Hong Kong Forum of Physics 2024:

Recent Progresses on 2D Quantum Materials

16 - 19 December, 2024 (Monday - Thursday)

The University of Hong Kong (Campus Map)
CYPP3, LG1/F, Chong Yuet Ming Physics Building, Main Campus, HKU

Organized by
Area of Excellence on 2D Materials Research
Department of Physics
HK Institute of Quantum Science & Technology

Organization committee

Dongkeun Ki (The University of Hong Kong) (Co-chair)
Wang Yao (The University of Hong Kong) (Co-chair)
Xiaodong Cui (The University of Hong Kong)
Maohai Xie (The University of Hong Kong)
Ning Wang (Hong Kong University of Science and Technology)
Jianbin Xu (The Chinese University of Hong Kong)
Hua Zhang (City University of Hong Kong)
S.P. Daniel Lau (The Hong Kong Polytechnic University)
Yipu Xia (The University of Hong Kong) (coordinator)

The Forum is supported by:
Area of Excellence on 2D Materials Research

Day 1 (December 16, Monday) 09:40 - 10:10

To screen or not to Screen: Correlated Electron Systems

Prof. Chun Ning Lau
The Ohio State University

Within a correlated electron system, the strength of electronic interactions depends on the screening provided by its electromagnetic environment, leading to different ground states. Here we will discuss our works on graphene-based flat band systems with different screening strengths, ranging from minimized screening in suspended rhombohedral few-layer graphene, to in situ tunable screening in twisted bilayer graphene. In the latter system, we demonstrate that superconductivity is suppressed by stronger screening, thus suggesting the possibility that pairing mechanism therein is driven by electronic interactions.

Day 1 (December 16, Monday) 10:10 - 10:40

Signatures of integer and fractional Chern insulators in twisted $MoTe_2$ trilayers

Prof. Weibo Gao
Nanyang Technological University

The interplay between topology and correlation in condensed matter leads to a plethora of exotic quantum phases. The recent discovery of integer and fractional quantum anomalous Hall (IQAH and FQAH) effects in twisted $MoTe_2$ bilayer and rhombohedral graphene/h-BN moiré superlattices broadens the playground of moiré-engineered strong correlated states with non-trivial topology and fractionalized quasi-particles. However, the layer degree of freedom in such a topologically correlated regime has hitherto remained unexplored in the $MoTe_2$ systems, which is a powerful tuning knob. Here, we report a rich spectrum of topological correlated states observed in the twisted $MoTe_2$ trilayer, where a monolayer is rotated by few degrees and stacked on top of a natural 2H bilayer. Doping-dependent photoluminescence (PL) discloses correlated states for both electron and hole doping. The optically detected Landau fan diagram demonstrates several incompressible states with non-zero Streda slopes, indicating not only integer Chern insulators (ICIs) at fillings ν = -1 and +1, but also fractional Chern insulators (FCIs) at ν = -4/5 and -2/3 for hole doping as well as at ν = 2/5, 4/7 and 3/4 for electron doping. In twisted $MoTe_2$ trilayers, the topological states at hole doping exhibit robust ferromagnetism as revealed by reflection magnetic circular dichroism (RMCD). Surprisingly, for the ICI and FCI states at electron doping, we observe the antiferromagnetic Curie-Weiss behaviors. Our results open the door to studying topological correlated phases in twisted $MoTe_2$ multilayers.

Day 1 (December 16, Monday) 11:00 - 11:30

Van der Waals Heterostructures and Superlattices Beyond 2D Materials: the Bo(u)ndless Frontier

Prof. Xiangfeng Duan
University of California, Los Angeles

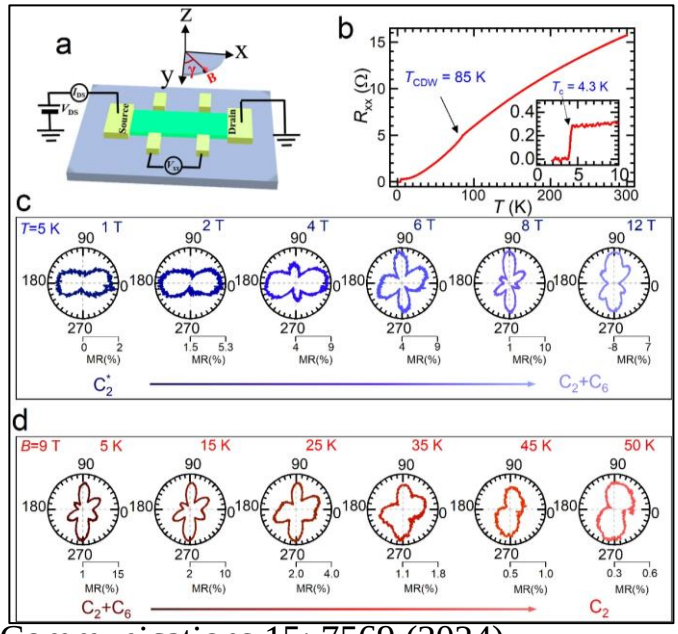
The rise of two-dimensional atomic crystals (2DACs) and van der Waals heterostructures (VDWHs) has inspired a bonding-free approach to constructing heterostructures beyond traditional epitaxial methods. This talk begins with an overview of early explorations into van der Waals (VDW) interactions for integrating disparate materials with pristine electronic interfaces. I will then focus on our recent advancements in synthesizing and exploring a diverse family of VDW superlattices (VDWSLs) composed of alternating layers of 2DACs and self-assembled molecular interlayers with customizable chemical compositions and structural motifs. I will highlight how these molecular interlayers can tailor the electronic and optical properties of 2DACs, with a particular emphasis on chiral molecular intercalation superlattices that exhibit robust chiral-induced spin selectivity and intriguing chiral superconductivity. With versatile molecular design and modular assembly strategies, 2D-molecular VDWSLs offer boundless opportunities to tailor electronic, optical, and quantum properties, creating a rich platform for emerging technologies.

Day 1 (December 16, Monday) 11:30 - 12:00

Hidden phases in kagome metal CsV_3Sb_5 and correlated superconductor 6R-TaS_2

Prof. Jian-Hao Chen
Peking University

The topology and correlation effects in van der Waals materials have received widespread attention in the fields of condensed matter physics and materials science. The topologically non-trivial band structure and electronic correlation can induce a very rich range of physical phenomena, one of which is the electronic orders. We will use two examples to show the tip of the iceberg of various exotic electronic orders: the first example is the unsaturated linear magnetoresistance and the three-dimensional hidden order observed in the kagome topological metal CsV_3Sb_5; The second example is the coexistence of hidden magnetism and nematic superconductivity discovered in the natural heterojunction 6*R*-TaS_2 of Mott insulators and Ising superconductors, which may be a good starting material for studying chiral spin liquids.



[1] Xinjian Wei, et al., Linear non-saturating magnetoresistance in kagome superconductor CsV3Sb5 thin flakes. 2D Materials 10, 015010 (2022)
[2] Xinjian Wei, et al., Three-dimensional hidden phase probed by in-plane magnetotransport in kagome metal CsV3Sb5. Nature Communications 15: 5038 (2024)
[3] Shao-Bo Liu, et al., Nematic Ising superconductivity with hidden magnetism in few-layer 6R-TaS2, Nature Communications 15: 7569 (2024)

Day 1 (December 16, Monday) 12:00 - 12:30

Electrical Control on Correlated States in Layered Quantum Materials

Prof. Hongtao Yuan
Nanjing University

Electric-field control of charge carrier density with a transistor geometry is both significant and remarkably straightforward for modulating physical properties of condensed matters. To realize gate-modulated emergent electronic phenomena in solids, a broad tunable range of attainable carrier density up to levels of over 10^{14} cm^{-2} has been demonstrated for electronic state control based on electric-double-layer transistors. This approach presents great tunability in a new paradigm that is unattainable with conventional methods. In the last decade, quite some great progresses on gating-induced emergent interfacial electronic phenomena have been demonstrated, including interface superconductivity, gating-tunable valleytronics, and gating-modulated spin polarization in correlated electronic systems.

In this presentation, I will discuss the electrical control on emergent electronic states in layered correlated materials in the following three directions. First, I will start with the newly discovered solid-state superionic fluoride gating dielectrics and their applications in realizing logic gate circuit towards advanced 2D electronics and quantum phase control on superconductivity-insulator phase transition in high-T_c superconductor Bi-2212 (Figure 1). Second, I will demonstrate the magnetic states control and the spin flop in layered ferromagnetic materials Fe_5GeTe_2, supported by anomalous Hall and magneto-optical Kerr effect measurements, along with the quantitative theoretical analysis using the Stoner-Wohlfarth model. We achieved a continuous and controllable manipulation of the magnetic easy axis through a spin-flop pathway, paving a new way for practically tunable spintronic applications (Figure 2). Third, I will demonstrate the arresting of an unconventional hidden Kondo state and its tunability by tuning the Fermi energy in the band structure by means of electrical gating, element substitution or applied pressure in Fe_5GeTe_2. Our first-principles calculations reveal that such hidden Kondo states are associated with the exact position of flat bands close to the Fermi level, which can serve as a unique tuning strategy for arresting these hidden Kondo states. Our studies extend the scopes of "iontronics" research within the realm of correlated quantum matters.

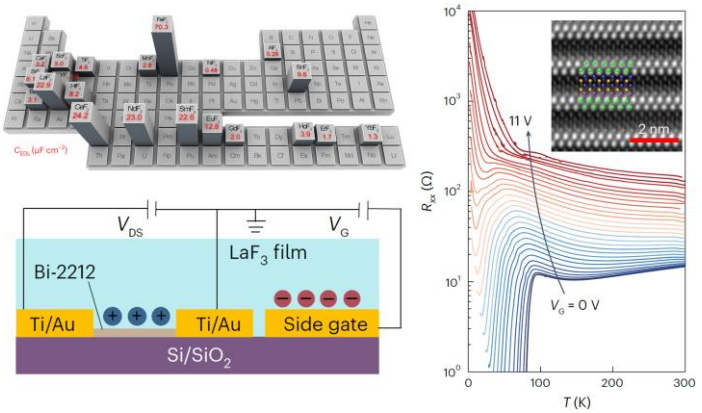


Figure 1 Gate-tunable superconductor-insulator transition in Bi-2212 via fluoride dielectrics[2].

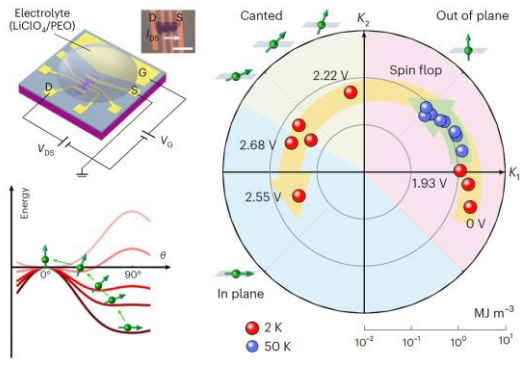


Figure 2 Gate-tunable spin-flop transition of magnetic easy axis in Fe_5GeTe_2 with electrolyte gating technique [4].

References

[1] Hongtao Yuan*, et al., Nature Nanotechnology doi: 10.1038/s41565-024-01732-z, (2024).
[2] Hongtao Yuan*, et al., Nature Nanotechnology 19, 932 (2024).
[3] Hongtao Yuan*, et al., Nature Nanotechnology, 18, 867 (2023).
[4] Hongtao Yuan*, et al., Nature Electronics 6, 28 (2023).

[5] Hongtao Yuan*, et al., Nature Communications 13, 6938 (2022).
[6] Hongtao Yuan*, et al., Nature Materials 21, 773 (2022).

Day 1 (December 16, Monday) 14:00 - 14:30

Quantum metric length in flat band materials

Prof. Kam Tuen Law
Hong Kong University of Science and Technology

coming soon

Day 1 (December 16, Monday) 14:30 - 15:00

Prof. Cui-Zu Chang
The Pennsylvania State University

coming soon

Day 1 (December 16, Monday) 15:00 - 15:30

Strong Inter-valley Electron-Phonon Coupling in Magic-Angle Twisted Bilayer Graphene

Prof. Yulin Chen
University of Oxford / ShanghaiTech University

The unusual properties of superconductivity in magic-angle twisted bilayer graphene (MATBG) have sparked enormous research interest. However, despite the dedication of intensive experimental efforts and the proposal of several possible pairing mechanisms, the origin of its superconductivity remains elusive. In this talk, using angle-resolved photoemission spectroscopy with micrometer spatial resolution, we show our observation on the replicas of the flat bands in superconducting MATBG unaligned with its hexagonal boron nitride (hBN) substrate, which are absent in non-superconducting MATBG aligned with the hBN substrate. Remarkably, the replicas are evenly spaced in energy, separated by 150 ± 15 meV, signaling the strong coupling of electrons in MATBG to a bosonic mode of this energy. By comparing our observations to simulations, the formation of replicas is attributed to the presence of strong inter-valley electron-phonon coupling to a K-point phonon mode. In total, the observation of these replica flat bands and the corresponding phonon mode in MATBG could provide important information for understanding the origin and the unusual properties of its superconducting phase.

Day 1 (December 16, Monday) 16:00 - 16:30

Quantum confinement of Dirac fermions

Prof. Lin He
Beijing Normal University

In graphene quantum dots, the quantum confined Dirac fermions lead to many exotic properties. Our results indicated that we can simulate the exotic predictions of quantum electrodynamics in graphene quantum dots [1-3]. For example, we demonstrated that whispering-gallery modes and atomic collapse states can coexist and change mutually in a graphene quantum dot. Moreover, our experiments demonstrated that we can realize exotic electronic properties beyond the parent material, i.e., the graphene, in graphene quantum dots [4-10]. In this talk, I will introduce two examples. One is the tunable Berry phase and quasibond states in graphene quantum dots [4,5]. The other is novel effects of local rotational symmetry-breaking potentials on the quantum confined states. Our study indicated that the scatterings between different orbital angular momentum states in rotational symmetry-breaking potential can generate additional phase singularity [10]. Moreover, the anisotropy of confining potential induces the *sd* hybridization between two quasibound states, which are also an atomic collapse state and a whispering gallery mode, in graphene quantum dots [11].

References

[1] Q. Zheng, Y.-C. Zhuang, Q.-F. Sun, L. He, Coexistence of electron whispering-gallery modes and atomic collapse states in graphene/WSe_2 heterostructure quantum dots. *Nat Commun.* 13, 1597 (2022).

[2] Z.-Q. Fu, Y.-T. Pan, J.-J. Zhou, K.-K. Bai, D.-L. Ma, Y. Zhang, J.-B. Qiao, H. Jiang, H. Liu, and L. He, "Relativistic artificial molecules realized by two coupled graphene quantum dots". *Nano Lett.* 20, 6738 (2020).

[3] Q. Zheng, Y. Zhuang, Y.-N. Ren, C. Yan, Q.-F. Sun, L. He, "Molecular collapse states in graphene/WSe_2 heterostructure quantum dots" *Phys. Rev. Lett.* 130, 076202 (2023).

[4] Y.-W. Liu, Z. Hou, S.-Y. Li, Q.-F. Sun, and L. He, "Movable valley switch driven by Berry phase in bilayer-graphene resonators" *Phys. Rev. Lett.* 124, 166801 (2020).

[5] Y.-N. Ren, Q. Cheng, Q.-F. Sun, L. He, "Realizing Valley-Polarized Energy Spectra in Bilayer Graphene Quantum Dots via Continuously Tunable Berry Phases". *Phys. Rev. Lett.* 128, 206805 (2022).

[6] S.-Y. Li, Y. Su, Y.-N. Ren, and L. He, "Valley polarization and inversion in strained graphene via pseudo-Landau levels, valley splitting of real Landau levels, and confined states" *Phys. Rev. Lett.* 124, 106802 (2020).

[7] Y.-N. Ren, Y. Zhuang, Q.-F. Sun, L. He, "Magnetic field-tunable valley-contrasting pseudomagnetic confinement in graphene". *Phys. Rev. Lett.* 129, 076802 (2022).

[8] H.-Y. Ren, Y.-N. Ren, Q. Zheng, J.-Q. He, L. He, "Electron-electron interaction and correlation-induced two density waves with different Fermi velocities in graphene quantum dots". *Phys. Rev. B* 108, L081408 (2023).

[9] X.-F. Zhou, Y. Zhuang, M.-H. Zhang, H. Shen, Q.-F. Sun, L. He, "Relativistic artificial molecule of two coupled graphene quantum dots at tunable distances". *Nature Commun.* 15, 8786 (2024).

[10] Y.-W. Liu, Y. Zhuang, Y.-N. Ren, C. Yan, X.-F. Zhou, Q. Yang, Q.-F. Sun, L. He, "Visualizing a single wavefront dislocation induced by orbital angular momentum in graphene". *Nat Commun.* 15, 3546 (2024).

[11] Y. Mao, et al. "Orbital hybridization in graphene-based artificial atoms". submitted

Day 1 (December 16, Monday) 16:30 - 17:00

Fractional Chern Insulator – from quantum many-body computation perspective

Prof. Ziyang Meng
University of Hong Kong

Recently, the fractional Chern insulator (FCI), or, fractional quantum anomalous Hall (FQAH) state, have been experimentally observed in twisted $MoTe_2$ bilayers and multilayer rhombohedral graphene, as well as cold-atom and circuit quantum electrodynamics systems. These ground-breaking advances not only provide opportunities for further experimental investigations but also ask for deeper understanding of these topological states. I will present the recent progresses on novel quantum phases and phase transitions in both fermionic and bosonic FCI models. The intertwinement of topological order and Landau order and the discovery of the collective excitations in FCIs and their role in tuning these transitions, will be discussed [1,2].

References:
[1]. From Fractional Quantum Anomalous Hall Smectics to Polar Smectic Metals: Nontrivial Interplay Between Electronic Liquid Crystal Order and Topological Order in Correlated Topological Flat Bands,
Hongyu Lu, Han-Qing Wu, Bin-Bin Chen, Kai Sun, Zi Yang Meng,
Rep. Prog. Phys. 87 108003 (2024)
[2]. Thermodynamic Response and Neutral Excitations in Integer and Fractional Quantum Anomalous Hall States Emerging from Correlated Flat Bands
Hongyu Lu, Bin-Bin Chen, Han-Qing Wu, Kai Sun, Zi Yang Meng
Phys. Rev. Lett. 132, 236502 (2024)

Day 1 (December 16, Monday) 17:00 - 17:30

Interlayer coupling in graphene-based moiré heterostructures

Prof. DongKeun Ki
The University of Hong Kong

When two (nearly) identical 2D crystals are stacked together, a quasi-periodic moiré structure on a scale much larger than either of the two constituents can be formed that generates new electronic band structures. Moreover, by tuning the moiré length scale, one can approach strong coupling regime where Coulomb interactions between the carriers are strongly enhanced, leading to many-body states. Here, we discuss our on-going efforts to investigate effects of the layer degrees of freedom on electronic properties of 2D moiré systems. After showing that interlayer interaction in van der Waals (vdW) heterostructures is strong enough to modify graphene band using our recent study on graphene on WSe_2 as an example [Nat. Com. **14**, 6124 (2023)], we will show that charge carriers in moiré mini-bands formed in graphene aligned with hexagonal boron-nitride (hBN) can be strongly coupled with those in original Dirac bands by measuring Coulomb drag effect in graphene-hBN-graphene moiré heterostructures [PRL **133**, 186301 (2024)]. This study demonstrates that Coulomb drag experiment can be used to investigate interlayer interactions in 2D moiré systems. We will discuss potential impacts of our works and possible new directions. Financial supports from the MOST China (2020YFA0309600) and the UGC/RGC of Hong Kong SAR (AoE/P-701/20, C7037-22G, 17300020, 17300521, 17309722, and 17301424) are acknowledged.

Day 2 (December 17, Tuesday) 09:30 - 10:00

2D Materials for Physical Computing

Prof. Feng Miao
Nanjing University

The continuous enhancement of computational power is crucial for driving societal progress. Currently, this improvement heavily relies on the integration of transistors. As this integration level nears its limit, marking the end of Moore's Law, the growth in hardware computational power has slowed and been struggling to meet the exponential data processing needs of the AI era. This presents a significant challenge. To overcome it, we need to explore entirely new computing approaches to process information. Unlike traditional digital computing, which relies on abstract symbolic representation and operates at the CMOS circuit level, physical computing processes information at the device level by leveraging material-specific physical processes, thus offering ongoing improvements in computational power. Two-dimensional (2D) materials, with their atomic-layer thickness, enable precise control of physical properties using external fields, creating a superior platform for future physical computing. In this talk, I will show how 2D materials open up unprecedented opportunities for harnessing new physics to advance physical computing. I'll begin by presenting our findings on Wigner crystals and ferroelectricity in graphene moiré systems and discuss how these properties can be applied to build basic solid-state quantum simulators [1], moiré synaptic transistors [2], and noise-resistant neuromorphic devices [3]. I will also show how adjusting the interface potential barrier in heterostructures composed of 2D materials can lead to the development of reconfigurable retinomorphic sensors [4-6], visual motion perceptrons [7], and in-sensor dynamic computing [8]. Finally, I will present our initial explorations on new physical computing schemes [9-10] and share our vision of future physical computing.

References

[1] ***Nature*** 609, 479 (2022).
[2] ***Chinese Physics Letters*** 40, 117201 (2023).
[3] ***Nature Nanotechnology*** (2024, in press).
[4] ***Science Advances*** 6, eaba6173 (2020).
[5] ***Nature Electronics*** 5, 248 (2022).
[6] ***National Science Review*** 8, nwaa172 (2021).
[7] ***Science Advances*** 9, eadi4083(2023).
[8] ***Nature Electronics*** 7, 225 (2024).
[9] ***Nature Nanotechnology*** 16, 1079 (2021).
[10] ***Nature Electronics*** 6, 381 (2023).

Day 2 (December 17, Tuesday) 10:00 - 10:30

Van der Waals Material Devices for Logic, Memory and Computing

Prof. Han Wang
The University of Hong Kong

coming soon

Day 2 (December 17, Tuesday) 11:00 - 11:30

Towards dissipationless topotronics

Prof. Xincheng Xie
Peking University / Fudan University

Electrical charge transport in traditional nanoscale integrated circuits is always accompanied by energy dissipation in the form of Joule heating, which imposes a thermal bottleneck constraining their performance. The emergence of novel topological systems opens up exciting avenues for optimizing thermal management based on the intuitive concept of “no backscattering, no dissipation”. However, whether energy dissipation can emerge without backscattering inside topological systems remains a question. In this work, we propose a microscopic picture that illustrates energy dissipation in the quantum Hall plateau regime of graphene. Despite the quantization of Hall, longitudinal, and two-probe resistances, we find that the energy dissipation emerges in the form of Joule heat. In practice, such energy dissipation phenomenon is universal in topological devices, which casts doubt upon whether it is possible to reach truly dissipationless in topotronics. We propose a criterion for judging whether energy dissipation occurs inside a topological device. This criterion establishes a concise algebraic relationship among the number of modes engaged in transport, $N_{in}=N_{tunl}+N_{bs}$. We advocate for the indispensability of Chern insulators with higher Chern numbers to achieve functional devices and uphold the no-dissipation rule simultaneously. Our work holds promise for shaping the future of integrated topological circuit designs towards no dissipation.

Day 2 (December 17, Tuesday) 11:30 - 12:00

Prof. Di Xiao
University of Washington

coming soon

Day 2 (December 17, Tuesday) 12:00 - 12:30

Helicity & Chirality in Quantum Materials

Prof. Zhenyu Zhang
University of Science and Technology of China

Helicity and chirality are fundamental and widespread concepts or phenomena in nature. Recent studies have also revealed various intriguing helical or chiral phenomena in quantum materials. In this talk, I attempt to give a brief coverage on several aspects of helical or chiral phenomena, including helical or chiral structural formation out of achiral building blocks, emergence of chiral phonons in otherwise achiral or nonmagnetic two-dimensional (2D) kagome lattices, chiral magnetic excitations in 2D quantum magnets, and topologically nontrivial or chiral superconductivity.

Day 2 (December 17, Tuesday) 14:00 - 14:30

Exciton insulators in two-dimensional systems

Prof. Kai Chang
Zhejiang University

Coming soon

Day 2 (December 17, Tuesday) 14:30 - 15:00

Molecular orbitals in solids and their role in physical properties

Prof. Hongming Weng
Institute of Physics, Chinese Academy of Sciences

Atomic orbitals and molecular orbitals in solids are no longer well defined due to translational periodic symmetry, but they are still the best basis vectors for understanding and constructing low-energy effective models. They are natural and have physically intuitive images. In some solids, molecules or clusters form the most basic structural units, in which the electron distribution follows molecular orbitals rather than atomic orbitals, with deviations from atomic positions, higher orbital angular momentum (different from the angular momentum of the orbitals), Similar local characteristics and other characteristics. In this talk, I will introduce how to use group representation theory and Wannier function theory to construct molecular orbitals in solids, and how to use molecular orbitals to study two molecular orbital Mott insulators, namely $GaTa_4Se_8$ and Nb_3Cl_8, to demonstrate ideal multi-band and the implementation of the single-band Hubbard model in materials composed of these transition metal electronics.

Hongming Weng, Professor of Physics at the Institute of Physics, Chinese Academy of Sciences, and director of the Condensed Matter Physics Data Center, Chinese Academy of Sciences. He received his undergraduate degree from the Department of Physics of Nanjing University in 2000 and his PhD in condensed matter physics from Nanjing University in 2005. He works in the direction of computational condensed matter physics. In addition to the development of computational methods and programs, he focuses on the computational research of novel quantum phenomena of solids, including topological materials, diluted magnetic semiconductor and transition-metal compounds. His papers on theoretical prediction and experimental discovery of Weyl semimetals were selected into the collection to celebrate 125^{th} anniversary of Physical Review journals by American Physical Society.

Day 2 (December 17, Tuesday) 15:00 - 15:30

TBD

Prof. Ting Cao
University of Washington

Coming soon

Day 2 (December 17, Tuesday) 16:00 - 16:30

New progresses in topological superconductors by proximity effect

Prof. Jinfeng Jia
Shanghai Jiaotong University / Southern University of Science and Technology

Topological superconductors attract lots of attentions recently, since they are predicted to host Majorana zero mode (MZM), which behaves like Majorana fermion and can be used in fault-tol- erant quantum computation relying on their non-Abelian braiding statistics. Currently, most topo- logical superconductors are artificially engineered based on a normal superconductor and the ex- otic properties of the electronic surface states of a topological insulator. As predicted, MZM in the vortex of topological superconductor appears as a zero energy mode with a cone like spatial dis- tribution. Also, MZM can induce spin selective Andreev reflection (SSAR), a novel magnetic property which can be used to detect the MZMs. Here, I will show you that the $Bi_2Te_3/NbSe_2$ hetero-structure is an ideal artificial topological superconductor and all the three features are ob- served for the MZMs inside the vortices on the $Bi_2Te_3/NbSe_2$. Especially, by using spin-polarized scanning tunneling microscopy/spectroscopy (STM/STS), we observed the spin dependent tunnel- ing effect, which is a direct evidence for the SSAR from MZMs, and fully supported by theoretical analyses. More importantly, all evidences are self-consistent. Recently, the strong proximity effect was found in SnTe-Pb heterostructure. The bulk pairing gap and multiple in-gap states induced by topological surface states can be clearly distinguished. The superconductivity of SnTe is consistent with a new type of topological superconductors under the protection of lattice symmetries. Under lattice-symmetry protection, the superconducting SnTe is proven to possess multiple MZMs in a single vortex. This system provides a platform to study the coupling of multiple MZMs without the need of real space movement of a vortex. Finally, the segmented Fermi surface induced by the Cooper pair momentum was observed in the $Bi_2Te_3/NbSe_2$ system.

References

[1] Mei-Xiao Wang, et al., **Science 336**, 52-55 (2012)
[2] J.P. Xu, et al., **Phys. Rev. Lett. 112**, 217001 (2014)
[3] J.P. Xu, et al., **Phys. Rev. Lett. 114**, 017001 (2015)
[4] H.H. Sun, et al., **Phys. Rev. Lett. 116**, 257003 (2016) [5] H.H. Sun, Jin-Feng Jia, **NPJ Quan. Mater. 2**, 34 (2017) [6] H. Yang, et al., **Adv. Mater. 31**, 1905582 (2019)
[7] H. Yang, et al., **Phys. Rev. Lett. 125**, 136802 (2020) [8] T.T. Liu, et al., **Nature 633**, 71–76 (2024)
[9] Z. Zhu, et al., **Science 374**, 1381 (2021)

Day 2 (December 17, Tuesday) 16:30 - 17:00

Unique Exchange Bias Phenomena in the $MnBi_2Te_4$ Family

Prof. Yu Ye
Peking University

As an A-type antiferromagnetic material, the interlayer coupling of the $MnBi_2Te4$ material can be extensively tuned by inserting non-magnetic Bi_2Te3 layers or introducing Mn-Bi site-mixing defects. The combination of strong interlayer ferromagnetic coupling and tunable interlayer antiferromagnetic coupling results in a multitude of magnetic ground states. The ubiquitous Mn-Bi site mixing modifies or even changes the sign of the subtle interlayer magnetic interactions, resulting in a spatially inhomogeneous interlayer coupling. In this context, we present evidence of a stable exchange bias effect in $MnBi_2Te_4(Bi_2Te_3)_n$ (n=1,2) resulting from the coupling between the ferromagnetic and antiferromagnetic components in the ground state. Furthermore, we report a defect-assisted domain nucleation-driven unique exchange bias in ultrathin uncompensated antiferromagnetic $MnBi_2Te4$. The magnitude and direction of the exchange field can be intentionally controlled by designing a magnetic field sweep protocol that does not require field cooling.

Day 2 (December 17, Tuesday) 17:00 - 17:30

Kagome monolayers: theoretical prediction and experimental realization

Prof. Wei Ji
Renmin University of China

Coming soon

Day 3 (December 18, Wednesday) 09:30 - 10:00

Self-doped molecular Mott insulator in bilayer Hubbard model at electron filling ¼ and application to high Tc superconducting $La_3Ni_2O_7$

Prof. Fuchun Zhang
Kavli Institute for Theoretical Sciences

coming soon

Day 3 (December 18, Wednesday) 10:00 - 10:30

Nonlinear transport theory at the order of quantum metric

Prof. Haizhou Lu
Southern University of Science and Technology

Quantum metric, a probe to spacetime of the Hilbert space, has been found measurable in the nonlinear electronic transport and attracted tremendous interest. We exhaust all mechanisms and their explicit formulas of nonlinear conductivity under the same symmetry that the quantum metric emerges. We analyze the nonzero nonlinear conductivity elements for materials classified by the magnetic point groups, calculate the nonlinear conductivity for the even-layered $MnBi_2Ti_4$ thin films with and without the C3 symmetry, and formulate scaling laws at the order of quantum metric to distinguish different mechanisms in the recent experiments. The theory will facilitate future experiments and applications of the nonlinear transport.

Day 3 (December 18, Wednesday) 11:00 - 11:30

Magnetic polymorphism in 2D layered antiferromagnets

Prof. Shiwei Wu
Fudan University

Polymorphism, commonly denoting the variety of molecular or crystal structures, is a vital element in many natural science disciplines. In van der Waals layered antiferromagnets, a new type of magnetic polymorphism is allowed by having multiple layer-selective magnetic structures with the same total magnetization. However, resolving and manipulating such magnetic polymorphs remain a great challenge. In this talk, I will report the use of phase-resolved magnetic second-harmonic generation microscopy to elucidate such magnetic polymorphism in the 2D semiconducting layered antiferromagnet chromium sulfur bromide (CrSBr), and demonstrate how the magnetic polymorphs can be deterministically switched in an unprecedented layer-selective manner. With the nonlinear magneto-optical technique unveiling the magnetic symmetry information through the amplitude and phase of light, we could unambiguously resolve the polymorphic spin-flip transitions in CrSBr bilayers and tetralayers. Remarkably, the deterministic routing of polymorphic transitions originates from the breaking of energy degeneracy via a magnetic “layer-sharing” effect: the spin-flip transitions in a tetralayer are governed by the laterally extended bilayer, which acts as a “control bit”. We envision such controllable magnetic polymorphism to be ubiquitous for van der Waals layered antiferromagnets, and could lead to conceptually new design and construction of spintronic and opto-spintronic devices for probabilistic computation and neuromorphic engineering.

Day 3 (December 18, Wednesday) 11:30 - 12:00

Magnetic exciton in van der Waals antiferromagnet

Prof. Je-Geun Park
Seoul National University

coming soon

Day 3 (December 18, Wednesday) 12:00 – 12:30

New perspectives on Rydberg excitons in 2D semiconductors

Prof. Yang Xu
Institute of Physics, Chinese Academy of Sciences

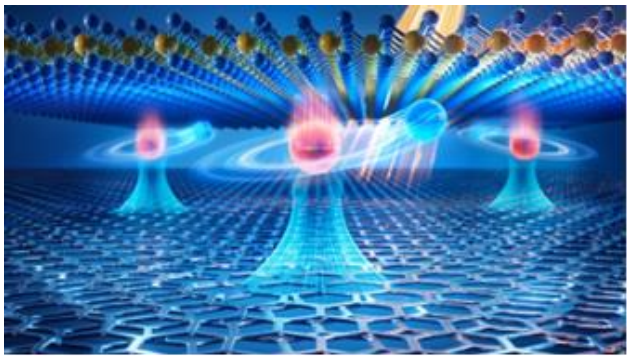


Fig. 1. Illustration of the Rydberg moiré excitons

The Rydberg excitons, first discovered in 1950s, are higher-order excited Coulomb bound states of electron-hole pairs. They are characterized by large spatial extensions and significantly enhanced sensitivity to the surroundings, holding promise for a wide range of quantum applications. However, the potential remains largely unexplored. In this talk, I would discuss some new perspectives on studying the Rydberg excitons in 2D semiconductors. First, I will introduce a recently developed Rydberg exciton sensing technique for detecting the correlated electronic states in 2D moiré superlattices, such as the WSe_2/WS_2 moiré heterobilayer and the magic-angle twisted bilayer graphene (TBG) [1-3]. In the latter case, we resolve the correlated Chern insulators (CCIs) under finite magnetic fields and unveil their direct link with the zero-field normal states, the "cascade transitions". Second, I would discuss the observation of Rydberg moiré excitons (Fig. 1), which are moiré-trapped Rydberg excitons in monolayer WSe_2 adjacent to small-angle TBG [4]. These Rydberg moiré excitons manifest as multiple energy splittings, pronounced red shifts, and narrowed linewidths in the reflectance spectra. We attribute these observations to the spatially varying charge distribution in TBG, which creates a highly tunable periodic potential landscape (moiré potential) for trapping and manipulating the Rydberg excitons.

References

[1] Yang Xu* *et al*., Nature **587**, 214–218 (2020).
[2] Yang Xu *et al*., Nature Materials **20**, 645–649 (2021).
[3] Yang Xu* *et al.*, Nature Nanotechnology **17**, 934-939 (2022).
[4] Qianying Hu *et al*., Science **380**, 1367-1372 (2023).

Day 3 (December 18, Wednesday) 14:00 - 14:30

Physics of moiré multilayers

Prof. Mikito Koshino
Osaka University

coming soon

Day 3 (December 18, Wednesday) 14:30 - 15:00

Tunable incommensurability, complete structural phase diagrams and peculiar electronic structures in trilayer moiré-of-moiré systems

Prof. Young-Woo Son
Korea Institute for Advanced Study

In this talk, we present a comprehensive structural analysis and the unique electronic properties of twisted trilayer graphene (TTG), a minimal multilayer configuration that extends beyond twisted bilayer graphene. We demonstrate a complete catalog of reconstructed moiré-of-moiré structural phases by manipulating combinations of two twist angles. Our findings reveal cascades of spontaneous symmetry breaking as a function of the twist angles, resulting in a diverse array of large-scale moiré lattices, including triangular, kagome, and corner-shared hexagram-shaped domain patterns. Furthermore, our analysis emphasizes the crucial role of long-range interactions across entire layers, alongside the well-known contributions of twist angles and strain between adjacent layers, in realizing various domain lattices. Building on our results for TTG, we apply our methods to other twisted trilayer (TTL) systems made from two-dimensional semiconductors, demonstrating how external fields can control domain lattices. The diverse tessellation of distinct domains, whose topological network can be adjusted by modifying the twist angles, positions TTL systems as a platform for exploring the interplay between emerging quantum properties and controllable nontrivial lattices.

Day 3 (December 18, Wednesday) 15:00 - 15:30

Correlated topological transport in ABC-stacked multilayer graphene

Prof. Guorui Chen
Shanghai Jiaotong University

coming soon

Day 3 (December 18, Wednesday) 16:00 - 16:30

Optical crystals of 2D materials

Prof. Kaihui Liu
Peking University

Nonlinear optical crystals are the key components in advancing laser technology, offering the crucial functionalities of frequency conversion, signal modulation and parameter amplification. Over the last few decades, the utilization of well-established materials for nonlinear optical crystals like BBO, LiNbO3, and KBBF has contributed to the fast development of quantum light sources, photonic integrated circuits and ultrafast lasers. The pursuit of suitable nonlinear optical crystals has led the exploration of the potential in two-dimensional (2D) materials, in which rhombohedral boron nitride (rBN) is particularly promising due to its high nonlinear susceptibility, broadband transparency, remarkable physicochemical stability, and compatibility with Si-based optical chips. However, the preparation of large-sized single-crystal rBN layers remains an extreme challenge. In this talk, I will introduce some recent progresses in the growth of large single-crystal rBN layers with both in-plane and out-of-plane controls[1-4], as well as the development of the twist-phase-matching theory for the design of 2D nonlinear optical crystals[5]. Twisted rBN will be a new useful optical crystal for future photonic and optoelectronic applications.

Reference:

[1] Li Wang, Kaihui Liu*, et al. Epitaxial growth of a 100-square-centimetre single-crystal hexagonal boron nitride monolayer on copper. Nature 2019, 570, 91
[2] Zhibin Zhang, Kaihui Liu*, et al. Continuous epitaxy of single-crystal graphite films by isothermal carbon diffusion through nickel. Nature Nanotechnology 2022, 17, 1258.
[3] Jiajie Qi, Kaihui Liu*, et al. Stacking-controlled growth of rBN crystalline films with high nonlinear optical conversion efficiency up to 1%. Advanced Materials 2023, 2303122.
[4] Biao Qin, Kaihui Liu*, et al. Interfacial epitaxy of multilayer rhombohedraltransition-metal dichalcogenide single crystals. Science 2024, 385, 99
[5] Hao Hong, Kaihui Liu*, et al. Twist-phase-matching in two-dimensional materials. Physical Review Letters 2023, 131, 233801.

Day 3 (December 18, Wednesday) 16:30 - 17:00

Tunable Chirality Couplings and Anomalous Photo-Nernst Effect in Magnetic Weyl Cones in $Co_3Sn_2S_2$

Prof. Dong Sun
Peking University

In this talk, we present our scanning photocurrent microscopy studies of magnetic Weyl semimetal **$Co_3Sn_2S_2$**. In the first part of the talk, we demonstrate that we can use mid-infrared circular polarized light to inject chiral polarized Weyl Fermion. Our results reveal interesting coupling between the circularly polarized mid-infrared light and the magnetic Weyl cones when an external electric field is applied, through third order nonlinear optical response. The coupling builds up versatile tunable chiral polarized Weyl fermions, which manifests as measurable directional photocurrent generation. In the second part of the talk, we show observation of zero-field anomalous photo-Nernst effect in **$Co_3Sn_2S_2$**. Experimentally, clear edge photocurrent response is observed due the anomalous photo-Nernst effect, and the effect can be used to image the magnetic domains.

Day 3 (December 18, Wednesday) 17:00 - 17:30

Tailoring polaritons via gradient moiré superlattices with space-variant switchable light-matter interactions

Prof. Zhiqiang Li
Sichuan University

Polaritons—hybrid light–matter excitations—in 2D materials provide unique opportunities for controlling light at nanoscales. Tailoring these excitations via gradient polaritonic surfaces with space-variant optical response can enable versatile light–matter interaction platforms with completely new phenomena and advanced functionalities. Here we report a natural class of gradient polaritonic surfaces based on superlattices of domain wall solitons in 2D moiré systems. In twisted bilayer graphene on boron nitride, we demonstrate on-off switching and continuous tuning of local polariton-soliton interactions with a critical yet unexplored degree of freedom—the soliton angle that characterizes the local strain direction. We show that such tunability arises from dramatic modifications of topological as well as conventional soliton states by local soliton angle. Furthermore, we reveal the capability of these structures to spatially modify the near-field profile, phase and propagation direction of polaritons in record small footprints, enabling generation and electrical switching of directional polaritons. Our results unlock the enormous potential of 2D moiré materials to serve as gradient polaritonic surfaces with spatially tailored light-matter interactions, opening up new avenues for nanoscale spatial polariton engineering and for exploring novel photonic physics in moiré soliton superlattices.