an intertwined dipolar and multipolar order.

Other co-authors: Yao Shen[1], Changle Liu[1], Yayuan Qin[1], Shoudong Shen[1], Yao-Dong Li[1,2], Robert Bewley[3], Astrid Schneidewind[4], Gang Chen[1,5,6], and Jun Zhao[1,6]

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Tuesday, January 8, 2019 (Day 2) 09:00 – 09:30

Experimental Realization of the Fu-Kane Proposal for Topological Quantum Computation

Prof. Li Lu

Institute of Physics, Chinese Academy of Sciences

In 2008, Fu and Kane proposed to induce p-wave-like superconductivity from s-wave superconductors via proximity effect in a hybrid structure. Since then, many hybrid structures have been proposed, and signatures of Majorana zero modes (MZMs) or chiral Majorana edge states have been observed in structures containing semiconducting nanowires, topological insulators, Chern insulators, iron chains, etc. However, the original proposal of Fu and Kane – to construct Josephson trijunctions on topological insulators, which could potentially serve as the basic components for universal topological quantum computation (TQC) – remains unexplored. Here, we report our systematic studies on various Josephson devices constructed on the surface of Bi_2Te_3. Minigap-closing as evidence MZMs was observed. Our study paves the way for further braiding MZMs and exploring TQC on scalable two-dimensional platforms.

Other co-authors: Guang Yang, Zhaozheng Lyu, Junhua Wang, Jianghua Ying, Xiang Zhang, Jie Shen, Guangtong Liu, Jie Fan, Zhongqing Ji, Xiunian Jing, Fanming Qu, and Li Lu, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

Tuesday, January 8, 2019 (Day 2) 09:30 – 10:00

Topological Classification of Quantum States of Bosons

Prof. Mahn-Soo Choi
Korea University

Recently, many-body ground states of non-interacting Fermions on various lattices have been classified in terms of their topological properties. Topological insulators, topological superconductors, and Weyl semimetals are popular examples.

Here we consider the topologically non-trivial quantum states of Bosons. Due to the commutation relation (compared with the anti-commutation relation for Fermions), the geometry underlying the Fock space for Bosons should be symplectic by nature. We study the effects of the symplectic geometry on the topological classification of the quantum states of Bosons

Other co-authors: Daniel Braun (University of Tübingen, Germany), Minchul Lee (Kyung Hee University)

Tuesday, January 8, 2019 (Day 2) 10:00 – 10:30

New Invariants, Complete Classification and Fast Diagnosis for Topological Crystalline Insulators

Prof. Chen Fang
Institute of Physics, Chinese Academy of Sciences

Topological crystalline insulators have nontrivial band topology jointly protected by onsite symmetries of time reversal and charge conservation, as well as by spatial symmetries of lattice. Different types of lattice symmetries correspond to different topological invariants in the bulk and distinct characteristic surface states. We discuss newly discovered Z2 invariants in 3D protected by rotation (screw) symmetry, inversion symmetry and roto-reflection symmetry, respectively. Each of the new invariants in the bulk is related to the (d-2)-dimensional edge states on the boundary. With the new invariants, we establish a complete classification of topological crystalline insulators for each of the 230 space groups in 3D, along with explicit, microscopic constructions for each class. To search for corresponding materials for the topological states in these new classes, we have established quantitative mappings from symmetry eigenvalues of valence bands to topological invariants all space groups. Applying these mappings, we have developed a fully automated diagnosis algorithm for all nonmagnetic crystals. The algorithm is applied to diagnosing 39519 materials, in which 8056 are found topological.

Tuesday, January 8, 2019 (Day 2) 11:00 – 11:30

Symmetry and Nonlinear Responses in TMD Nanostructures

Prof. Yoshihiro Iwasa
University of Tokyo & RIKEN

Due to their favorable and rich electronic and optical properties, group-VI-B transition-metal dichalcogenides (TMDs) have attracted considerable interest. They have earned their position in the materials portfolio of the spintronics and valleytronics communities. The electrical performance of TMDs will be enhanced by rolling up the two-dimensional (2D) sheets to form quasi-one-dimensional (1D) tubular structures. Actually, the TMD nanotubes were first synthesized back in 1992 [1], but only recently device related researches have been conducted [2].In this presentation, we discuss transport and optoelectronic properties ranging from field effect transistor (FET) operation to solar cell actions in tungsten disulfide multiwalled nanotubes (WS_2-NT).

We first fabricated electric double layer transistor (EDLT) of an individual WS_2-NT and found an ambipolar operation, in sharp contrast to the solid gated FET devices which exhibits only n-type conduction. Furthermore, we found that gating with $KClO_4$/polyethylene glycol electrolyte, induce superconductivity at Tc = 5.8 K. This is the first superconductivity in the individual nanotube structure. Importantly, this superconductivity of gated WS_2 exhibited peculiar transport properties arising only from tublar and chiral structure [3].

Using the EDLT devices, we were able to fabricate a p-n junction in an individual WS_2-NT, and found that this p-n junction shows current-driven light emission, and photovoltaic actions [4]. Another unique aspect of the WS_2 nanotube is their polar nature, in sharp contrast to carbon nanotubes as well as to the 2D WS_2. We found the bulk photovoltaic effect which are absent in 2D WS_2 structures, and attributed this new phenomenon to shift current due to the polar nature of WS_2 nanotubes

[1] R. Tenne et al., Nature 360, 444 (1992).
[2] R. Levi et al., Nano Lett. 13, 3736 (2013).
[3] F. Qin et al., Nat. Comm. 8, 14465 (2017).
[4] Y. J. Zhang et al., 2D Mater. 5, 035002 (2018).

Tuesday, January 8, 2019 (Day 2) 11:30 – 12:00

Nonlinear Optical Response of Massless Dirac Fermions in Graphene

Prof. Shiwei Wu
Fudan University

Graphene exhibits extraordinarily strong coupling to light owing to its unique linear and gapless two-dimensional band structure that hosts massless Dirac fermions. In this talk, I will focus on its nonlinear optical response. For centrosymmetric monolayer graphene, the second-order optical nonlinearity is forbidden under the electric-dipole approximation. Yet, it possesses exceptionally strong third-order optical nonlinearity. Recently we show that the third-order nonlinearity including THG and FWM could be electrically tuned by orders of magnitude [1]. Furthermore, the electric-quadrupole response is also gate tunable, leading to strong doping-induced second harmonic generation (SHG) beyond the electric-dipole approximation [2]. In contrast to the electric dipole allowed THG, the electric quadrupole SHG strictly vanishes at zero doping, manifesting the electron-hole symmetry of massless Dirac fermions. We believe the findings in graphene are readily applicable to other related Dirac materials such as topological insulators, Dirac and Weyl semimetals. And the giant nonlinearity in graphene can be utilized to develop nonlinear optoelectronic devices.

[1] Tao Jiang,† Di Huang,† Jinluo Cheng, Xiaodong Fan, Zhihong Zhang, Yuwei Shan, Yangfan Yi, Yunyun Dai, Lei Shi, Kaihui Liu, Changgan Zeng, Jian Zi, J.E. Sipe, Yuen-Ron Shen, Wei-Tao Liu,* Shiwei Wu*, Gate tunable third-order nonlinear optical response of massless Dirac fermions in graphene Nature Photonics 12, 430-436 (2018).

[2] Yu Zhang,† Di Huang,† Yuwei Shan, Tao Jiang, Zhihong Zhang, Kaihui Liu, Lei Shi, Jinluo Cheng, John E. Sipe, Wei-Tao Liu,* Shiwei Wu*, Doping induced second harmonic generation in centrosymmetric graphene from quadrupole response. (submitted).

Tuesday, January 8, 2019 (Day 2) 14:00 – 14:30

Intrinsic topological states in $(MnTe)_m(Bi_2Te_3)_n$ family materials

Prof. Jing Wang
Fudan University

Topological states of quantum matter have attracted great attention in condensed matter physics and materials science. The study of time-reversal-invariant topological states in quantum materials has made tremendous progress. However, the study of magnetic topological states falls much behind due to the complex magnetic structures. Here, we predict the tetradymite-type compound $MnBi_2$\$$Te_4$ and its related materials host topologically nontrivial magnetic states. The magnetic ground state of $MnBi_2$\$$Te_4$ is an antiferromagetic topological insulator state with a large topologically non-trivial energy gap (~0.2 eV). It is the parent state for the axion state, which has gapped bulk and surface states, and the quantized topological magnetoelectric effect. The ferromagnetic phase of $MnBi_2$\$$Te_4$ might lead to a minimal ideal Weyl semimetal. We further present a simple and unified continuum model to capture the salient topological features of this kind of materials.

Tuesday, January 8, 2019 (Day 2) 14:30 – 15:00

Bulk-Boundary Correspondence of Non-Hermitian Systems

Prof. Zhong Wang
Tsinghua University

An intriguing issue of non-Hermitian systems is the fate of bulk-boundary correspondence. In this talk, I will show that a previously overlooked ``non-Hermitian skin effect'' necessitates a non-Bloch bulk-boundary correspondence, which is based on a complex-valued Brillouin zone. This generalization of bulk-boundary correspondence is illustrated in the non-Hermitian Su-Schrieffer-Heeger models and Chern insulator models. We analytically obtain their topological phase diagrams, which are dramatically different from those of the Bloch Hamiltonians. As a formulation of the non-Bloch bulk-boundary correspondence, non-Bloch topological invariants are defined in the complex Brillouin zone (instead of the standard Brillouin zone with real-valued momentum), which faithfully predict the number of topological edge modes. Specifically, the chiral edge modes of two-dimensional non-Hermitian Chern bands are determined by the non-Bloch Chern numbers.

[1] Shunyu Yao, Zhong Wang, Phys. Rev. Lett. 121, 086803 (2018)

[2] Shunyu Yao, Fei Song, Zhong Wang, Phys. Rev. Lett. 121, 136802 (2018)

Other co-authors: Shunyu Yao (Tsinghua University), Fei Song (Tsinghua University)

Tuesday, January 8, 2019 (Day 2) 15:00 – 15:30

Anomalous Hall Effect in Topological Matter with Kagome Lattice

Prof. Hechang Lei
Renmin University of China

The origin of anomalous Hall effect (AHE) in magnetic materials is one of the most intriguing aspect in condensed matter physics and has been a controversial for a long time. Recent studies indicate that the intrinsic AHE is closely related to the Berry curvature of occupied electronic states. In a magnetic Weyl semimetal with broken time-reversal symmetry, there are significant contributions to Berry curvature around Weyl nodes, which would lead to a large intrinsic AHE. On the other hand, the kagome lattice is known to host exotic quantum magnetic states. Theoretical work has predicted that kagome lattices may also host topological electronic states. In this work, we introduce two kind of materials Fe_3Sn_2 and $Co_3Sn_2S_2$ with Kagome lattice, which show large AHE, and it can be ascribed to the existence of Weyl or Dirac fermions in these systems. It indicates that magnetic kagome metals provide a new platform to study on the emergent topological electronic properties in a correlated electron system.

Tuesday, January 8, 2019 (Day 2) 16:00 – 16:30

Classification and Construction of Symmetry Protected Topological (SPT) Phases in Interacting Fermion Systems

Prof. Zhengcheng Gu
The Chinese University of Hong Kong

Classification and construction of symmetry protected topological (SPT) phases in interacting boson and fermion systems have become a fascinating theoretical direction in recent years. It has beens shown that the (generalized) group cohomology theory or cobordism theory can give rise to a complete classification of SPT phases in interacting boson/spin systems. Nevertheless, the construction and classification of SPT phases in interacting fermion systems are much more complicated, especially in 3D. In this talk, I will revisit this problem based on the equivalent class of fermionic symmetric local unitary (FSLU) transformations. I will show how to construct very general fixed point SPT wavefunctions for interacting fermion systems. I will also discuss the procedure of deriving a general group super-cohomology theoy in arbitrary dimensions.

Other co-authors: Qingrui Wang, CUHK

Tuesday, January 8, 2019 (Day 2) 16:30 – 17:00

Symmetry-Protected Topological Phases in (3+1) D with Both Spatial and Internal Symmetries

Prof. Peng Ye
Sun Yat-sen University

Symmetry-protected topological (SPT) phases with either internal or spatial symmetries have been classified in different methods within this decade. In this paper, we study the classification of 3+1d topological phases protected simultaneously by both spatial and internal symmetries from the topological response theory. Physical observables derived from these response theories are discussed and compared with their analogs in 2+1d systems, some of which have been well-studied in quantum Hall (QH) systems, like the Wen-Zee (WZ) term. We then study the bulk topological gauge theories for the corresponding SPT phases. Generalizations to symmetry-enriched topological (SET) phases are also discussed at the end of this paper.

Other co-authors: Bo Han (UIUC); Huajia Wang (UIUC, moved to UCSB)

Tuesday, January 8, 2019 (Day 2) 17:00 – 17:30

Real-Space Recipes for General Topological Crystalline States

Dr. Yang Qi
Fudan University

Topological crystalline states are short-range entangled states jointly protected by onsite and crystalline symmetries. While the non-interacting limit of these states, e.g., the topological crystalline insulators, have been intensively studied in band theory and have been experimentally discovered, the classification and diagnosis of their strongly interacting counterparts are relatively less well understood. Here we present a unified scheme for constructing all topological crystalline states, bosonic and fermionic, free and interacting, from real-space "building blocks" and "connectors". Building blocks are finite-size pieces of lower dimensional topological states protected by onsite symmetries alone, and connectors are "glue" that complete the open edges shared by two or multiple pieces of building blocks. The resulted assemblies are selected against two physical criteria we call the "no-open-edge condition" and the "bubble equivalence", which, respectively, ensure that each selected assembly is gapped in the bulk and cannot be deformed to a product state. The scheme is then applied to obtaining the full classification of bosonic topological crystalline states protected by several onsite symmetry groups and each of the 17 wallpaper groups in two dimensions and 230 space groups in three dimensions. We claim that our real-space recipes give the complete set of topological crystalline states for bosons and fermions, and prove the boson case analytically using a spectral sequence expansion of group cohomology.

Other co-authors: Zhida Song and Chen Fang, Institute of Physics, Chinese Academy of Sciences

Wednesday, January 9, 2019 (Day 3) 09:00 – 09:30

Topological Excitations in 1D and 2D Charge Density Wave Systems

Prof. Han Woong Yeom
POSTECH, Korea

Topological excitations or domain walls in magnetic, ferroelectric, multiferroic, and charge density wave (CDW) materials have played multiply important roles for various fundamental and technological issues. In this talk, we will review our recent research activity for atomic scale observation and manipulation of domain wall topological excitations in prototypical 1D and 2D CDW systems. In a 1D CDW system of indium atomic wires, we identified a new type (Z4) of soliton topological excitations [1, 2], which can deliver and manipulate topologically protected quaternary-digit information. Domain walls of the unique Mott-CDW insulating states of 1T-TaS_2 are also investigated in detail [3-5], where domain walls have been related with the emerging superconductivity and novel device applications. We discover not only a method to manipulate domain walls in nanoscale [3] but also two well defined in-gap states within domain walls [4]. These states are largely determined by strong electron correlation intrinsic to this material and structural reconstruction, indicating the multiple internal degrees of freedom within domain walls [4]. A network of such domain walls, as formed in the nearly commensurate CDW phase, can host novel electronic states, which can explain the emergence of superconductivity [5]. As another prototypical 2D CDW system, we focus on 2H-$NbSe_2$. Its CDW ground state has been known as being incommensurate for last 30 years, but the domain wall discommensuration has not been identified. We identify this discommensuration domain wall for the first time and reveals its unusual atomic scale structures [6]. All these results tell us the rich physics within topological excitations, which in turn indicates the possibility of manipulating exotic quantum states through topological excitations in 1D/2D systems.

[1] S. M. Cheon, S.-H. Lee, T.-H. Kim and H. W. Yeom, Science 350 (2015), 6257.
[2] T.-H. Kim, S. M. Cheon, and H. W. Yeom, Nature Phys. 13 (2017), 444.
[3] D. Cho et al., Nat. Commun. 7 (2016), 10453.
[4] D. Cho et al., Nat. Commun. 8 (2017), 392.
[5] J. H. Park, G. Y. Cho, D. Cho, and H. W. Yeom, Nat. Commun. under review.
[6] G. Gye, E. Oh, and H. W. Yeom, Phys. Rev. Lett. under review.

Wednesday, January 9, 2019 (Day 3) 09:30 – 10:00

Large-Scale Numerical Investigations of Correlated Electron Systems, Present and Future

Dr. Zi Yang Meng
Institute of Physics, Chinese Academy of Sciences

In this talk, I will present recent developments in conceptual and technical aspects of large-scale numerical simulations of correlated electron systems, in particular new quantum Monte Carlo methods. Fresh results on itinerant quantum critical points, i.e. the critical phenomena arising from the strong coupling between Fermi surface and bosonic fluctuations will be discussed and the thereby discovered non-Fermi-liquid will be illustrated, as well as its extension to the situation of gauge fields coupled to matter fields, which is fundamentally connected to the understanding of deconfined quantum criticality. In the end, I will propose promising directions in combining numerical methods and quantum field theory in the era of big-data and artificial intelligence in pursuing the understanding of correlated electron systems.

Reference:

Phys. Rev. X 7, 031058 (2017)

arXiv:1807.07574

arXiv:1808.08878

Wednesday, January 9, 2019 (Day 3) 10:00 – 10:30

Machine Learning Many-Body Localization: Search for the Elusive Nonergodic Metal

Prof. Xiao Li
City University of Hong Kong

The breaking of ergodicity in isolated quantum systems with a single-particle mobility edge is an intriguing subject that has not yet been fully understood. In particular, whether a nonergodic but metallic phase exists or not in the presence of a one-dimensional quasiperiodic potential is currently under active debate. In this Letter, we develop a neural-network-based approach to investigate the existence of this nonergodic metallic phase in a prototype model using many-body entanglement spectra as the sole diagnostic. We find that such a method identifies with high confidence the existence of a nonergodic metallic phase in the midspectrum at an intermediate quasiperiodic potential strength. Our neural-network-based approach shows how supervised machine learning can be applied not only in locating phase boundaries but also in providing a way to definitively examine the existence or not of a novel phase.

Reference: Phys. Rev. Lett. 121, 245701 (2018).

Other co-authors:
Yi-Ting Hsu: University of Maryland, College Park
Dong-Ling Deng: Tsinghua University
S. Das Sarma: University of Maryland, College Park

Wednesday, January 9, 2019 (Day 3) 11:00 – 11:30

Proximity Josephson Coupling in Heterojunctions of 2D Materials

Prof. Hu-Jong Lee
POSTECH, Korea

Realization of proximity coupling in Josephson junctions, incorporating various two-dimensional (2D) van der Waals materials including graphene, has recently attracted much research interest. In this talk, I will first focus the short-ballistic (SB) strong Josephson coupling realized in vertical and planar proximity Josephson junctions with mono-layer graphene as the thin normal-conducting spacer. The short-ballistic junction characteristics provide highly robust coherent states to be utilized for possible quantum-device applications. Here, for vertical graphene Josephson junctions (GJJs), the SB strong proximity coupling is realized by shortening the channel length down to the thickness of mono-layer graphene between two superconducting-layer electrodes. For planar GJJs, the SB strong coupling is realized via the ballistic conducting channel of a boron-nitride-encapsulated graphene layer. Then, I will discuss how the Josephson effect is utilized to study fundamental material properties such as the robust surface conduction in a topological insulator and the edge conduction in 2D materials such as quantum spin Hall insulators and graphene. For detailed review on the topics, please refer to Ref. [1].

[1] “Proximity coupling in superconductor–graphene heterostructures”, Gil-Ho Lee and Hu-Jong Lee, Reports on Progress in Physics **81**, 056502 (2018).

Wednesday, January 9, 2019 (Day 3) 11:30 – 12:00

Strain induced Mott gap collapse in 1*T*-TaS_2

Prof. Yi Yin
Zhejiang University

Tuning electronic properties of a matter is of fundamental interest in scientific research as well as in applications. In a pristine layered transition metal dichalcogenides 1*T*-TaS_2, it undergoes a spontaneous metal-insulator transition when the temperature is lowered. A Mott insulating ground state is suppressed and a superconducting state emerges via doping and pressure.

However, the mechanism behind the melting of the Mott phase is far from understood.

Here we apply scanning tunneling microscopy (STM) to study the electronic properties of 1*T*-TaS_2. We find the coexistence of insulating and metallic mosaic charge density wave (CDW) domains in a strain-rich area. The Mott gap collapses on a corrugated surface, with the smooth evolution detected and analysed. Our observations provide a direct evidence for the important role of strain in melting of the Mott phase. This guides the strain engineering on the switching device design and enhance our understanding of the metal-insulator transition.

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Wednesday, January 9, 2019 (Day 3) 14:00 – 14:30

3/2 Fractional Quantum Hall Plateau and Possible 1/2 Quantization of Fractional Quasi-Particles

Prof. Xi Lin
Peking University

In a single layer two-dimensional electron gas, we observed a new even-denominator fractional quantum Hall plateau quantized at $(h/e^2)/(3/2)$ under confinement, at a bulk filling factor of 5/3. This unexpected plateau develops below 300 mK with a quantization of 0.02%. The conductance transmitting through the confined region is also quantized at 3/2 e^2/h, and the conductance of 1/6 e^2/h is backscattered. A new elemental excitation with e/6 effective charge, the further fractionalization of the e/3 quasi-particles, through topological soliton and topological phase transition is proposed as a tentative explanation.

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Wednesday, January 9, 2019 (Day 3) 14:30 – 15:00

Interacting Flatland Electrons Never Stop Surprising

Prof. Yang Liu
Peking University

At low temperature (~ 20 mK) and high magnetic field (~ 10 T), the electrons' in-plane cyclotron motion will be quantized into different harmonic oscillators which have discrete energy levels, the Landau levels (LLs). The two-dimensional electron system (2DES) exhibits the integer quantum Hall effect (IQHE) when the electron density is an integer multiple of the LL degeneracy. When a LL is partially filled, the clean 2DES displays a myriad of novel many-body quantum phases -- such as the fractional quantum Hall effect, the charge density waves, the Wigner crystal (WC) -- arising from the dominance of the Coulomb interaction energy over the kinetic energy.

In my talk, I will first give a brief introduction to the fascinatingly rich physics seen in ultra-clean GaAs 2DESs when interaction dominates over other energies. Then I will discuss some recent progress in the following topics:

1. Commensurability oscillations when we introduce a one-dimensional periodic potential to a Fermi sea of composite fermions (CFs), quasi-particles formed by attaching two flux-quanta to each interacting electron.

2. A proposal and experimental results that directly probe the magnetic-field-induced Wigner crystal (WC) in a two-dimensional (2D) electron system.

3. We observe multiple transitions of the fractional quantum Hall states (FQHSs) near filling factors $\nu = 3/4$ and 5/4. The data reveal that these are spin-polarization transitions of interacting two-flux composite Fermions, which form their own FQHSs at these fillings. The fact that the reentrant integer quantum Hall effect near $\nu = 4/5$ always develops following the transition to full spin polarization of the $\nu = 4/5$ FQHS strongly links the reentrant phase to a pinned ferromagnetic Wigner crystal of two-flux composite Fermions.

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Tight-Binding Piezoelectric Theory and Electromechanical Coupling Correlations for Transition Metal Dichalcogenide Monolayers

Dr. Yunhua Wang
Sun Yat-sen University

The lack of inversion symmetry in semiconducting transition metal dichalcogenide monolayers (TMDMs) enables a considerable intrinsic piezoelectricity, which opens prospects for atomically thin piezotronics and optoelectronics. Here, based on the tight-binding (TB) approach and Berry phase expression for electronic polarization difference, we establish an atomic-scale TB theory for demonstrating piezoelectric physics in TMDMs. Using the TB piezoelectric theory, we predict the electronic Grüneisen parameter (EGP), which measures the electron-phonon couplings for TMDMs. By virtue of the constructed analytical piezoelectric model, we further reveal the correlation between the electronic contribution to piezoelectric coefficients and strain-induced pseudomagnetic gauge field (PMF). These predicted EGP and PMF for TMDMs are experimentally testable, and hence the TB piezoelectric model is an alternative theoretical framework for calculating electron-phonon interactions and PMF.

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Competing Orders in The Mott Insulating Phase of SU(4) Anisotropic Dirac Fermions

Mr. Han Xu
Wuhan University

We employ large-scale projector quantum Monte Carlo (PQMC) simulations to study the ground-state properties of the SU(4) Hubbard model with staggered flux. With the influence of both on-site repulsion and flux, our simulation shows continuous phase transitions between the semimetal, antiferromagnetic (AFM) and valence-bond-solid (VBS) phases. Interestingly, in terms of the gap opening mechanism and the order parameter distribution, both the columnar VBS (c-VBS) ordering and the plaquette VBS (p-VBS) ordering emerge in the VBS phase. The phase diagram features a tricritical point where the semimetal, AFM and VBS phases meet.

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$Pr_2Ir_2O_7$: When Luttinger Semimetal Meets Melko-Hertog-Gingras Spin Ice State

Mr. Xuping Yao
Fudan University

In quantum materials with multiple degrees of freedom such as itinerant electrons and local moments, the interplay between them leads to intriguing phenomena and allows the mutual control of each other. Here, we study band topology and engineering from the interplay between local moments and itinerant electrons in pyrochlore iridates. For metallic $Pr_2Ir_2O_7$, the Ir 5d conduction electrons interact with the Pr 4f local moments via the f-d exchange. While the Ir electrons form a Luttinger semimetal, the Pr moments can be tuned into an ordered spin ice with a finite ordering wave vector, dubbed the Melko-Hertog-Gingras state, by varying Ir and O contents. We point out that the Pr Ising order generates an internal field and reconstructs the Ir bands. Besides the broad existence of Weyl nodes, we predict that the magnetic translation of the Pr Melko-Hertog-Gingras state protects the Dirac-band touching at certain time-reversal invariant momenta for the Ir electrons. We propose the magnetic fields to control the Pr magnetism and thereby indirectly influence the Ir conduction electrons. Our prediction can be immediately tested in ordered $Pr_2Ir_2O_7$ samples. Our theory should stimulate experiments on pyrochlore iridates, constitute a nontrivial and realistic example for the interplay between itinerant electrons and local moments in three dimensions, and shed light on hybrid quantum materials with multiple degrees of freedom.

Other co-authors: Gang Chen, University of Hong Kong

Gate Tuning from Exciton Superfluid to Quantum Anomalous Hall in Van Der Waals Heterobilayer

Dr. Qizhong Zhu
The University of Hong Kong

Van der Waals heterostructures of 2D materials provide a powerful approach towards engineering various quantum phases of matters. Examples include topological matters such as quantum spin Hall (QSH) insulator, and correlated matters such as exciton superfluid. It can be of great interest to realize these vastly different quantum matters on a common platform, however, their distinct origins tend to restrict them to material systems of incompatible characters. Here we show that heterobilayers of two-dimensional valley semiconductors can be tuned through interlayer bias between an exciton superfluid (ES), a quantum anomalous Hall (QAH) insulator, and a QSH insulator. The tunability between these distinct phases results from the competition of Coulomb interaction with the interlayer quantum tunnelling that has a chiral form in valley semiconductors. Our findings point to exciting opportunities for harnessing both protected topological edge channels and bulk superfluidity in an electrically configurable platform.

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