

DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG



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WELCOME

Dear prospective research postgraduate students,

We hope you find this booklet a valuable resource, providing both reference material and background information to assist you in your research postgraduate application process. We are very proud of our exceptional track record of distinguished and innovative research at HKU, covering a variety of fields in the physical sciences. These include,

- i) condensed matter physics and material science,
- ii) astrophysics,
- iii) quantum information science,
- iv) optics and photonics,
- v) nuclear and particle physics.

We are very much in an uptrend. Both the quality and the quantity of the physics research activities at HKU have grown steadily in recent years. We are doing outstanding research in all the above research areas. For instance, Prof. Wang Yao, a Chair Professor in Physics, has published some very highly cited papers in the field of condensed matter physics. We have been winning more awards - two Croucher Senior Research Fellowships, one by Prof. Wang Yao and one by Prof. Xiaodong Cui; Prof. Shizhong Zhang received Hong Kong RGC Fellowship; Prof. Wang Yao received the 2021 (the Ninth) Nishina Asia Award; Prof. Wang Yao and Prof. Yi Yang received the Xplorer Prize; Prof. Shuang Zhang and Prof. Wang Yao appeared on the list of New Cornerstone Investigator Program sponsored by Tencent; Prof. Lixin Dai, Prof. Jenny Hiu Ching Lee, Prof. Chenjie Wang, and Prof. Yi Yang won China's Excellent Young Scientists Fund 2021, Croucher Tak Wah Mak Innovation Awards 2024 and Prof. Yi Yang was selected as the Inventor of the 2022 Innovators Under 35 (China) by the MIT Technology Review.

We have been getting some of the largest research grants in Hong Kong (e.g. two out of four AoEs awarded in 2021, including one led by Prof. Wang Yao). The Department has grown steadily over the past few years, having attracted some very outstanding young scientists in the fields of condensed matter physics, ultrafast optics, and astronomy. Three professors from the Department have appeared on the list of globally highly cited researchers over the last five years (Wang Yao, Lance Li, Xiaobo Yin, Shuang Zhang). In terms of citation numbers, our annual citations (ISI) increased from 17285 in 2018 to 24262 in 2023. Prof. Wang Yao and Prof. Shuang Zhang have been nominated the Fellow of the American Physical Society and Fellow of Optica, in recognition of their exceptional contributions to the field of physics. This was truly impressive!

We believe we provide an exceptional program of M.Phil. and Ph.D. research opportunities for top students to grapple with. We believe you will be engaged, enthused, challenged and rewarded by the projects on offer. So please browse, digest and choose wisely and if you apply and are successful, we look forward to welcoming you to the HKU research family.

Prof. Shuang Zhang
Interim Head and Chair Professor
Department of Physics, HKU

August 2024.

INTRODUCTION
POSTGRADUATE STUDY AND RESEARCH ACTIVITIES
IN PHYSICS
AT THE UNIVERSITY OF HONG KONG

Besides commitment to excellence in undergraduate education, the staff of the Physics Department are engaged in active world-class research in many areas of physics. The department offers both M.Phil. and Ph.D. programs for full-time postgraduate students. In alignment with the university and faculty's overarching vision, our mission and goal as a research unit are to become locally pre-eminent, leading in Asia, and globally competitive in selected sub-fields in research.

Currently, there are 28 faculty members in the Physics Department. There are four strategic research areas. They are 1) condensed matter physics and material science, 2) astrophysics, 3) quantum information science and 4) optics and photonics including atomic and molecular physics.

HKU has long-standing research strengths in the first two research areas: condensed matter physics and astrophysics, which have delivered world-class research outcomes. We intend to further strengthen these two research areas, particularly the experimental side of condensed matter physics.

Our two new strategic research directions are quantum information science and optics and photonics. Our Department has long-standing existing strength on the theoretical side of quantum information science. Over the next few years, we will grow strongly on the experimental side. In fact, we have initiated the Institute of Quantum Science, which is currently led by Prof. Zidan Wang. We will also grow in a fourth and closely related research area, optics and photonics including optical metamaterials.

We will also work towards building a bigger tent to link up various research areas within the Department and to collaborate with other departments in HKU and externally.

Furthermore, the nuclear and particle physics group will play a key role in Hong Kong's joint participation in international and regional collaborations on big science.

- **The Facilities:**

The department houses a number of state-of-art research facilities for multi-disciplinary researches in condensed matter physics, quantum information science, optics and photonics, astrophysics, high-energy and nuclear physics.

- **Theoretical Studies**

For theoretical studies, besides the central computing facility of the university, staff and students of the department have at their disposal an IBM Computer Cluster 1 master + 12 slave blade dedicated to research.

- **Scholarships and Funding Support:**

We are proud to provide **full financial support** to all our research postgraduate students to cover both the tuition fees and living expenses. In addition to standard funding support, various special scholarships including HKU Presidential Scholarships are also available.

- **Growth in quality and quantity of Publications and Citation Numbers:**

Over the last few years, our research activities have grown substantially: For instance, (i) annual research outputs increased from 280 scientific papers in 2015 to 392 in 2023; (ii) publications in Science and Nature series, and in Phys. Rev. Lett. increased from 19 in 2018 to 38 in 2023; (iii) annual citations (ISI) increased from 17285 in 2018 to 24262 in 2023. These growing publication and citation numbers demonstrate the growth in world-class research in our department. Here are some examples of recent papers being published in top scientific journals:

Layer-dependent ferromagnetism in a van der Waals crystal down to the monolayer limit, Nature 546, 270-273 (2017)

Giant tunneling magnetoresistance in spin-filter van der Waals heterostructures, Science 360, 1214 (2018)

Giant nonreciprocal second-harmonic generation from antiferromagnetic bilayer CrI₃, Nature 572, 497- 501 (2019)

Signatures of moiré-trapped valley excitons in MoSe₂/WSe₂ heterobilayers, Nature 567, 66-70 (2019)

Experimental observation of non-Abelian topological charges and edge states, *Nature* 594, 195-201 (2021)

Linked Weyl surfaces and Weyl arcs in photonic metamaterials, *Science* 373, 572-577 (2021)

Light-induced ferromagnetism in moiré superlattices, *Nature* 604, 468-473 (2022)

Photonic flatband resonances for free-electron radiation, *Nature* 613, 42-47 (2023)

Programming correlated magnetic states with gate-controlled moiré geometry, *Science* 381, 325-330 (2023)

Signatures of Fractional Quantum Anomalous Hall States in Twisted MoTe₂, *Nature* (2023)

Overcoming losses in superlenses with synthetic waves of complex frequency, *Science* (2023)

- **Community Service and Outreach**

The department is also actively engaging with the general public through citizen science, liaising with government bodies and fostering industrial partners in its efforts to translate basic and applied research into meaningful economic and societal impact. Teachers and RPG students are encouraged to visit schools to give talks on their research and the role and importance of physics in society.

- **Location of Physics Department**

The Physics Department is housed in the Chong Yuet Ming Physics Building, conveniently situated on the main campus with easy access to the Main Library and other facilities. All our main laboratories are located in the lower floors of this building. The main administration section is on the 5th floor. The Main University Library has an extensive collection of books and journals related to the various research fields, while the Department also runs its own small library specifically for use by staff and research students.

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Dr. H.W. Chen	Dr. J.H. Chen
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Dr. X. Wang	Dr. L.B. Xia
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Dr. C. Zhang	Dr. X.D. Zhang
Dr. L. Zhang	Dr. C.K. Zhou

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Prof. T.L. Ho
Prof. T. Ishihara
Prof. S.A. Maier
Prof. E. Wang
Prof. J. Wang
Prof. S.J. Xu
Prof. F.C. Zhang

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Technicians

Executive Officer

Clerks I

Clerk II

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Shadow Chung, Carfulin Tam, Anna Wong

Mandy Tse, Eva Wong, Queenie Yue

Ken Chow

Ling Wong

RESEARCH GROUPS/ CENTRE HOUSED IN DEPARTMENT OF PHYSICS, HKU

Condensed Matter Physics group:

Condensed matter physics group's research consists of both 1) experimental and 2) theoretical aspects. Regarding experimental condensed matter and material science, research activities include electronics and optoelectronics of two-dimensional materials, organic/inorganic nanocomposite optoelectronic devices, epitaxial thin films and surface properties of new quantum materials, defects and nanostructures in semiconductors, and semiconductor optics.

Theoretical condensed matter physics is a very important area in physical sciences. It concerns with many fundamental subjects and has very wide and potentially important applications in material science, biophysical science, high technology, and even economy and finance. We have very active research activities in this field with focuses in topological matter, 2D materials, spintronics and valleytronics, nanoelectronics, and quantum many-body physics.

There are a lot of interactions and collaborations between experimentalists and theorists within the condensed matter physics group.

In what follows, we will discuss about the two branches of the condensed matter physics group, namely 1) experimental condensed matter and material science group and 2) theoretical and computational condensed matter, one by one.

Academic staff: ***Prof. X.D. Cui***
 Prof. A.B. Djurišić
 Prof. D.K. Ki
 Prof. L.J.L. Li (by courtesy)
 Prof. F.C.C. Ling
 Prof. Z.Y. Meng
 Prof. S.Q. Shen

Prof. C.J. Wang

Prof. Z.D. Wang

Prof. M.H. Xie

Prof. W. Yao

Prof. X.B. Yin (cross-listing from Optics and Photonics group)

Prof. S.Z. Zhang

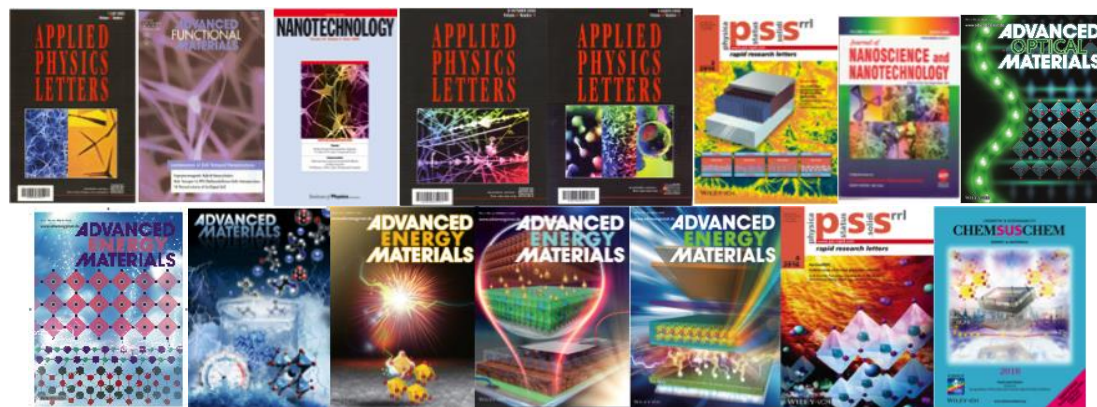
Prof. Y.X. Zhao

1. Experimental Condensed Matter and Material Science

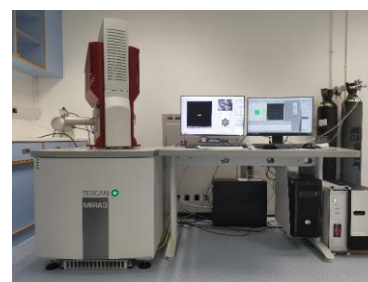
Prof. Cui's lab focuses on optical and electrical properties of nanostructures and emerging semiconductors. The laboratory is equipped with a home-made confocal spectroscopy system, a time-resolved spectroscopy system and an electric charactering system. Current research's emphases include characterizations and applications of low dimensional materials, particularly emerging low dimensional semiconductors. Recently we focus on optical properties of atomic 2 dimensional (2D) crystals, particularly atomic layers of transition metal dichalcogenides (TMD). We explore the interplay of electron's spin, valley degrees of freedom and electron-electron interactions with semiconductor optics techniques.

Prof. Djurišić's research activities include fabrication and characterization of organic/inorganic halide perovskite optoelectronic devices (light emitting diodes and solar cells), as well as fabrication and characterization of wide band gap semiconductor nanostructures, primarily for application as charge transport materials in optoelectronic devices. The study of optoelectronic devices aims at improving the understanding of the operating principles and processes taking place at interfaces. The obtained results are then used for fabrication of devices with improved performance, with particular emphasis on device stability. This research also includes the investigation of novel halide materials, and understanding the relationship between their chemical composition and their optical and electronic properties. The laboratory is equipped with fume cupboards, glove box, tube furnaces, spin-coater, thermal evaporator for fabrication

of optoelectronic devices, and E-beam/sputtering deposition system, while characterization facilities include UV/Vis/NIR spectrometers for characterization of light emitting diodes and experimental setups for power conversion efficiency and external quantum efficiency measurements for solar cells.



Prof. Ki's quantum device lab investigates quantum transport phenomena in nano-electronic devices, realized by state-of-the-art nanofabrication and engineering techniques, such as electron-beam lithography and van der Waals assembly techniques. For this, the group is equipped with a complete set of nanofabrication and engineering facilities, such as electron-beam writer, mask-free photolithography system, metal deposition chambers, reactive ion etcher, and home-made micro-manipulators to assemble atomically thin 2D crystals with high precision. There are also two atomic force microscopes (AFMs) to check and clean 2D materials' surfaces. For transport measurements, we have one zero-field 10K CCR cryostat, one 100 mK dilution fridge with 14-T magnet, one 400mK He-3 fridge with 12-T magnet, and one 1.8K 9-T PPMS. Current research focuses on discovering new transport phenomena, understanding their microscopic origins, and learning to control their properties. Materials of interest include 2D materials, topological insulators, unconventional magnets, and low-dimensional Perovskite nanostructures as they not only have interesting electronic properties but also offer large experimental flexibilities to study and



Electron-beam writer



14-T dilution fridge

engineer them. We are also interested in bridging the gap between the fundamental research and real-life applications. More details can be found at <https://www.physics.hku.hk/~dkkilab/>

Prof. Li's research focuses on Materials & Technologies for Future Electronics. Electronics have been deeply embedded in modern humans' lives, with applications involving the economy, government, defense, education, research, smart cities, health care, and entertainment. State-of-the-art electronic components and integrated circuits have shrunk to almost reach the physical limit in dimensional scalability. Therefore, radically new innovations on new materials and device architecture are needed to continue the dimension and power scaling to realize the strong demand for future extreme electronics. Drawing from his unique dual-track research background, Professor Lance Li envisions that 2D materials such as boron nitrides, transition metal dichalcogenides, etc. hold tremendous promise in replacing Si as the transistor materials for manufacturing compact and low-energy-consuming nanodevices. His main research interest is to understand the fundamentals and provide solutions for major bottlenecks that prevent their integration with micro/nanoelectronics technologies. These main tasks include (1) develop a reproducible approach for growing wafer-scale single-crystalline and low-defect-density 2D crystals, (2) demonstrate a reliable layer transfer method that does not induce defects, (3) systematic exploration of appropriate process integration, and (4) develop turnkey solutions for 3D device stacking.

More details can be found at <https://www.lancelilab.com/>

Prof. Ling's current focused interests of the Material Physics Laboratory include:

- (1) Characterizing atomic scale defects in wide band gap semiconductors and 2D and molecular solid films. These includes the optical characterization using luminescence and Raman methods; the electrical properties using deep level transient spectroscopy, admittance and impedance spectroscopies; dielectric characterization and analysis; the electronic structure using synchrotron and x-ray spectroscopy; and vacancy structure characterization using positron annihilation spectroscopy. Also focusing on studying the correlation between the defects and the

materials electrical, optical and dielectric properties.

- (2) Suppressing or introducing new defects (or defect complex) to control the material properties; or to create new functionality for old materials.
- (3) Defect engineering of commercial devices to enhance device performance via industry collaboration.

Current projects of the Materials Physics Laboratory include:

- (a) Dielectric materials and dielectric engineering. Aim to enhance the oxide permittivity via introducing acceptor-donor defect complex. It was demonstrated the permittivity of ZnO film and ZnO ceramic can be enhanced to respectively ~ 200 and ~ 10000 , whereas the enhancement is associated to the correlated barrier hopping between the acceptor-donor defect complex.
- (b) Wafer scale high-k van de Waals thin film growth and phase control via defect engineering. This is the ideal material for fabricating the gate of the field effect transistor. The absence of the material dangling bond implies a good gate/channel interface thus less scattering and larger mobility. Wafer scale pure alpha phase Sb_2O_3 van de Waals films was fabricated via controlling the oxygen vacancy with resultant permittivity of ~ 100 .
- (c) Defect engineering of SiC devices for enhancing device performance. This is a collaborated project with the Mainland industry.

The lab is equipped with specialised equipment such as Laplace transformed deep level transient spectroscopy system; Liquid nitrogen optical cryostat; 10 K liquid He free optical cryostat; Electrical characterization equipment: semiconductor parameter analyzer, multi-frequency LCR meter, and impedance analyzer (10M Hz); Photoluminescence system: 30 mW HeCd laser, 500 nm and 800 nm monochromator, PMT and CCD detecting system; UV-visible spectrophotometer; Radio frequency magnetron sputtering system; Pulsed laser deposition system; Chemical vapor deposition system; Thermal evaporator; Tube furnace and box furnace.



Prof. Xie's research aims at understanding the processes and properties that occur at the boundary of materials — surface. Current researches focus on the growth and surface characterizations of low-dimensional materials, such as transition-metal dichalcogenides and their hetero-structures. We use molecular-beam epitaxy (MBE), one of the most versatile techniques to grow materials with precise control, to fabricate new quantum materials and artificial structures with single atomic layer precision. We characterize the structural and electronic properties by surface tools such as scanning tunneling microscopy and spectroscopy (STM/S) and ultraviolet photoelectron spectroscopy (UPS).



A multi-chamber ultrahigh vacuum system consisted of multi-facilities such as MBE, UPS, LEED and STM

2. Theoretical and Computational Condensed Matter

The current research interests include:

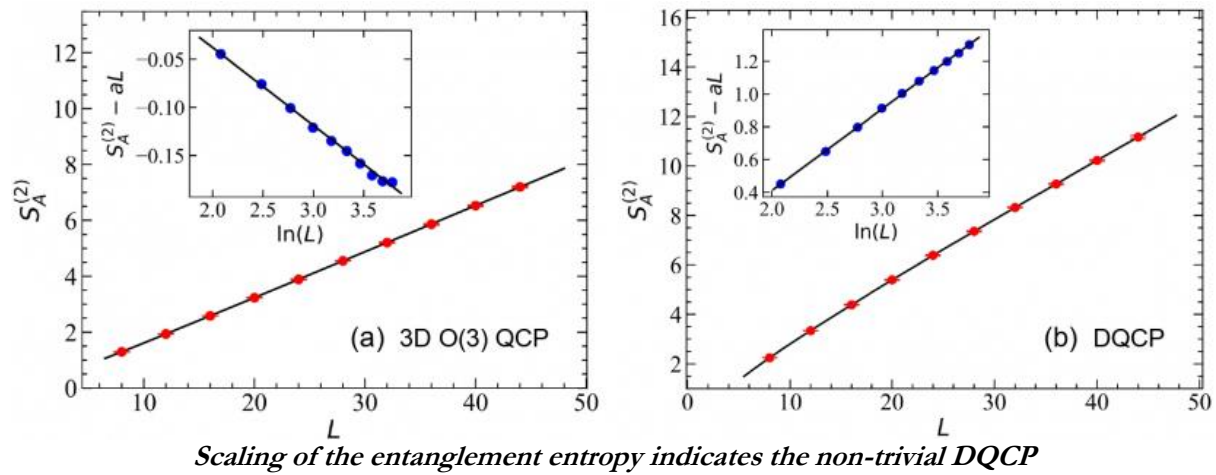
- (1) strongly correlated electron systems (Z.Y.Meng, C.J.Wang, S.Z. Zhang);
- (2) topological matter (Z.Y.Meng, S.Q.Shen, C.J.Wang, Z.D. Wang, W.Yao, Y.X. Zhao);
- (3) quantum materials (Z.Y.Meng, S.Q. Shen, Z.D. Wang, W.Yao, S.Z. Zhang);

- (4) quantum computing and quantum simulation (Z.D. Wang);
- (5) quantum magnetism (Z.Y. Meng);
- (6) spintronics and valleytronics (W.Yao);
- (7) quantum transport (S.Q. Shen, S.Z. Zhang, W.Yao);
- (8) semiconductor optics (S.Q.Shen, W.Yao);
- (9) interdisciplinary study of cold atom physics and condensed matter physics (S.Z.Zhang)
- (10) computational approaches in quantum many-body systems (Z.Y.Meng, C.J.Wang)
- (11) scientific computing and neuromorphic AI accelerator in physics (Z.Y.Meng)
- (12) crystal symmetry (Y.X. Zhao)

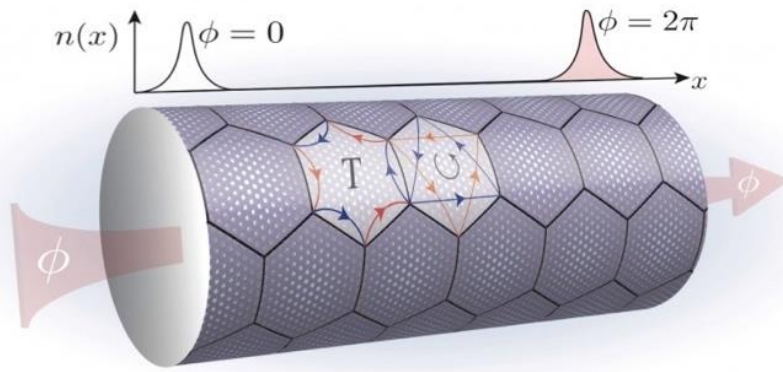
The research activities of theoretical and computation condensed matter physics cover almost the full spectrum of modern condensed matter physics research, from strongly correlated electron systems, topological state of matter, quantum computation and magnetism, transports and spin and valleytronics, to the quantum materials (2D materials, graphene heterostructure, for example) and the fast growing computational approaches such as large-scale quantum many-body simulation and artificial intelligence assisted researches. We are among the top researchers in our corresponding subfields and are pursuing the fundamental questions of the modern quantum matter, including the identification and classification of the topological state matter (C.J.Wang, Z.D.Wang, S.Q.Shen, Y.X.Zhao), the model construction and their quantum many-body solutions towards the new paradigms of quantum matter (Z.Y.Meng), quantum computation and quantum Simulation (Z.D.Wang), cold atomic gases (S.Z. Zhang), novel transports in 2D materials and novel mechanisms (S.Q.Shen, W.Yao), and crystal symmetry (Y.X. Zhao), etc. In all these fields, we have made great impact and participating and leading the research directions at a global level.

Prof. Meng's research focuses on strong correlated electron systems and

computational quantum many-body physics. For example, the fundamental questions, such as the paradigm beyond Landau's Fermi liquid that would eventually describe the ubiquitous observations of non-Fermi-liquid in correlated electron systems such as high temperature superconductors, 2D material and graphene heterostructures; and the paradigm beyond the Landau-Ginzburg-Wilson of phases and phase transitions, where the fractionalization and topological classifications will play the dominate role, are within the research scope of his group members. And many of them have already contributed constructively in the establishments of these new paradigms of quantum matter. His group has made "Break through" in understanding quantum phase transition beyond the Landau-Ginzburg-Wilson, where deconfined quantum critical points has been revealed by measuring the Rényi entanglement entropy, <https://www.hku.hk/press/press-releases/detail/24042.html>



The group has also teamed with researchers from mainland China and employed quantum many-body simulations, performed on the world's fastest supercomputers (Tianhe-I and Tianhe-III prototype at National Supercomputer Center in Tianjin and Tianhe-II at National Supercomputer Center in Guangzhou), to discover the quantum anomalous Hall effect in a *bona fide* topological Mott insulator in twisted bilayer graphene model, which gives an inspiration to reveal the mechanism of the superconductivity and provide better tunability of these exotic phenomena in this and other 2D quantum moiré material, <https://www.hku.hk/press/press-releases/detail/23300.html>



Measurement of Hall conductance via flux insertion in the quantum anomalous Hall phase of the twisted bilayer graphene lattice model

Last but not least, the new paradigm of quantum matter research with the emergent features of correlated electronic systems are inherently nonperturbative, and large-scale quantum many-body numerical simulations assisted with field theoretical analysis are becoming the most prominent and indispensable techniques to tackle such difficult problems. Members of the group have rich experience in developing algorithms and performing cutting edge simulations on the world largest supercomputing facilities in China. And we are now working actively in addressing the critical situation of missing team efforts into large-scale computational physics within Hong Kong and the extended Greater Bay area. Leveraging on current robust development in artificial intelligence and quantum computation in the region, i.e. through collaboration with National supercomputer centers in Guangzhou/Shenzhen, and building their own intermediate size of high-performance computing facility, the group hopes to boost related developments into quantum material research.

Prof. C.J. Wang is a theorist working on condensed matter physics. His current research focuses on theories of interacting topological phases of matter and consequences of generalized symmetries (those beyond groups) on quantum phase transitions. He is also working on localization physics. Previously, he worked on quantum transport, fractional quantum Hall liquids, Luttinger liquids, and fluctuation theorems in non-equilibrium statistical mechanics.

Prof. Z.D. Wang investigates theoretically quantum information physics, and explores implementation of quantum computation and quantum simulation in physical systems, including superconducting quantum circuits and cold atoms as well as trapped ions. Current research interests

extend to include topological quantum computing and quantum machine learning. Recently, his group has established a hybrid theory for realizing quantum machine learning tasks, taking the both advantages of discrete and continuous quantum variables.

Prof. Yao is a condensed matter theoretician. His research interests span an interdisciplinary area across condensed matter physics, quantum physics, and optical physics, with a current focus on atomically thin two-dimensional materials and their van der Waals heterostructures. He has played a decisive role in creating an important new research direction – valley optoelectronics in 2D semiconductors, which aims to exploit valley, a quantum degree of freedom of electron, in future optoelectronic devices.

Prof. Zhang studies ultra-cold atomic gases, which have emerged as a multi-disciplinary subject and is at the interface of modern atomic and molecular physics, quantum optics and condensed matter physics. It proves to be an excellent laboratory for investigating strongly interacting quantum many-body systems and in particular correlated quantum phases and phase transitions. Current topics of interest include strongly interacting two-component Fermi gases and BEC-BCS crossover, physics of high partial wave quantum gases and more generally, transport in strongly interacting gases in reduced dimensions.

Prof. Zhao's research focuses on the algebraic and topological aspects of solids. Recently, his group has been developing projective representations of crystal symmetries and the resulting novel topological classifications. This research project evokes various modern mathematical concepts, including group cohomology, Mackey's unitary representation theory of group extensions, equivariant homotopy theory, and equivariant K theory. Additionally, Prof. Zhao is interested in the topological aspects of non-linear sigma models for disorders and quantum anomalies in topological matter.

Facilities

A summary of the major facilities include Multi-chamber UHV system consisted of MBE, STM, UPS, and LEED facilities, low-temperature (4K) STM, Pulsed laser deposition system, RF sputtering system and

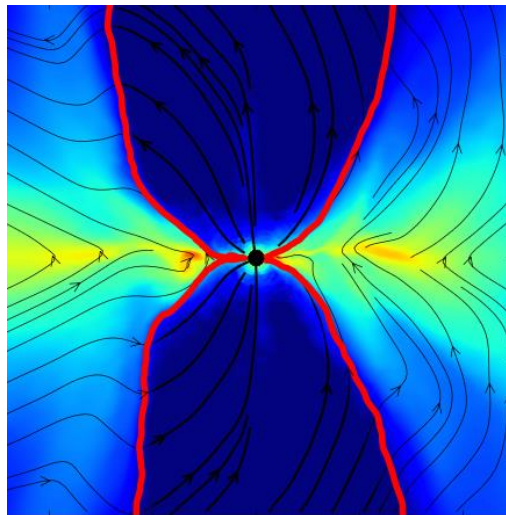
electron beam evaporators, micro-optics system for photoluminescence and Raman spectroscopy and pump-probe spectroscopic systems, Home-assembled large ultra-precise magneto-photoluminescence system, Comprehensive semiconductor parameter analyzing system, Scanning electron microscope with E-beam lithography function, Superconducting magnet, 9T with closed cycled cooling system, Ultralow temperature cryogen-free measurement system with 14-T and 12-T superconducting magnets, 9-T Physical Properties Measurement System (PPMS).

Astrophysics group:

The group's research mainly focuses on high-energy astrophysics, late stage stellar evolution, observational cosmology and planetary science (including the solar system).

Academic staff: ***Prof. L.X. Dai***
 Prof. M. Gu
 Prof. M.H. Lee (Dept. Earth Sciences
 adjunct with Dept. Physics)
 Prof. J.J.L. Lim
 Prof. S.C.Y. Ng

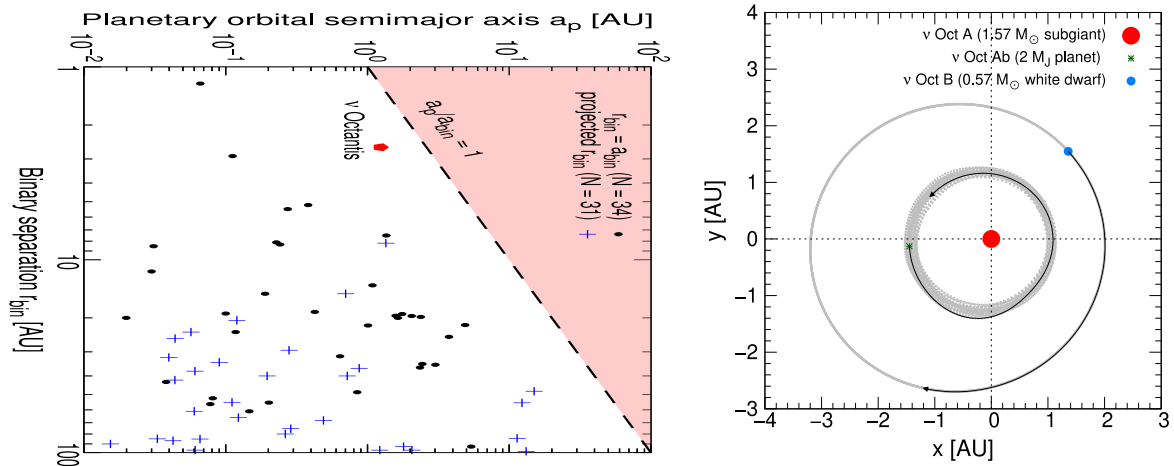
Prof. Dai is a theoretical and computational astrophysicist, working to understand relativistic phenomena around black holes. She is broadly interested in black hole accretion and outflows, tidal disruption events, active galactic nuclei, time-domain astronomy, and multi-messenger astrophysics. She mainly develops and employs novel numerical simulations to model these energetic phenomena and connect theory to observations. She co-chairs the supermassive black hole science topical panel of Einstein Probe, an international X-ray mission dedicated to time-domain high-energy astrophysics.



Snapshot from a state-of-the-art GRMHD simulation of a super-Eddington accretion disk around a black hole and the relativistic jet launched

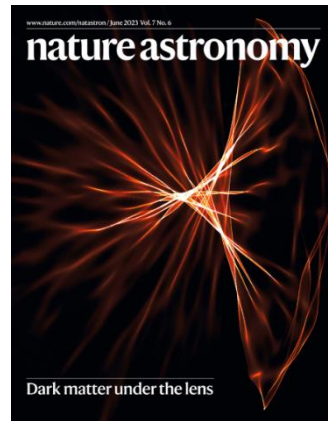
Prof. Gu is an observational astronomer studying galaxy evolution. She specializes in stellar population synthesis modeling, and spectroscopic observations and analysis of early-type galaxies. Her research seeks to understand the physical mechanisms driving the complicated interplay between star formation and galaxy mass assembly, and answering several known open issues: What is the stellar initial mass function of galaxies, how does it vary globally and locally, and impact on the mass measurement? What is the influence of environments on galaxy formation and evolution? How do massive galaxies grow, and what can we learn from the spatial information of stellar populations? She works on observational datasets from world class telescopes such as the Magellan telescopes, ESO's Very Large Telescope, and the [Sloan Digital Sky Survey](#). She is involved in the Subaru Prime Focus Spectrograph Survey, and three approved projects by the James Webb Space Telescope related to redshift 1-2 early-type galaxies.

Prof. Lee is a planetary dynamicist who works on the formation and dynamical evolution of planetary bodies (planets, moons, etc.) in our Solar System and in planetary systems around other stars. He is also an expert in numerical methods for dynamical simulations of planetary systems. His current research interests include the dynamics and origins of (1) orbital resonances in extrasolar planetary systems, (2) planets in binary star systems, (3) the orbital architecture of the planets in our Solar System, and (4) the satellite systems of Jupiter, Uranus and Pluto-Charon.



The primary star of the ν Octantis binary hosts a circumstellar planet on an exceptionally wide orbit relative to the binary separation. The planetary orbit must be retrograde to be stable.

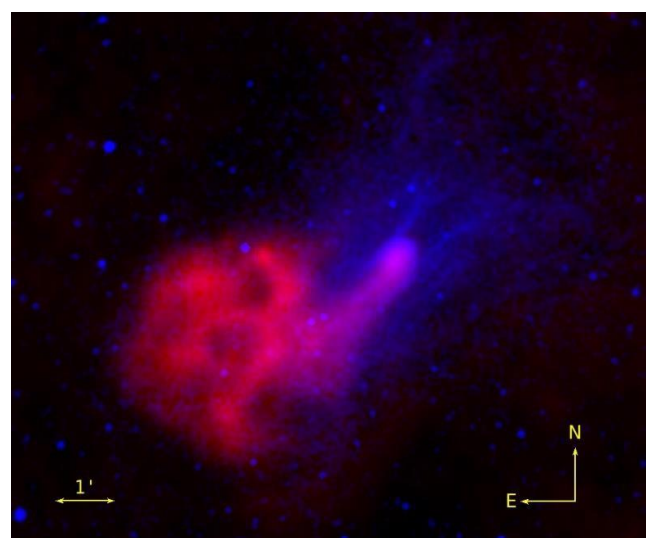
Prof. Lim is an observational astronomer who has worked on a broad range of topics in astrophysics, starting from the Sun and stars to now galaxies near and far as well as galaxy clusters, using telescopes operating at wavelengths spanning radio to X-rays. His research team comprises primarily graduate, undergraduate, and even high school students, along with collaborators based in USA, Europe and Asia. Focused on the astrophysical applications of gravitational lensing, they address topics such as: (i) the constituents of Dark Matter, along with the distribution of Dark Matter in both galaxies and galaxy clusters; and (ii) the formation and evolution of galaxies in the early universe. Another focal area is the formation and evolution of the largest galaxies in the universe, the giant elliptical galaxies at the centers of galaxy clusters, and how their evolutionary growth relate to that of their host clusters. His research team uses primarily data from the Hubble Space Telescope, as well as the James Webb Space Telescope through a collaboration with guaranteed time access. Their work has been featured in the popular press, and recently chosen for the cover of Nature Astronomy.



Caustics – areas over which galaxies lying behind massive foreground galaxies are strongly gravitationally lensed – as predicted by Prof. Lim’s research team if Dark Matter comprises ultra-light bosons. Such particles are predicted by theoretical extension to the Standard Model of Particle Physics as well as String Theory. The complex caustics predicted, in stark contrast to the relatively simple caustics predicted if Dark Matter comprises ultra-massive particles (such as WIMPs, as are predicted by different theoretical extensions to the Standard Model) appear to resolve longstanding problems in gravitational lensing known as lensing anomalies.

Prof. Ng studies extreme objects in our Galaxy, including magnetars, energetic pulsars, pulsar wind nebulae (PWNe), and supernova remnants. He has led observational projects using world-class telescopes in X-rays and radio, such as the Chandra X-ray Observatory, XMM-Newton, the Expanded Very Large Array, and the Australia Telescope Compact Array. He has identified a pulsar moving at an enormous velocity over 2,000 km/s. He is also involved in the development of future telescopes, including the Square Kilometre Array, the Athena X-ray Observatory, and the Imaging X-ray Polarimetry Explorer.

Prof. Ng's latest research focuses on the magnetic fields of neutron stars and their environments. Employing X-ray observations, he measures the surface temperature of magnetars, which are stars with the strongest magnetic fields in the Universe, to understand their extreme properties and their connection with ordinary radio pulsars. In addition, he maps the magnetic field configurations of



Comparison between the radio (red) and X-ray (blue) emission of the Snail pulsar wind nebula

PWNe using radio telescopes, in order to probe the cosmic ray production and transport in these systems. Further information can be found at the webpage <https://astro.physics.hku.hk/~ncy/>.

Facilities

Our on-campus facilities in observational astrophysics include a 40 cm diameter reflector telescope located on the top of the CYM physics building equipped with a charged couple device (CCD) imager and spectrometer, and a 2.3 m diameter small radio telescope. These are all used for teaching, training and outreach. For professional observational astrophysics research we regularly win access to a wide range of cutting-edge international telescopes via competitive peer review. These include ground based facilities such as the Gemini 8-metre Telescopes in Chile and Hawaii, the 8-metre telescopes of the European Southern Observatory in Chile, telescopes of the Beijing Astronomical Observatories and South African and Australian facilities. We also win access to space based facilities like the Hubble Space Telescope and Chandra X-Ray Observatory and data from the Fermi Gamma ray telescope. The quality of our projects and proposals leads to success in gaining frequent access on such facilities.

We also have a medium size computer cluster “Blackbody”, which has more than 1000 CPUs. This cluster is mainly used for conducting simulations in theoretical astrophysics.

Quantum Information Science group:

Quantum information science is the study of information processing using the laws of quantum mechanics, rather than classical physics. Quantum information processing promises to revolutionize information processing as we know it today. On one hand, quantum computing offers an exponential speed-up to some specific computing problems such as the factoring of large integers, thus breaking standard public key encryption schemes such as RSA. On the other hand, quantum cryptography promises information-theoretic security, a Holy Grail in communication security. A Quantum Internet allows quantum signals to be exchanged securely between two locations all over the world. Study of quantum information science can also advance our understanding in foundational problems in quantum mechanics.

To unleash the full power of quantum information processing, numerous conceptual and engineering challenges remain. Some of the notable problems in this cutting edge research field include how to build a quantum computer, how to secure data transmission in the quantum world, are there novel information processing tasks made possible by quantum mechanics, and the nature of quantum entanglement. Teaming up with experts in the Condensed Matter Physics Group as well as the Optics and Photonics Group, researchers in the HKU Physics Department, Quantum Information Science Group attacks these problems by studying the feasibility of various quantum computer proposals including superconducting quantum circuits, cold atoms and topological quantum computing. They provide the foundations of security to quantum cryptographic protocols. They also propose new quantum cryptographic methods and investigate their security and efficiency in practice. Last but not least, they study the consequences of quantum mechanics for fundamental notions like time and causal order, and explore quantum superpositions in time and causal structure can be used as a resource for new communication and computation tasks.

Traditionally, the quantum information science group has been strong on the theoretical side. With the recent establishment of the Institute for Advanced Quantum Study, we are going to expand in this area, both theory and experiment.

Academic staff:

Prof. H.F. Chau

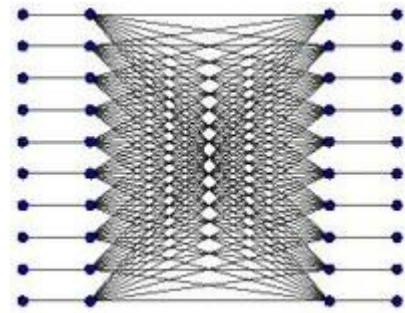
Prof. G. Chiribella (by courtesy)

Prof. Z.D. Wang (cross-listing from condensed matter physics group)*

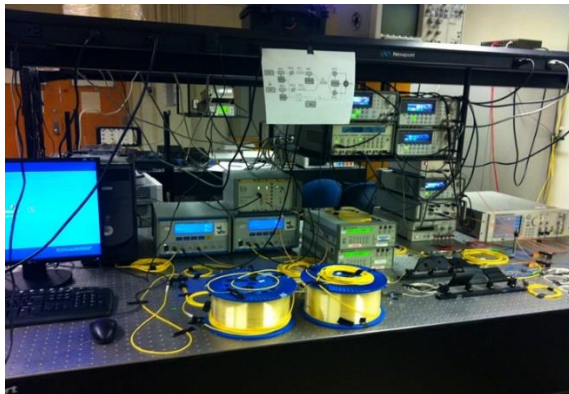
Prof. S. Z. Zhang (cross-listing from condensed matter physics group)*



"Twin-field" quantum key distribution



All photonic quantum repeaters graph states



Prof. Hoi-Kwong Lo's lab



IBM super-conducting quantum processors

Prof. Chau focuses on the theoretical study of quantum information theory and quantum computation. Prof. Chau and his collaborator Prof. Hoi-Kwong Lo were among the first to prove the information-theoretic security of quantum key distribution (QKD), thus solving a long-standing problem. Prof. Chau is interested in proposing new quantum cryptographic protocols and proving their security as well as getting a better understanding of how to manipulate quantum information by quantum error-correction codes.

Prof. Giulio Chiribella is a By-Courtesy Professor in Physics and a Professor in Computer Science. He works on quantum information

theory and on the foundations of quantum mechanics. He is interested in the design of new communication protocols powered by quantum resources, and in the study of the ultimate quantum limits to information processing, including precision limits for quantum measurement devices and efficiency limits for quantum computers. In quantum foundations, he investigates the interplay between the protocols of quantum information and the fundamental notions of space, time, and causal structure.

Prof. Wang investigates theoretically quantum information physics, and explores implementation of quantum computation and quantum simulation in physical systems, including superconducting quantum circuits and cold atoms as well as trapped ions. Current research interests extend to include topological quantum computing and quantum machine learning. Recently, his group has established a hybrid theory for realizing quantum machine learning tasks, taking the both advantages of discrete and continuous quantum variables.

Quantum Information Science Group is closely related to the Optics and Photonics group, which will be discussed below.

Optics and Photonics group:

Light-matter interaction powers a vast majority of phenomena happening in our daily life, from our visual observation to the lithography process that makes the integrated circuits empowering our ubiquitous electronic devices. Therefore, Optics and Photonics, study of light-matter interaction and its applications, have always been a fundamental pillar of physics. At every revolution of modern science and technology, one can find signature of Optics and Photonics, from special relativity, general relativity, to more practical applications such as laser, telecommunication, to quantum information. Hence, pursuing research in Optics and Photonics would likely equip students with the highly qualified skills which are not only required for frontier research in academia, but also to an extremely high job satisfaction regardless of the institution where they work ([SPIE global report 2019](#)). In HKU, [Department of Physics](#) is expanding in the direction of light-matter interaction with research groups focusing on manipulating matter ([plasmonic devices and optical metamaterials – Chair Prof. S. Zhang, Prof. Y. Yang and Prof. X.B. Yin](#)) and light ([Prof. T.T.Luu](#) and [Prof. Y. Yang](#)).

The Optics and Photonics Group is closely connected to the Quantum Information Science Group, where we can find world-class research groups on Quantum Computing and Information Theory ([Chair Prof. Z.D.Wang](#) and [Prof. H.F.Chau](#)) and [Theoretical Atomic Physics and Degenerate Quantum Gases \(Prof. S.Z.Zhang\)](#). We also have close collaboration with other groups in Department of Physics, including but not limited to, [Prof. Yao's group on quantum valley and spintronics](#), [Prof. Cui's group on optical spectroscopy](#), [Prof. C. J. Wang's group on topological physics](#), and [Prof. Ki's group on quantum devices](#). As HKU is situated in the Greater Bay Area, research and applications of Optics and Photonics have surged steadily over the past ten years; we highly believe that it would be an exciting, yet rewarding time for students to pursue a research program with us.

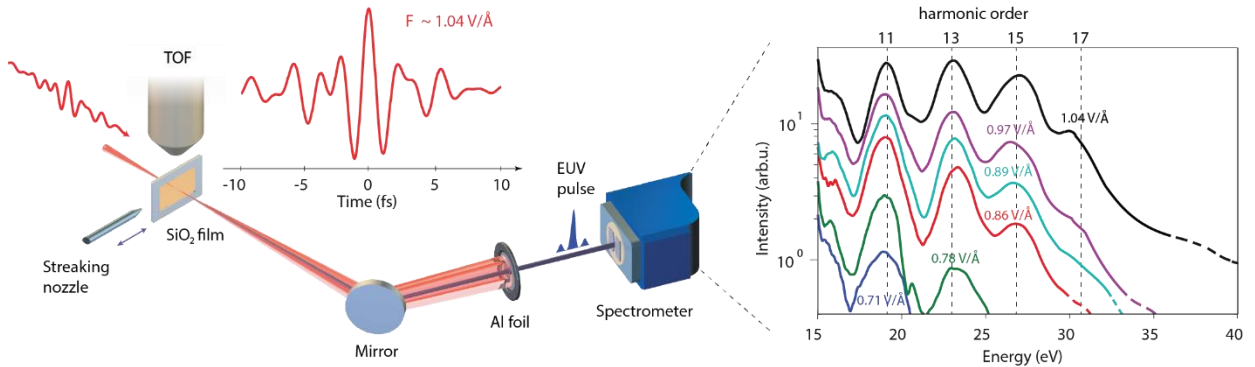
Academic staff:

Prof. A.B. Djurišić* (*cross-listing from condensed matter physics group*)

Prof. T.T. Luu

Prof. Y. Yang
Prof. X.B. Yin (by courtesy)
Prof. S. Zhang

Prof. Luu's research focuses on studying light-matter interaction using manipulation of light. By creating light pulses that are extremely fast, i.e. as fast as hundreds of atto-second ($1\text{as} = 10^{-18}\text{ s}$) that reside either in extreme ultraviolet or optical domain, we can study electronic process in their native time scale. These laser pulses play a crucial role in time-resolved spectroscopy where the extreme temporal resolution allows one to initiate, follow, and control electronic processes in matters with the highest possible fidelity. Furthermore, they additionally enable studies of electronic properties of matters in a novel approach.



Experimental apparatus (left) to generate coherent extreme ultraviolet radiation (right) from laser-solid interaction

Prof. Y. Yang is an assistant professor under the HKU-100 scheme in the Department of Physics. He conducts both theoretical and experimental research in nanophotonics, free electron optics, and topological photonics. In particular, he is interested in the extreme light-matter interaction between photons and material electrons, free electrons, and synthetic gauge fields. His recent research includes a general electromagnetic framework at the extreme nanoscale, a fundamental upper limit to spontaneous free-electron radiation, the observation of strong interaction between free electrons and photonic flat bands, and the realization of the long-sought non-Abelian Aharonov-Bohm effect.

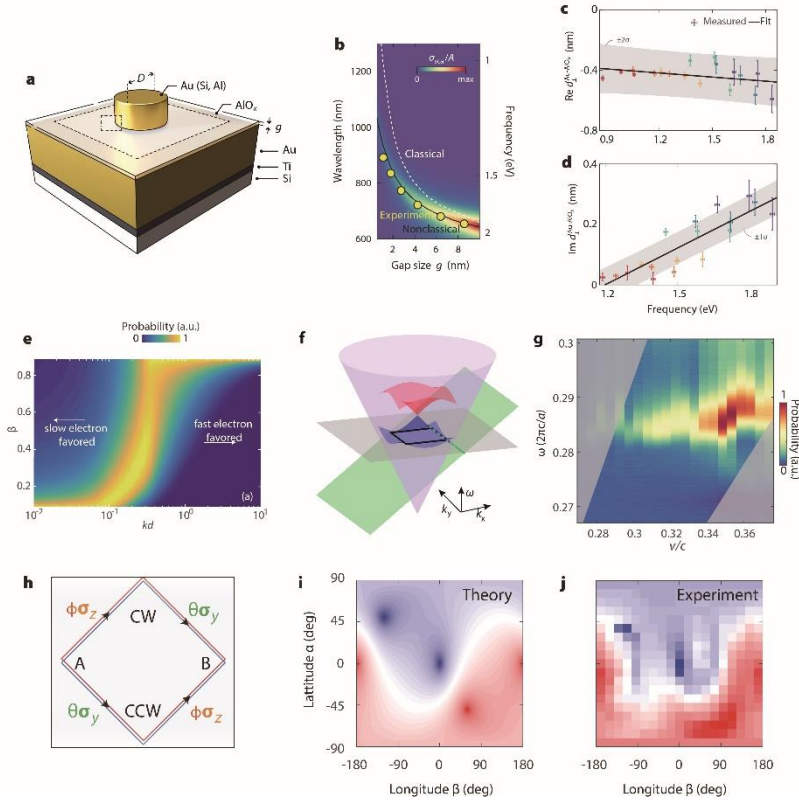
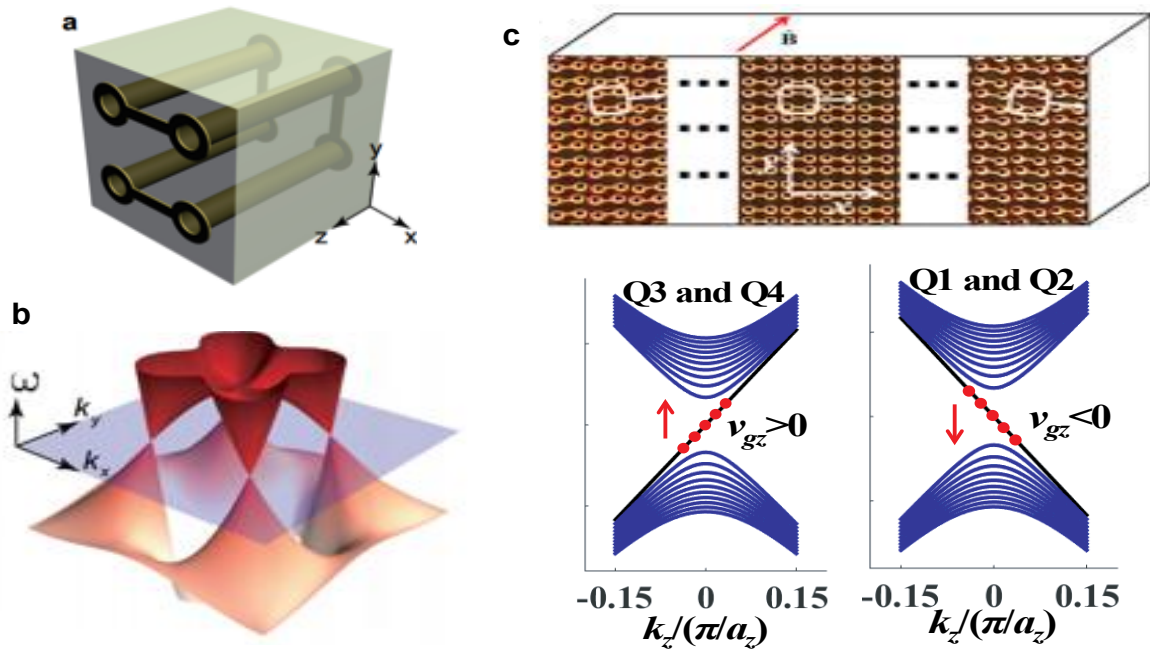


Figure. Photons interacting with material electrons, free electrons, and synthetic gauge fields. a-d. A general nanoscale electromagnetic framework and the experiment that measured its Feibelman d parameter. e-g. An upper limit to spontaneous free-electron radiation and the measured enhanced interaction between photonic flat bands and free electrons. h-j. Realization of Non-Abelian Aharonov--Bohm effect: a spinful particle self-interferes after undergoing reversely ordered path integrals [clockwise (CW) and counter-clockwise (CCW), respectively] that contains inhomogeneous gauge fields.

Professor X. B. Yin's research focuses on the optical and electrical properties of nanomaterials and artificially engineered metamaterials. His group has invented a set of ultrafast laser spectroscopy techniques and discovered the unique structural symmetry and excitonic parity symmetry in 2D semiconductors. The group was the first to transform spin-orbit physics in solid-state systems into photonics, enabling the manipulation of spin-orbit interactions of photons in optical metamaterials. His research on optical metamaterial has led to the first large-scale demonstration of passive radiative cooling, a new method for space cooling that requires no electricity. The group has a broad range of research interests and activities, ranging from the design and fabrication of discrete optoelectronic devices to the manufacturing of nanostructured metamaterials for large-scale utilization in energy and sustainability applications. The group's current projects include exploring spin-orbit physics in metamaterials, free-space electron

optics, and optics for the nexus of food, energy, and water.

Prof. S Zhang's research focuses on metamaterials, artificially engineered photonic structures for manipulating the propagation of electromagnetic waves. He is particularly interested in metasurfaces and topological photonics. His group has developed geometric phase based metasurfaces for various applications such as lenses, holography and generation of structured light beams. He demonstrated continuous control over the nonlinearity phase by extending the concept of geometric phase to nonlinear optics for harmonic generations. His research on topological metamaterials has led to observation of ideal Weyl points, photonic chiral zero modes, three-dimensional photonic Dirac degeneracies, optical nodal lines, Yang monopole and linked Weyl surfaces, and non-abelian nodal links. In addition, he has recently demonstrated a novel synthesized complex-frequency approach to compensate for loss in plasmonic materials, enabling various applications including super-imaging and ultrasensitive sensors.



Metamaterials hosting ideal Weyl points in the momentum space. a. the unit cell of the ideal Weyl metamaterial formed by saddle-shaped metallic loop. b. The band structure of metamaterial shows that there are four ideal points located at the same frequency, as protected by the symmetry of the unit cell. c. By introducing inhomogeneity to the ideal Weyl metamaterial, an effective magnetic field can be induced, which leads to formation of chiral zero modes, which are one-way propagating bulk modes.

Nuclear and Particle Physics group:

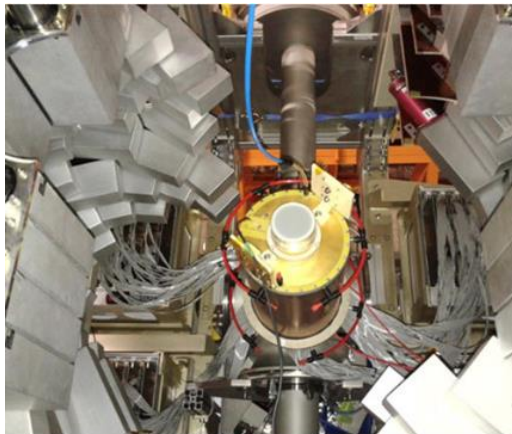
The group is established as part of the Joint Consortium for Fundamental Physics by three universities in Hong Kong – HKU, CUHK and HKUST, through which we participate in international collaborations on big science.

Academic staff: ***Prof. J.H.C. Lee***
 Prof. Y.J. Tu

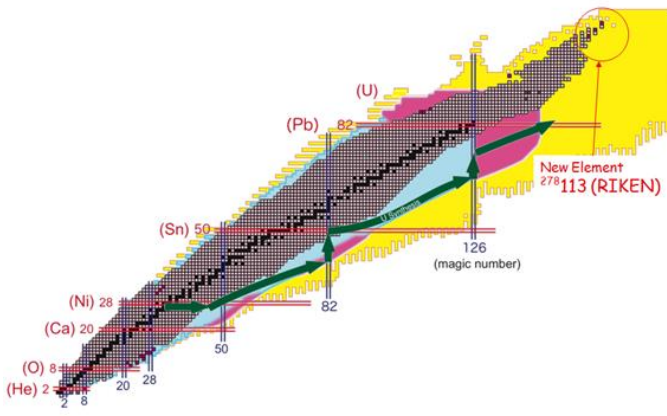
Prof. Lee is a leader of the experimental nuclear physics sub-group. Nuclear physics aims at understanding the structure of atomic nuclei and the nature of fundamental forces, addressing a big science question on how the heavy elements from Iron were synthesized in the universe which is governed by the properties of exotic nuclei. Recent experimental work exploiting radioactive ion beams found many novel features of exotic nuclei, such as the loss of classical magicity and emergence of new magic numbers, significantly advancing our knowledge of fundamental forces and benchmarking structure theories.

The main research of HKU experimental nuclear physics group is to explore the evolution of shell closures and examine the magicity of extremely exotic nuclei with classical magic numbers in medium-mass regions (proton number Z and/or neutron number $N = 20, 28, 40, 50$). We performed in-beam γ -ray spectroscopy with nucleon knockout reaction of these exotic nuclei using the high efficiency and energy-resolution γ -ray detector array DALI2+ and the world's most intense radioactive isotope beams at RIBF facility of RIKEN (Japan) based on SUNFLOWER international collaboration. Some interesting results including quantitative confirmation of the vanishing of $N=20$ magicity in ^{30}Ne and the first direct evidence for the nature of the $N=34$ shell closure corroborating a new $N=34$ magicity in neutron-rich calcium isotopes. Our near-future experiment is precise structure measurement of the flagship nucleus ^{100}Sn to examine its nature of double-magicity ($Z=N=50$). The results would serve stringent constraints to establish reliable theories and network calculations of nucleosynthesis.

The two world's leading nuclear physics facilities, “High Intensity Heavy-ion Accelerator Facility (HIAF)” and “China Initiative Accelerator Driven System (CIADS)” under the CAS's Institute of Modern Physics (IMP), being constructed at Huizhou Guangdong (about 100 km in straight-line distance from Hong Kong), provide Hong Kong unprecedented excellent opportunities for nuclear physics research and applications.



MINOS target surrounded by DALI2+ gamma-ray detection array for in-beam gamma-ray spectroscopy measurement



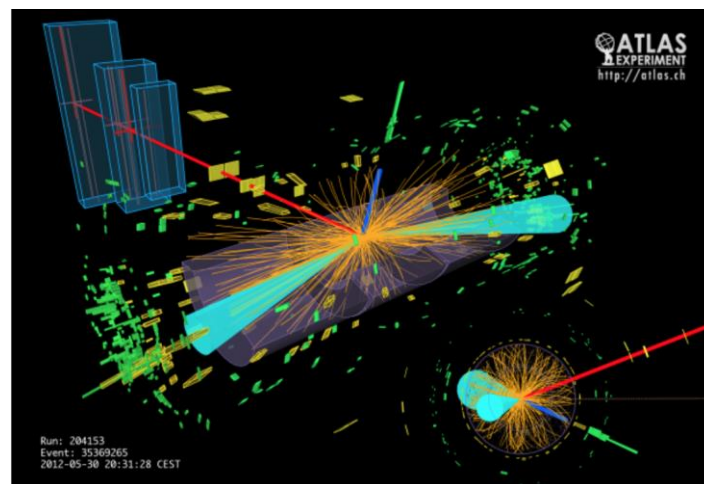
Nuclear Chart. The horizontal and vertical axes represent N and Z , respectively

Prof. Tu is a leader of the experimental particle physics sub-group. The field of particle physics has been very successful in the last century. The discovery of sub-atomic structure raises interests of studying so-called fundamental particles, e.g. quarks. The most successful particle physics model so far is the Standard Model, which describes the fundamental particles and their interactions. It successfully explains and predicts many experimental phenomena. However, many questions remain unanswered. For example, what is the origin of particle masses? what are dark matter and dark energy? why we see more matter than anti-matter in the Universe? can fundamental forces be unified? In order to answer these questions, new physics models are needed.

The HKU experimental particle physics group aims at search for new physics in order to understand the origin of Electroweak Symmetry Breaking (EWBS) and mass of fundamental particles. We are members of the ATLAS experiment at the Large Hadron Collider (LHC), the highest energy particle accelerator in the world. Over 10000 scientists and engineers from more than 100 countries have been working on the LHC.

We make leading and primary contributions on searches for Supersymmetry particles, Vector-like quarks, Flavour-Changing-Neutral-Current (FCNC) top quark decays, four top quark productions, and heavy Higgs bosons at the ATLAS experiment. Some of these searches have provided the best sensitivities at the ATLAS or LHC in constraining new physics models.

The group is a part of the Hong Kong ATLAS cluster (including three universities in Hong Kong: HKU, CUHK and HKUST). We are making joint efforts on Phase I and Phase II muon detector upgrade at the ATLAS in collaborating with the University of Michigan in United States and the University of Science and Technology in China. In Phase II, we work on the electronics upgrade in one of the most important upgrade projects replacing the Muon Drift Tubes electronics and adding another layer of trigger chambers. The work is supported by the RGC Area of Excellence grant AoE/P-404/18. Another important missions led by the Hong Kong ATLAS cluster is to build up a Tier-2 computing center in Hong Kong. Meanwhile, we have access to the Worldwide LHC Computing Grid, which is the world's largest computing grid.



A collision event at the ATLAS

HK Institute of Quantum Science & Technology 香港量子研究院

The HK Institute of Quantum Science & Technology is a collaborative effort of world-renowned physicists, computer scientists, mathematicians, and engineers. Together, they have created a multi-disciplinary scientific research platform at the University of Hong Kong. The goal of this institute is to utilize the full potential of quantum laws of nature and develop cutting-edge technologies, with the aim of driving future economies and benefiting both national and local economies.

The institute is composed of Regular Members from the University of Hong Kong (HKU) and Associate Members from other sister institutions. Together, these members will work on cutting-edge research in quantum science and technology, with a focus on quantum information, quantum materials, and quantum AI, among other areas.

The Department of Physics at HKU is proud to have a distinguished team of members who are significantly contributing to the efforts of the institute. Our professoriate staff members include Prof. CHAU Hoi Fung, Prof. CHIRIBELLA Giulio, Prof. CUI Xiaodong, Prof. KI Dongkeun, Prof. MENG Zi Yang, Prof. SHEN Shunqing, Prof. WANG Chenjie, Prof. WANG Zidan, Prof. XIE Mao Hai, Prof. YAO Wang, Prof. YANG Yi, Prof. YIN Xiaobo, Prof. ZHAO Yuxin, Prof. ZHANG Shizhong, Prof. ZHANG Shuang, and Prof. ZHANG Xiang.

In addition to its research endeavors, the institute will also run various academic programs to facilitate international exchange and collaboration. These programs include International Visitors Programs and Seminars Series, an international exchange students program, joint postdocs, joint Ph.Ds, and more. To further support its academic activities, the institute will create prestigious postdoctoral fellowships and graduate scholarships, which may be established under the names of donors.

2025/2026 POSTGRADUATE PROJECTS
DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG

The following M.Phil./Ph.D. projects are available in 2025/2026 academic year. Students are encouraged to contact their prospective supervisors directly to obtain the further detailed information of the project. We also welcome students to visit our laboratories and research facilities.

Full-time MPhil and PhD students who hold a first degree with second-class honours first division (or equivalent) or above are normally considered eligible to receive a Postgraduate Scholarship (HK\$18,760 per month) during the normative study period. This year we expect to admit a large number of postgraduate students. Students please visit the homepage of HKU graduate school at <https://gradsch.hku.hk/gradsch/> and get the information as well as application forms there.

For other details, please contact Prof. X.D. Cui (Tel. 2859 8975, email address: xdcui@hku.hk), Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong.

SPECIFIC RPG RESEARCH PROJECTS AVAILABLE WITHIN THE DEPARTMENT OF PHYSICS

Condensed Matter Physics group:

Project XDC01: Optical Properties in Emerging 2 Dimensional Materials

Supervisor: Prof. X.D. Cui

The emerging atomic 2D crystals offer an unprecedented platform for exploring physics in 2 dimensional systems. As the material dimension shrinks to atomically thin, quantum confinements and enhanced Coulomb interactions dramatically modify the electronic structure of the materials from the bulk form and incur sophisticated consequences featuring strong electron-electron interactions and robust quasiparticle of excitons. We are to investigate physics properties in emerging 2D materials with emphasis in optical properties with semiconductor optics technique.

Project DKK01: Designing New Topological Quantum States in Artificial Interfaces and Superlattices

Supervisor: Prof. D.K. Ki

Topological states of matter represent the new class of materials that are characterized by their low-energy quasiparticles at the boundaries, such as Majorana Fermions in topological superconductors and non-Abelian anyons in even-denominator fractional quantum-Hall insulators. These states are under intense focus as they have exotic topological properties that are not only fundamentally interesting but also promise great potentials for realizing new types of device applications (e.g., topological quantum computing). In this context, we will ‘artificially design’ the new topological states by creating atomically sharp interfaces between different 2D crystals where van der Waals interactions can engineer new properties on-demand. Examples include graphene-on-transition metal dichalcogenides (where the spin-orbit coupling—the critical element for realizing topological states—can be controlled) and multi-domain Moiré superlattices (where two topologically different states can be joined to reveal new effects). Having known that nearly hundreds of 2D crystals

exist with diverse properties, we will further explore various possibilities that different combinations of these crystals may offer. This study will therefore expand the ‘zoo’ of topological materials available in the reality and bring us one-step closer to the realization of topological electronics.

Project DKK02: Exploring New Many-Body Physics in Extremely Clean 2D Crystals

Supervisor: Prof. D.K. Ki

Electrons in solid interact with each other and studying the resulting many-body effects is one of the recurring main themes of condensed matter physics. Recently, atomically thin 2D crystals, such as graphene, have emerged as interesting material systems with novel electronic properties that can be tuned widely in the experiments. The objective of this project is therefore to take full advantages of such large experimental flexibilities to explore or engineer new many-body phenomena in these crystals. For this, we will realize extremely clean devices with various geometries (e.g., suspended graphene devices with suspended dual-gates) and approach zero energy where the interactions become the strongest. The effects of particular interests are fractional quantum-Hall effect and spontaneous symmetry breaking in semimetallic 2D crystals, such as graphene and tungsten ditelluride (WTe₂).

Project LJLL01: Semiconductor devices based on advanced 2D materials

Supervisor: Prof. L.J.L. Li (Department of Mechanical Engineering)

The Si complementary metal oxide semiconductor (CMOS) technology has followed the Moore’s Law to scale the size and thickness of active channels, but become very challenging when Si approaches its physical limit. The ultimate channel thickness for a field-effect transistor (FET) would be in the sub-1nm range, not readily accessible for any 3D semiconductors. The semiconducting 2D materials with an ultra-thin body and smooth surfaces have great potential and are being seriously investigated to replace Si. In this project, we shall develop the materials and device technologies to construct high-performance and low-power devices. The students may choose the following topics: (1) Growth of high-quality p-type 2D semiconductors. (2) Ultra-thin complex oxide

dielectrics for device applications. (3) Integration of p- and n-type transistors for CMOS circuits.

Project CCL01: High dielectric constant oxides via defect functionalization

Supervisor: Prof. C.C. Ling

Materials with high dielectric constant and low dielectric loss are essential for the miniaturization of capacitive microelectronic devices, and also have the potential in compact high-density energy storage applications. Colossal dielectric constant $>10^4$ has been achieved in acceptor-donor co-doped oxides, and was speculated to be associated with the electron-pinning defect complex [1]. The physics and the action of the electron-pinning defect is unclear. The current project aims to fabricate oxide materials with high dielectric constant and low dielectric loss, to study the physics of the colossal dielectric constant, as well as to explore the identity and the action of the electron-pinned defect. The project also aims to fabricate high performance high permittivity capacitive device with the high-k oxide films [2-4].

Ref

[1] ‘Electron-pinned defect dipoles in (Li,Al) co-doped ZnO ceramics with colossal dielectric permittivity’, Dong Huang, Wen-Long Li, Zhi-Fu Liu, Yong-Xiang Li, Cuong Ton-That, Jiaqi Cheng, Wallace C. H. Choy, and Francis Chi-Chung Ling, J. Mater. Chem. A 8, 4764 (2020). Editor chosen as journal issue cover.

[2] ‘High dielectric transparent film tailored by acceptor and donor co-doping’, D. Huang, Y. Shi, M. Younas, R.T.A. Khan, M. Nadeem, K. Shati, M. Harfouche, U. Kentsch, Z. Liu, Y. Li, S. Zhou, A. Kuznetsov and F.C.C. Ling, Small 18, 2107168 (2022). Editor chosen as featured article.

[3] ‘Wafer-scale PLD-grown high- κ GCZO dielectrics for 2D electronics’, Jing Yu, Guoyun Gao, Wei Han, Changting Wei, Yueyang Wang, Tianxiang Lin, Yianyu Zhang, Zhi Zheng, Dong-Keun Ki, Hongyuan Zhang, Man Ho Ng, Hang Liu, Shuangpeng Wang, Hao Wang and Francis Chi-Chung Ling, Advan. Electron. Mater. 8, 2200580. Editor chosen as featured article.

[4] ‘Two-dimensional molecular crystal Sb₂O₃ for electronics and

optoelectronics', Jing Yu, Wei Han, Ruey Jinq Ong, Jing-Wen Shi, Suleiman, Abdulsalam Aji Abdulsalam, Kailang Liu, Francis Chi-Chung Ling, Applied Physics Review 11, 021326 (2024). Editor chosen as featured article.

Project CCL02: Optimizing performance of 4H-SiC power devices via defect control

Supervisor: Prof. C.C. Ling

4H-SiC is a third generation semiconductor having wide band gap emerging into the commercial market of high performance high-power electronic devices that find applications in electric vehicle, high speed train, and wind power station. As compared to the conventional Si devices, SiC devices have a lower turn-on voltage, higher operating temperature and voltage, more compact size and lighter in weight.

Intrinsic defects and their relevant defect complexes exist in as-grown 4H-SiC material and would be formed in device fabrication and processing. These defects are not easily removed and would deteriorate the device performance. The present project involves identifying and controlling the defects in different 4H-SiC power devices, with the aim to optimizing the device performance. This project is a collaboration with Mainland and Hong Kong industries and would involve attachment to the companies.

Ref.

Suppression of the carbon vacancy traps and the corresponding leakage current reduction in 4H-SiC diodes by low-temperature implant activation in combination with oxidation', Tianxiang Lin, Lok-Ping Ho, Andrej Kuznetsov, Ho Nam Lee, Tony Chau, Francis Chi-Chung Ling, IEEE Electron Device Lett. 44, 578 (2023).

Project CCL03: Defects in functional oxides

Supervisor: Prof. C.C. Ling

Functional oxides exhibit a number of physical phenomena including ferroelectricity, piezoelectricity, magnetism, dielectric and optoelectronic processes. With the suitable optical, electrical, dielectric and magnetic

properties, functional oxides find a variety of applications in electronic, sensor, photovoltaic, optoelectronic, spintronic, energy harvesting and storage and photocatalysis etc. Defect states in the band gap determine the material's electrical, optical, dielectric and magnetic properties. The current project includes the fabrication of a specific oxide (e.g. Ga₂O₃ and ZnO), characterization of the defect, and control of the defects with a specific application. The research activities will involve oxide film fabrication by pulsed laser deposition, defect characterization using deep level transient spectroscopy, luminescence spectroscopy and positron annihilation spectroscopy etc.

Ref.

- 'Correlation between small polaron tunnelling relaxation and donor ionization in Ga₂O₃', Ying-Li Shi, Dong Huang, Francis Chi-Chung Ling, Qi-Sheng Tian, Liang-Sheng Liao, Matthew R Phillips, Cuong Ton-That, Appl. Phys. Lett. 120, 172105 (2022).
- 'Non-volatile optoelectronic memory based on a photosensitive dielectric', Rui Zhu, Huili Liang, Shangfeng Liu, Ye Yuan, Xinqiang Wang, Francis Chi-Chung Ling, Andrej Kuznetsov, Guangyu Zhang, Zengxia Mei, Nat. Commun. 14, 5396 (2023). Editor chosen as featured article

Project ZYM01: Fundamental properties of metallic quantum critical point

Supervisor: Prof. Z.Y. Meng

Landau's Fermi-liquid theory is the cornerstone in the condensed matter physics. However, in many modern correlated electron systems, ranging from Cu- and Fe-based superconductors, heavy-fermion compounds and the recently discovered twist angle graphene layer systems, metallic behaviors that deviated from the Fermi-liquid paradigm are universally presented, such as pseudogap, anomalous transport and vanishing of quasiparticle fractions. These novel phenomena, associated with quantum critical fluctuations coupled to low-energy fermionic degrees of freedom, are dubbed non-Fermi-liquid in the metallic quantum critical regions.

In this project, we will develop relevant models and numerical

methodologies to study various metallic quantum critical points, such as ferromagnetic, antiferromagnetic and nematic fluctuations coupled to different Fermi surface geometries. With the help of numerical method developments, such as the self-learning Monte Carlo invented by us, and the guidance of advanced field-theoretical approaches, we will be able to address the problem of fermions coupled to critical bosons, although highly non-perturbative in nature, with better affirmative than previously known. Furthermore, many aspects of frustrated magnetism and deconfined quantum critical points also belong to similar setting of fermion and boson coupled systems at their quantum criticality, for example, emergent fractionalized anyons (spinons and visons) coupling with emergent gauge fields in frustrated magnets and deconfined quantum criticality, can also be addressed with aforementioned combined numerical and theoretical approaches [for example, see Refs. Phys. Rev. X 9, 021022 (2019) and Phys. Rev. B 98, 174421 (2018) Editors' Suggestion]. Therefore the outcome of this project will give rise to building a bulk of the new paradigms in quantum matter that are beyond Fermi liquid theory for metals and the Landau-Ginzburg-Wilson framework of phases and phase transitions.

Project ZYM02: Thermodynamics and dynamics in quantum magnets

Supervisor: Prof. Z.Y. Meng

With the fast development of modern computational technology, we are now able to compute the excitation spectrum in quantum magnetic systems and provide explanation beyond simple mean-field analysis on the nature of exotic magnetic excitations [such as in [Phys. Rev. X 7, 041072 \(2017\)](#)]. To understand the experimental results in quantum magnetic systems and in particular the frustrated ones, in which the putative quantum spin liquid state might emerge, it is of vital importance that thermodynamic and dynamic results can be captured and explained in unbiased quantum many-body calculations, including Z2 quantum spin liquid in kagome lattice [such as in [Phys. Rev. Lett. 121, 077201 \(2018\)](#)] and U(1) quantum spin liquid in pyrochlore lattice [such as in [Phys. Rev. Lett. 120.167202 \(2018\)](#)]. This is a new research direction in which both the understanding of experiment results including the material properties

and measurement details, and more importantly, the quantum many-body methodologies that could capture the thermodynamic and dynamic responses, are required to their best level.

In this project, we will employ and develop Density Matrix Renormalization Group (DMRG) and Tensor-network Renormalization Group (TRG) methods, combined with quantum Monte Carlo (QMC) calculations, to find way to calculate phase transition and thermodynamic properties of quantum many-body models, and then compare the obtained results with experimental results of promising quantum magnetic compounds which might realize quantum spin liquid states or other novel quantum many-body phases and phase transitions. These comparisons would help us to find the correct model description of the quantum magnetic systems and could eventually lead to discovery of quantum states of matter that are beyond the Landau-Ginzburg-Wilson paradigm of phases and phase transitions. Example including deconfined quantum critical point, in which the emergent spinon and gauge field are strongly coupled with each other [such as in [Phys. Rev. B 98, 174421 \(2018\) Editors' Suggestion](#)]. To pursue the understanding of interaction effects on topological state of matter, such as the validity of topological index in the interaction-driven topological phase transitions, the identification and classification of emergent bosonic and fermionic symmetry protected topological phases in interacting models [such as in [Phys. Rev. B 93, 115150 \(2016\)](#)]; to reveal the duality relations between the interaction-driven topological phase transition and the deconfined quantum critical point via numerical investigations [such as in [Phys. Rev. X 7, 031052 \(2017\)](#)]. We will continue our pursuit along this line to build the new paradigm of quantum phase transitions.

Project ZYM03: Towards next-generation scientific computing via neuromorphic-AI accelerators

Supervisor: Prof. Z.Y. Meng

The futuristic advancement in technology will involve, to a large extent, the engineering of artificial intelligence into almost all aspects of our industry. The widespread adoption of AI is becoming increasingly challenging to 1) remain sustainable at the current power consumption

rate, and 2) become comparable with human intelligence.

As a first step, we need to establish a datacenter that is capable of neuromorphic-AI acceleration within the design of modern-age Infrastructure-as-a-Service (IaaS) / Platform-as-a-Service (PaaS) architecture. Whilst the core research will be done in the Jupyter-Python layer -- dockerized within Kubernetes, the target architecture is one that is resilient, which is capable of handling bigdata and service redundancy. With Elastic schema-free NoSQL database and Kafka/Solace bigdata messaging bus (with Golang/gRPC proxy), our core research is immediately deployable as business logic implemented within Java-Spring connected via Kafka. The server-client architecture ensures that our research is architectural compatible and integrable with current modern-age technologies, especially Google APIs. This connects the possibilities of industrial-standard AI technologies such as Dialogflow and Tensorflow. For the purpose of core research, the performance of Python code can further be enhanced with C++. Last but not least, the data I/O will be streamed to/from the neuromorphic accelerators via the underlying Kafka/Solace architecture.

Project SQS01: Novel Topological States and Transport Properties of Quantum Matter

Supervisor: Prof. S.Q. Shen

In this proposal, we propose to investigate quantum anomalous semimetals, *i.e.*, novel topological phases with a half-integer topological invariant, investigate electromagnetic responses and the stability against the disorder and interaction and measurable physical effects, and explore the possible realization of quantum anomalous semimetals in materials and other physical systems. We will intend to establish a novel type of bulk-boundary correspondence, *i.e.*, the relation of the boundary effect and the half-integer topological invariant in the bulk for the proposed topological phases. At the completion of the proposal, we expect to bring a new member to the family of the topological states of matter and topological materials. We also propose to investigate quantum transport in topological materials for the purpose of application.

Project CJW01: Topological and Quantum Critical Phases of Matter with Strong Interaction

Supervisor: Prof. C.J. Wang

Topological phases of matter have gained lots of attention due to their richness and wide connections to other fields of physics. In particular, in certain systems, there exist so-called non-Abelian anyon excitations that can be used for fault-tolerant quantum computation. While topological phases with weak correlation can be well understood through conventional mean field theories, it requires many new concepts and tools to understand strongly correlated topological phases. We work on fundamental theories of topological phases, including braiding statistics of particle and loop-like topological excitations, bulk-boundary correspondence, quantum anomaly of global symmetries, etc. More recently, the study of interplay between symmetry and topology has led to a development in symmetry itself, namely general symmetries should be described by the mathematics of category theory, beyond the textbook notion of symmetry groups. We aim to understand how generalized symmetries can be applied to study quantum phase transitions. When it comes to realistic models, we also perform numerical studies.

Project CJW02: Localization Physics

Supervisor: Prof. C.J. Wang

Anderson localization is a physical phenomenon in which waves cease to propagate in a disordered medium due to the destructive interference of random scattering. In electronic materials, it is one of the few mechanisms responsible for metal-insulator transitions. It is also a key component of the quantum Hall effects, the first example of topological phases of matter. While theories of localization are well studied, many problems remain open when new factors such as disorder correlation and anisotropy are included. We are working on a project to investigate the phenomenon of directional localization, where the wave function of a particle is localized in certain directions but delocalized in others, using either numerical methods or field theoretical methods.

Project ZDW01: Topological Metals/Semimetals and Quantum Simulations

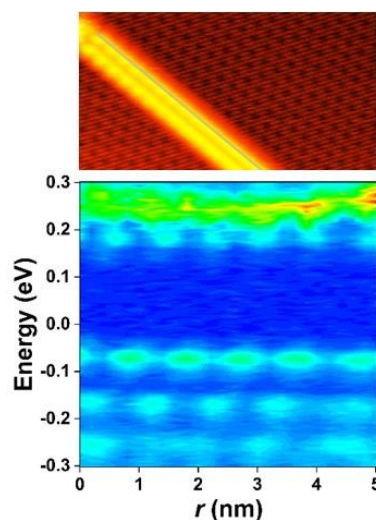
Supervisor: Prof. Z.D. Wang

Topological quantum materials have significantly intrigued research interest. Investigations of the gapless and gapped systems pave the way for discovering new topological matter. Recently, our group at HKU established a unified theory for topological gapless systems, including novel metals and semimetals consisting of topological Fermi surfaces. Based on our basic theory, we plan to explore various exotic quantum properties of topological metals/semimetals for different dimensions and their quantum simulations with artificial systems.

Project MHX01: MBE Growth and Surface Studies of Two-Dimensional Materials

Supervisor: Prof. M.H. Xie

Two-dimensional (2D) materials exhibit many interesting properties, which are attracting extensive research attentions in recent years. Examples include monolayers of transition metal dichalcogenides (TMDCs) and phosphorene, which hold potentials for nano electronic,



Quantized Tomonaga-Luttinger liquid in mirror domain boundaries in single atomic layer MoSe₂

optoelectronic, spin- and valley-tronic applications. In this project, ultrathin films of 2D materials and their heterostructures will be fabricated by molecular beam epitaxy and characterized by the surface tools, such as

electron diffraction (LEED/RHEED), scanning tunneling microscopy and spectroscopy (STM/S), ultraviolet photoemission spectroscopy (UPS), etc. Attention will be paid towards the physics related to low dimensionality, quantum confinement, localization and electron interaction in 2D films and heterostructures.

Project WY01: Valley-spintronics in 2D materials

Supervisor: Prof. W. Yao

A trend in future electronics is to utilize internal degrees of freedom of electron, in addition to its charge, for nonvolatile information processing. Suitable candidates include the electron spin, and the valley pseudospin. The latter labels the degenerate valleys of energy bands well separated in momentum space. 2D materials offer an exciting platform to explore valleytronics and spintronics. Van der Waals stacking of the 2D materials further provide a powerful approach towards designing quantum materials that can combine and extend the appealing properties of the building blocks. In this project, we will investigate the physics of valley and spin and their control in 2D materials and their van der Waals heterostructures by external magnetic, electric and optical fields. We will also explore the exciting opportunities to manipulate valley and spin from their emergent properties in the moiré superlattices formed by the inevitable lattice mismatch and twisting between the 2D building blocks in heterostructures.

Project WY02: Moiré superlattice physics in van der Waals structures

Supervisor: Prof. W. Yao

Moiré pattern is the superlattice structure created when van der Waals 2D materials are stacked with crystallographic misalignment resulting in spatial variation in the interlayer atomic registries. Because of the inevitable mismatch in lattice constants of different 2D materials and twisting between their crystalline axes, moiré pattern can be generally present in the van der Waals layered structures. The creation of long-wavelength moiré pattern is becoming a powerful approach to engineer the electronic and optical properties of vdW structures of 2D materials. This project will investigate moiré superlattices formed in various van der

Waals layered structures, and their exploitation as versatile new platforms to explore a number of frontiers of condensed matter physics.

Project SZZ01: Transport properties of strongly interacting systems

Supervisor: Prof. S.Z. Zhang

We are interested in investigating the transport properties of resonantly interacting quantum gases close to either a s-wave or p-wave resonances. In the strongly interacting regime, no well-defined quasi-particles exist and the construction of reliable transport theory becomes challenging. Our goal is to study a few transport quantities, such viscosity, that is intimately connected with the symmetry of the system and compare with possible experiments.

Project YXZ01: Non-standard symmetry classes of solids

Supervisor: Prof. Y.X. Zhao

The Altland-Zirnbauer or the tenfold symmetry classes present a closed algebraic structure of time reversal, charge conjugate and chiral symmetry. The particular algebraic structure involves the idea of projective symmetry as revealed by Freed and Moore. In this respect, the tenfold symmetry classes can be appropriately extended to incorporate crystal symmetries. The project consists of three successive steps: (i) What are the meaningful ways to make the extension? (ii) For a given meaningful extension method, exhaust all possible symmetry classes. (iii) Work out nontrivial physical consequences of novel symmetry classes.

Project YXZ02: Topological classifications of projective symmetry classes

Supervisor: Prof. Y.X. Zhao

The most fundamental notion of symmetry protected topological matter is that: Symmetry determines possible topological classifications. So far, topological classifications of non-interacting fermions have been completely solved for the tenfold Altland-Zirnbauer symmetry classes and thoroughly investigated for 230 space groups. Recently, we have applied the idea of projective symmetry to extended crystal symmetry classes. The

aim of this project is to classify topological phases under certain projective crystal symmetry classes, and thereby to discover novel topological phenomena embodying intrinsic projective symmetry.

Project YXZ03: Quantum anomalies in non-linear sigma models

Supervisor: Prof. Y.X. Zhao

The tenfold topological classification table of insulators and superconductors were first deduced by observing the global structure of possible appearance of topological terms in the nonlinear sigma models that describe disordered boundary states. However, no systematical derivation of these topological terms has been given, although a few specific cases were derived in previous works [Zhao & Wang, PRB 92, 085143 (2015) and PRL 114, 206602 (2015)]. The aim of this project is to present in some systematical manner the analytic derivation of these topological terms. The underlying mathematics may involve the interlinking of real K theory and the Atiyah-Patodi-Singer index theorem for a class of operators that couple Dirac operators with sigma fields valued in symmetric spaces.

Project XBY01: Electron Microscopy and Spectroscopy in Air

Supervisor: Prof. X.B. Yin (Department of Mechanical Engineering)

Focused electron beam has been widely used for nanoscale imaging, spectroscopy, and material processing in the past decades. However, we are now witnessing transformative breakthroughs in this field, including the Nobel Prize-winning cryogenic electron microscopy and in situ electron microscopy enabled by integrated liquid cells. In this project, we aim to develop electron beam tool that can operate in air, at ambient atmospheric pressure (1 atm) for imaging and fabrication. This is enabled by a vacuum-sealing and electron-permeable membranes, which encapsulates the entire electron optics column and isolates it from the surrounding environment. This development will result in a novel focused electron beam tool for nanoscale imaging and cathodoluminescence spectroscopy studies of materials, regardless of their physical state (solid or liquid) or electrical properties (conductive or insulating, organic or inorganic). In addition to this core development, various related topics and projects are under exploration, including interface assembling at the

liquid-vapor and liquid-liquid interfaces, correlated light and electron imaging, in situ observation of interface phase transitions (e.g., condensation or ice nucleation at the water surface) with reactive flows, in situ imaging of electrochemical cells or batteries, and electron beam-guided or induced thin film growth and/or etching. All were not possible under a conventional electron microscope.

Astrophysics group:

Project LXD01: Black Hole Accretion Disk & Jet Simulations

Supervisor: Prof. L.X. Dai

Black hole accretion is the central engine powering some of the most luminous astronomical phenomena in the universe, such as quasars, blazars and X-ray binaries. As black holes consume gas, they often produce not only radiation but also winds and relativistic jets. These energetic outputs from massive black holes can even influence their formation and evolution of their hosting galaxies. Besides powering persistent sources, black hole accretion can also power transient flares such as tidal disruption events and gamma-ray bursts.

We use state-of-the-art numerical codes to investigate a few different types of black hole accretion systems, which currently includes tidal disruption events, ultra-luminous X-ray sources and other newly discovered black hole systems. We encourage students who are passionate about numerical simulations to apply for this project. Possible PhD/ MPhil projects include: 1) design and perform novel general relativistic simulations of black hole accretion systems including tidal disruption events, X-ray binaries and AGNs; 2) carry out radiative transfer simulations to calculate disk/jet emissions and compare with observations.

Project LXD02: Theory/Simulations of Tidal Disruption Events

Supervisor: Prof. L.X. Dai

The study of tidal disruption events has been a hot topic in recent decades. Stars in centers of galaxies can occasionally wander too close to the central massive black holes and get torn apart by the tidal force. As stellar materials collide and accrete onto the black hole, bright flares are produced, often outshining the whole galaxy. So far, about 100 tidal disruption events have been observed in X-ray, optical, UV, radio and mm wavebands. In the next decade, many time-domain instruments, including Einstein Probe (a joint CAS-MPE-ESA X-ray transient probe), will be launched to catch transients such as tidal disruption events. This will give us the chance to detect thousands of such events and make a lot

of new, exciting discoveries in this field.

PhD/ MPhil projects on this topic include: 1) simulate the accretion and emission processes in tidal disruption events; 2) study the relativistic jets formed in tidal disruption events; 3) calculate the rates of tidal disruption events; 4) study gravitational waves and high-energy astroparticles produced by tidal disruption events.

Project LXD03: Black Hole X-Ray Reflection & Reverberation

Supervisor: Prof. L.X. Dai

The novel technique of X-ray reflection and reverberation has proven to be very powerful in probing the geometry of accretion disks and probe the parameters of black holes. Using this technique, we can analyze the temporal and spectra features of the “echoes” produced by the reflection of the black hole corona emission off the accretion disk, using which we can then investigate the properties of black holes and their accretion disks. We have been pioneering in extending this technique into the regime of super-Eddington accretion around black holes.

PhD/ MPhil projects on this topic include: 1) investigate X-ray reverberation features in transient or extreme black hole accretion systems; 2) transform our results into packages and tools for observers.

Project MG01: The Initial Mass Function In Early-Type Galaxies

Supervisor: Prof. M. Gu

The initial mass function (IMF) describes the distribution of stellar masses at birth in one star formation event. It is a crucial element in astrophysics but hard to constrain. For early-type galaxies, independent methods include stellar dynamical modeling, strong gravitational lensing, and stellar population synthesis modeling. These methods agree that there is a general trend of increasingly bottom-heavy IMF in more massive systems, however their consistency on an object-by-object basis is under debate. In addition, the IMF variation within galaxies is an important topic under much exploration. The physical processes driving the IMF variation is still an open and crucial question.

The following independent projects on this topic are available for PhD/ MPhil students:

- 1). Stellar IMF measurement with near infrared spectroscopy
- 2). The local IMF variation from stellar population synthesis modeling and dynamical constraints

Project MG02: Environmental Impact on Galaxy Evolution

Supervisor: Prof. M. Gu

The environment affects galaxy quenching and star formation activity, leaving imprints on their stellar populations. For example, a measurement of the relative abundance between alpha-elements and iron in early-type galaxies can be used to indicate the past star formation timescales due to its sensitivity to the time delay between type II and type Ia supernova. Previous studies revealed massive galaxies are older, more metal-rich, and more α -enhanced. A direct way to study the environmental dependence is to observe and compare satellite galaxies in the same groups and clusters. Another way to explore the topic is to compare the inner and outer region of massive galaxies, and even the intra-cluster light, to compare the stellar components dominated by in-situ and ex-situ processes. The following independent projects on this topic are available for PhD/ MPhil students:

- 1). Environmental Dependence of Stellar and Gas-phase Chemistry in Groups and Clusters at redshift 0.1
- 2). Origin of Stellar Halo & the ICL in Massive Galaxy Clusters

Project MHL01: Dynamics and Origins of Planetary Systems

Supervisor: Prof. M.H. Lee (Adjunct with Department of Physics)

Extrasolar planet searches have now yielded thousands of planets around other stars. The discoveries include planetary systems with two or more detected planets and planets in binary star systems. Multiple-planet systems and, in particular, those with planets in or near orbital resonances provide important constraints on the formation and dynamical evolution of planetary systems. We are investigating the current dynamical states and origins of resonant planetary systems and planets in binary star systems. In addition, there are projects related to

the formation and dynamical evolution of the planets and their satellites in our Solar System. Prior knowledge of classical mechanics and numerical methods would be an asset.

Project JJLL01: Astrophysical Applications of Gravitational Lensing

Supervisor: Prof. J.J.L. Lim

Gravitational lensing provides a natural cosmic telescope for magnifying distant galaxies in both size and brightness. We have used gravitational lensing by galaxy clusters to study the luminosity function of distant galaxies; a comparison between the measured luminosity function against that predicted by different theories for dark matter (DM) finds better agreement with wavelike DM rather than the currently favoured particle DM (Leung et al. 2018). We have also used gravitational lensing by a galaxy cluster to infer the presence and to weigh the supermassive black hole in the most massive galaxy of that cluster (Chen et al. 2018). This work provides the first direct mass measurement of a supermassive black hole in the distant Universe, and represents a crucial link in studying the co-evolution (or otherwise) of supermassive black holes and their host galaxies. We also have used gravitational lensing by individual galaxies, galaxy groups, and galaxy clusters to infer the distribution and structure of DM in these objects, so as to: (i) test alternative theories for General Relativity such as MOND (Chen et al. 2020); and (ii) test the predictions of standard particle DM versus wavelike DM (Amruth et al. 2023). The first step in conducting all these works is to generate lens model for the lensing galaxy, galaxy group, or galaxy cluster based on a robust identification of lensed images and measurements of their redshifts; followed by delensing and relensing of the lensed images to check the accuracy and robustness of the lens model derived. The work is challenging, and most suited to students wishing to pursue an FYP and to challenge themselves in one of the most important questions in (astro)physics: what is Dark Matter?

Project JJLL02: Star Formation in Giant Elliptical Galaxies at the Centers of Galax Clusters

Supervisor: Prof. J.J.L. Lim

Galaxy clusters are immersed in hot X-ray-emitting gas that constitutes the bulk of their baryonic mass. In relaxed clusters where the density of this gas increases rapidly towards the cluster center, the hot gas around the center is predicted to cool rapidly so as to produce an inflow of relatively cool gas (i.e., an X-ray cooling flow). Indeed, relaxed clusters exhibit relatively cool X-ray gas in their cores, and preferentially exhibit relatively large quantities of gas at even lower temperatures. Relativistic jets from the central giant elliptical galaxy, however, can churn and reheat the cool gas, complicating our understanding of the nature of this gas. Our work focuses on determining the origin, excitation and therefore physical properties, and fate of relatively cool gas in the giant elliptical galaxies at the center of galaxy clusters; as well as the recent history of star formation in these galaxies, and the manner in which their AGNs are fueled. We find that all these phenomena are related to global disturbances in galaxy clusters – and am currently working to address all these connections.

Project CYN01: Mapping the Magnetic Fields of Pulsar Wind Nebulae

Supervisor: Prof. S.C.Y. Ng

Pulsars lose most of their rotational energy through relativistic particle winds. The consequent interactions with the ambient medium result in synchrotron bubbles known as pulsar wind nebulae (PWNe). While the PWN magnetic fields play an important role in the particle acceleration and transport processes, little is known about the field configurations. In this observational project, we will map the PWN magnetic fields using radio interferometric observations. This can offer a powerful probe of the physical conditions and evolutionary history of PWNe. The results will be compared with other systems to understand the critical parameters that determine the field properties.

Quantum Information Science group:

Project HFC01: Quantum Information Theory

Supervisor: Prof. H.F. Chau

A lot of activities are going on in the field of quantum information theory recently. This field is about the study of quantum mechanical system from an information theoretical point of view. We ask questions like what information can be stored, transmitted and extracted using quantum mechanical systems. In this theoretical Ph.D. project, one is expected to focus on the tradeoff between different resources in quantum information processing such as energy, time, space and communication. Knowledge in the following fields is required: quantum mechanics in Sakurai level, quantum optics, statistical mechanics, coding theory, classical information theory, computational complexity, functional analysis and algebra. Although it is not necessary for you to have all the above subjects, but the more you know them the better prepared you are. I am looking for a hardworking, self-motivated individual who is both physically and mathematically sound to take up the challenge.

Project ZDW01: Quantum Computation

Supervisor: Prof. Z.D. Wang

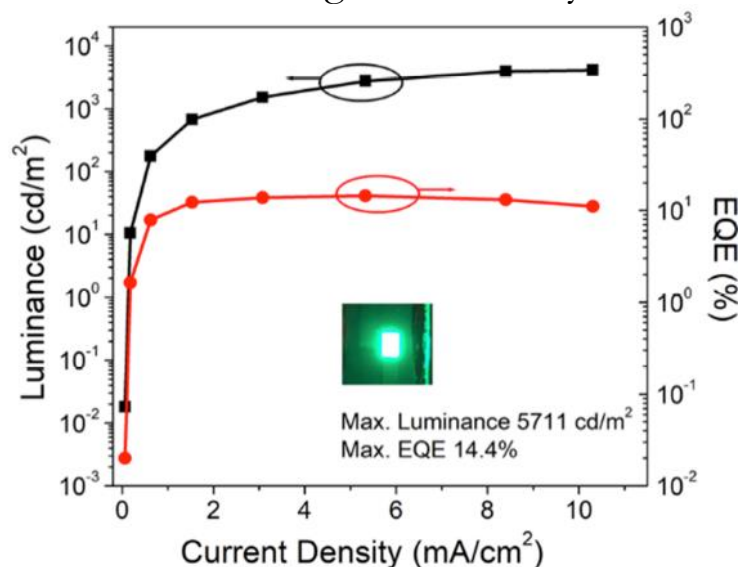
Quantum computers, based on principles of quantum mechanics, could efficiently solve certain significant problems which are intractable for classical computers. For the past several years, they have become a hot topic across a number of disciplines and attracted significant interests both theoretically and experimentally. In physical implementation of quantum computation, a key issue is to suppress a so-called decoherence effect, which can lead to major computing errors. A promising approach to achieve built-in fault tolerant quantum computation is based on geometric phases, which have global geometric features of evolution paths and thus are robust to random local errors. In this project, it is planned to first study geometric phases in relevant physical systems and then to design geometric quantum gates. Physical implementation of these gates in solid state systems will be paid particular attention.

Optics and Photonics group:

Project AD01: Halide Perovskite Materials and Optoelectronic Devices

Supervisor: Prof. A.B. Djurišić

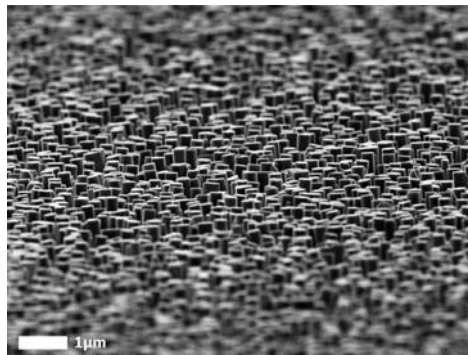
Recent advances in organometallic halide perovskite solar cells have resulted in increasing interest in next generation solar cell based on these materials. In spite of great interest for practical applications, there are still a number of unanswered questions concerning their fundamental properties and principles of operation. This is particularly the case for quasi-2D perovskite materials, and understanding their properties as a function of their chemical composition, in particular different spacer cations. The objective of this research is to develop perovskite materials with improved performance (in particular improved stability and increased PLQY), advance understanding of the relationship between their composition and deposition conditions and their crystallization and fundamental material properties. Then, the next step is the application of modified materials in perovskite optoelectronic devices, with the focus on improved understanding of the role of interfaces and overall device architecture in device performance, namely efficiency and stability. Other applications of perovskite materials, such as thermoelectrics, are also of potential interest. The student should have basic knowledge of optics and solid state physics. Some knowledge of chemistry would be beneficial.



Luminance and EQE of a perovskite LED as a function of current bias

Project AD02: Wide Band Gap Nanostructures

Supervisor: Prof. A.B. Djurišić



SEM image of ZnO nanorods

Due to exceptional properties different from bulk materials, nanostructures of different semiconductors have been attracting increasing attention. The obtained morphology of the nanostructures and their optical properties are strongly dependent on the fabrication conditions. The objective of this work is to investigate the properties of wide band gap nanostructured films (ZnO, TiO₂, SnO₂, NiO_x) as a function of deposition conditions and dopants introduced, with the objective of developing high quality uniform thin films deposited at low temperatures. The fabricated nanostructured films will be characterized using scanning electron microscopy (SEM), transmission electron microscopy (TEM), X ray diffraction (XRD), photoluminescence and photoluminescence excitation (PL and PLE). The project will involve extensive experimental work, with the focus of the work on application of these materials as charge transport layers in optoelectronic devices.

Project TTL01: Ultrafast spectroscopy of condensed matters

Supervisor: Prof. T.T. Lau

We have been actively working on and contributing to the field of high-order harmonic generation in solids and its spectroscopic applications. Once we drive a condensed matter system using a strong electric field that is beyond perturbation regime, ultrafast electronic currents, generated inside the materials, give rise to the generation of coherent, intense extreme ultraviolet radiation in the form of high-order harmonics. Careful observation of these harmonics and the related time-resolved measurements would allow us to study very interesting electronic

properties and dynamics of the involved system. In this project, we will first construct a state-of-the-art experimental apparatus (involving high power laser pulses and its applications in nonlinear optics) that would not only allow us to do attosecond streaking measurements (direct measurement of light waves) but also generate high-order harmonics from novel condensed materials. Direct spectroscopic applications will follow immediately.

Project TTL02: Generation of intense few-cycle laser pulses

Supervisor: Prof. T.T. Luu

Intense few-cycle laser pulses play an important role in studies of electronic dynamics at the native time scale of electrons. The generation of high power few-cycle laser pulses has become attractive over the last few decades. New progresses have been continuously developed and reported. The major route towards this end is the compression of already high-power laser pulses to shorter pulse duration (reaching few-cycle regime) instead of the multi-cycle input laser pulses. In this project, we are going to employ supercontinuum generation from solids as a major technique to perform this pulse compression. Manipulation of the spectral phase/chirp of the laser pulses would be carried out to maximize the compression efficiency, thus, achieving the shortest possible pulse duration. The newly created, ultrashort, few-cycle laser pulses would be utilized for ultrafast spectroscopy measurements.

Project YY01: Nonclassical optical responses at the extreme nanoscale

Supervisor: Prof. Y. Yang

Classical electromagnetism lacks electronic length scales, rendering its failure at the extreme nanoscale. A general and unified framework for nanoscale electromagnetism—amenable to both analytics and numerics, and applicable to multiscale problems—was recently presented [Nature 576, 248 (2019)]; it reintroduces the electronic length scale to the Maxwellian framework via surface-response functions known as Feibelman d parameters. This project aims to measure the d parameters of various interfaces of photonic and plasmonic prominence in different

electromagnetic regimes. In the visible regime, this project will establish the measurement protocol of d parameters via measuring the scattering properties of judiciously designed photonic systems and quasi-normal-mode perturbation analysis. In the infrared towards Terahertz regimes, this project will measure the proximity effect of metals on the dispersion of highly confined plasmons and phonon polaritons (e.g. in graphene, hexagonal boron nitride, and other 2D materials) to extract the d parameters using scanning near-field scattering measurements. Moreover, the consequences of d parameters in nonlinear optics, surface chemistry, and optoelectronics will also be discussed.

Project YY02: Interaction between light and free electrons

Supervisor: Prof. Y. Yang

light-matter interaction between free electrons and photons is a fundamental quantum electrodynamical process. Their interaction is pivotal for many applications including free electron lasers, microscopy and spectroscopy, and particle accelerators. The interaction gives rise to a multitude of radiative processes (such as Cherenkov, Smith-Purcell, and transition radiation) that constitute an invaluable diagnostic platform, however, usually at low coupling strength in the perturbative regime. We previously theoretically derived and experimentally validated a universal upper limit to free electron radiation in arbitrary photonic environments [Nature Physics 14, 894 (2018)]; we also observed strong the interaction between free electrons and photonic flat bands [Nature 613, 42 (2023)]. Both research outputs indicate the potential for strong free-electron-light interaction. This project aims to pursue the maximally possible quantum interaction strength between free electrons and photons, and to put forward realistic designs for experimental realizations. Concrete thrusts include the realization of the slow-electron-efficient radiation regime, the interplay between free electrons and Moire superlattices, and free electrons as pumps and probes for topological photonics.

Project YY03: Photonic synthetic gauge fields

Supervisor: Prof. Y. Yang

Synthetic gauge fields open a versatile toolbox to manipulate geometric

phases in engineered physical systems. These gauge fields can be classified into Abelian (commutative) and non-Abelian (non-commutative), depending on the commutativity of the underlying group. A plethora of success has been achieved in synthesizing Abelian (commutative) gauge fields on different platforms. It is more demanding to synthesize non-Abelian (non-commutative) gauge fields because they require internal degrees of freedom and non-commutative matrix-valued gauge potentials. We recently synthesized the first non-Abelian gauge fields in real space in any physical systems using an optical fiber network [Science 365, 1021 (2019)]. We leveraged such gauge fields to observe the long-sought non-Abelian Aharonov--Bohm effect. This project plans to explore photonic realizations of synthetic gauge fields and their topological consequences. We will discuss the interplay between non-Hermiticity, interaction, and synthetic gauge fields and the possible resulting synthetic symmetries that are absent in electronic topological band theory. We will theoretically and experimentally study photonic dynamic and Floquet systems immersed in synthetic gauge fields on integrated photonics and fiber optics platforms.

Project XBY01: Spin-Orbit Coupling at Metamaterial

Supervisor: Prof. X.B. Yin (Department of Mechanical Engineering)

Spintronics is a classic example of turning fundamental science into commercial success, from the Nobel Prize for the discovery of magnetoresistance in 2007 to every single hard disk drives today. Yet this field still offers a plethora of new physics that is of fundamental importance and has potential practical applications. We aim to develop a spin-orbit echo system that can serve as a highly feasible approach to preserve spin information. The central challenge of spintronics is extending spin lifetime and maintaining lossless spin information. The feasibility of a spin-orbit echo device benefits from the properties of optical metamaterials, which enable a customized electromagnetic response. The proposed projects include spin-orbit coupling systems with controllable spin angular momentum and orbital angular momenta, photonic spin Hall effect, metamaterials that manifest echo of relaxed magnetizations, and learning-based wavefront shaping for spin dynamics and interference.

Project XBY02: Optics at the Nexus of Food, Energy, and Water

Supervisor: Prof. X.B. Yin (Department of Mechanical Engineering)

Optical sciences and the underlying principles of light-matter interactions have contributed substantially to applications that are critical to our society. We aim to revisit some of the most important questions, such as photosynthesis and photovoltaics, and challenge ourselves with how today's modern optics, nano-optics, and advanced optical materials can transform traditional approaches. The proposed projects include high-entropy ultra-high temperature materials for concentrated solar systems, which can withstand extreme temperatures and enable more efficient solar energy conversion. Another project involves spectral-shifting thin films for augmented photosynthesis, where by tailoring the spectral properties of these films, we can enhance the efficiency of photosynthetic processes in plants and algae. We develop passive radiative cooling materials and systems that dissipate heat and harvest energy from cold space, providing an energy-efficient cooling solution by passively radiating heat into the cold expanse of space. We also explore materials and systems that leverage solar water interactions for purifications, condensations, and more, harnessing the interactions between solar energy and water to develop innovative solutions for water-related applications. Each project typically involves materials and optics design, prototyping, demonstration, system integration, and, in certain cases, scalable manufacturing of the designed functional materials. These advancements aim to transform traditional approaches and push the boundaries of what's possible in optical sciences, ultimately contributing to applications that are critical to our society.

Project SZ01: Inhomogeneous topological metamaterials and anomalous scattering inside ideal Weyl metamaterials

Supervisor: Prof. S. Zhang

Most research on topological systems have focused on homogeneous systems, while introduction of inhomogeneities may lead to discovery of new physics, such as chiral zero mode in an inhomogeneous Weyl system.

On the other hand, the scattering properties of wave by defects embedded inside the 3D Weyl metamaterials have not been studied in experiments. It has been theoretically shown that for ideal Weyl systems, due to the diminishing density of states at the Weyl frequency, the scattering cross section of a resonant defect inside the medium could become infinitely large or small depending on how close the resonance frequency of the defect is relative to the Weyl frequency. This project aims to investigating the scattering behaviour of resonant defects inside realistic ideal Weyl metamaterials, and to prove the diverging scattering cross section. Given this effect is successfully proved, a novel active system will be developed in which a single active defect is incorporated into the Weyl medium. By actively controlling a single active defect through electrical or optical pumping, one expects to observe the dynamic control over the transmission of a beam through the Weyl medium.

Project SZ02: Electromagnetic modelling of large scale topological metamaterials with strong nonlocal effect

Supervisor: Prof. S. Zhang

Topological metamaterials usually consist of complex arrangement of metallic inclusions. Although commercial software such as CST Microwave Studio and Comsol are effective in calculating the dispersion with periodic boundary conditions, it becomes highly impractical to simulate wave transport in a Weyl systems consisting a large number of unit cells of complex configurations, in particular when the metamaterial is not spatially homogeneous. Thus, an effective medium approach that can take into account the nonlocal effect is highly desirable for simulating the topological wave propagation inside an inhomogeneous topological system of large spatial dimensions. In these materials, the anisotropic and spatially dispersive constitutive relationship are described by matrices with tensors elements expressed as functions of both wavenumber k and frequency ω . These tensor elements will be obtained by numerically solving the band structure around the Weyl frequencies based on a single unit cell with periodic boundary conditions in all directions, and by fitting the band structure by an analytical k -dependent expression of the dispersion. Subsequently, these spatially dispersive material parameters will be fed into a weak form formulation of the effective Hamiltonian of the system to solve the wave propagation inside the inhomogeneous system without

involving the metamaterial unit cell structures. We will further implement suitably formulated boundary conditions to simulate the interface effects such as the topological surface waves. This will greatly reduce the numerical calculation time and will allow the simulation of intriguing physical effects arising from the inhomogeneity of the system.

Project SZ03: Non-abelian topology in the momentum space with metamaterials

Supervisor: Prof. S. Zhang

Most of the demonstrated topological invariants belong to \mathbb{Z} or \mathbb{Z}_2 classes, which belong to the Abelian homotopy groups. They are usually manifested as the Chern numbers or the winding numbers in topological physics. Very recently, non-Abelian topological charges (for example, quaternion charges for three-band systems) were proposed for nodal links and Weyl points in non-interacting metals, which exhibit highly interesting braiding topological structures and trajectory dependent node collisions. Prof. Zhang's group recently experimentally demonstrated the presence of such non-abelian topological charges in biaxial hyperbolic media, which host nodal links in the Brillouin zone formed by three bands - two transverse modes and one longitudinal mode. This system provides an exciting platform for studying interesting phenomena associated with non-abelian topological charges, such as braiding, nodal collision, and admissible nodal link transformations. In this project we will investigate these interesting non-abelian topological phenomena based on a series of judiciously engineered optical metamaterials with modified nodal link configurations.

Nuclear and Particle Physics group:

Project JHCL01: In-beam gamma spectroscopy of ^{100}Sn

Supervisor: Prof. J.H.C. Lee

^{100}Sn is the heaviest self-conjugate exotic doubly-magic nucleus. It lies on the proton drip-line and on the astrophysical rp-process path. Characterizing the magicity of ^{100}Sn and the nature of single-particle states in its neighboring nuclei is therefore essential to the fundamental understanding of nuclear forces and nucleosynthesis. In particular, the location of the first $2+$ state in ^{100}Sn indicates how strong the $N=Z=50$ shell closures are and provides essential benchmark to assessing various structure models. These are crucial input to establish structure models for reliable calculations of $A \sim 100$ $N \sim Z$ nuclei region which is important for nuclear structure and astrophysics. We aim at in-beam gamma spectroscopy of ^{100}Sn , particularly the energy of the first $2+$ state, and the low-lying states in the neighboring nuclei (^{101}Sn , ^{99}Cd and ^{99}In), at the RIBF facility via nucleon knockout reactions, with the use of MINOS device coupled with DALI2+ gamma spectrometer and ZeroDegree Spectrometer.

Project YJT01: Searching for Supersymmetry at the Large Hadron Collider

Supervisor: Prof. Y.J. Tu

The Standard Model (SM) works beautifully to predict and explain various experimental results. However, the SM has many open questions thus it is believed not a complete theory. Among many models, supersymmetry (SUSY) is the most promising candidate for new physics. SUSY predicts a partner particle for each particle in the SM. These new particles would solve a major problem in the SM, hierarchy problem - The masses of the W , Z particles are 10^{16} smaller than that of the Planck mass. SUSY also provides good dark matter candidate and a solution to the baryon asymmetry of the universe. We will search for super particles decaying into SM leptons plus missing transverse energy. Such experimental signatures have rich interpretations in various new physics scenarios, e.g. in SUSY, when the charginos and neutralinos (mixtures of

superpartners of the gauge bosons and the Higgs bosons) produced via electroweak interactions and decay into the W , H plus the lightest neutralino or gravitino (Dark Matter candidate), where W , H further decay, the final state will contain leptons plus missing transverse momentum. The same final states also appear in the Heavy Higgs association production. Therefore, the projects are not only key searches for SUSY, but also good probes for Dark Matter and beyond the SM Higgs physics.

Project YJT02: Searching for Higgs Beyond the Standard Model at the Large Hadron Collider

Supervisor: Prof. Y.J. Tu

The Standard Model (SM) works beautifully to predict and explain various experimental results. However, the SM has many open questions thus it is believed not a complete theory. Among various new theories, models with an extended Higgs sector are extensively existing and well motivated, such as the SUSY, Two Higgs Doublet Model (2HDM) and Composite Model. The group will work on searching for Higgs predicted in physics beyond the Standard Model. The focus will be in the scenario where such Higgs decays into top quarks.

POSTGRADUATE COURSES OFFERED BY DEPARTMENT OF PHYSICS, HKU

PHYS8950 Postgraduate Seminar

Course Objectives:

This course aims to initiate students into research culture and to develop a capacity for communication with an audience of varied background.

Course Contents & Topics:

Students will be required to attend and take part normally in all the colloquiums and a specified number of seminars organized by Department of Physics. Students will be also required to follow a course of independent study on a topic to be selected in consultation with his/her supervisor, and to give a presentation of 30-40 mins duration

PHYS8001 Selected Topics in Computational Modelling and Data Analysis in Physics

Course Objectives:

This course aims to familiarise students with research oriented techniques in computer modelling and data analysis.

Course Contents & Topics:

Topics include:

1. Advanced techniques, with emphasis on recently developed techniques, in branches of experimental physics.
2. Data analysis and computer modelling relevant to experiments

Topics in condensed matter physics and the physics of materials will predominate but other fields such as nuclear physics, astrophysics etc. will also be featured from time to time.

PHYS8002 Advanced Topics in Theoretical Physics

Course Objectives:

To provide an opportunity for students to extend their studies in theoretical aspects of fundamental physics.

Course Contents & Topics:

A series of lectures on advanced topics in theoretical physics, including quantum theory, electromagnetism and statistical mechanics, and their application to several fields of physics of contemporary interest, including astrophysics and condensed matter physics.

PHYS8201 Basic Research Methods in Physical Science

Course Objectives:

This course introduces basic research methods commonly used in various sub-fields in physics.

Course Contents & Topics:

This course comprises of four modules, each introduces commonly used research methods in physics. Students are required to take two out of the four modules. They are

1. Astrophysical techniques: Commonly used techniques and packages in astrophysical data gathering and data analysis are introduced.
2. Computational physics and modelling techniques: Commonly used computational physics and physical modelling methods are introduced.
3. Experimental physics techniques: Commonly used experimental physics apparatus and techniques are introduced.

Theoretical physics: Theoretical physics: Commonly used techniques in mathematical and theoretical physics are introduced.

PHYS8202 Special Topics in Physics

Course Objectives:

This course covers a broad range of topics in physics that are of immediate research interest for graduate students. Topics include most recent advances in both theoretical and experimental physics, including modern quantum many-body physics, quantum information and novel materials.

Course Contents & Topics:

Topics covered in this course are mostly of current research interests.

PHYS8351 Graduate Quantum Mechanics

Course Objectives:

This course introduces postgraduates to theory and advanced techniques in quantum mechanics, and their applications to selected topics in condensed matter physics.

Course Contents & Topics:

The course covers the following topics: Dirac notation; quantum dynamics; the second quantization; symmetry and conservation laws; permutation symmetry and identical particles; perturbation and scattering theory; introduction of relativistic quantum mechanics.

PHYS8352 Quantum Information

Course Objectives:

This course covers the theory of quantum information and computation and its applications in physics and computer science.

Course Contents & Topics:

Topics include: Quantum computer; quantum algorithms; quantum error correction; quantum information processing; quantum entanglement and quantum cryptography.

PHYS8450 Graduate Electromagnetic Field Theory

Course Objectives:

The aim of this course is to provide students with the advanced level of comprehending on the theory of classic electromagnetic field, enabling them to master key analytical tools for solving real physics problems.

Course Contents & Topics:

This course introduces and discusses the following topics: Boundary-value problems in electrostatics and Green's Function method; electrostatics of media; magnetostatics; Maxwell's equations and conservation laws; gauge transformations; electromagnetic waves and wave guides.

PHYS8550 Graduate Statistical Mechanics

Course Objectives:

This course covers advanced topics in equilibrium statistical physics.

Course Contents & Topics:

Topics include: Ensemble theory; theory of simple gases, ideal Bose systems, ideal Fermi systems; statistical mechanics of interacting systems; statistical field theory; some topics in the theory of phase transition may be selected.

PHYS8552 Condensed Matter Physics

Course Objectives:

This course introduces many-body physics in quantum matter. Systems consisting of many particles (bosons or fermions) display novel collective phenomena that individual particles do not have, for example, ferromagnetism and superfluidity. It aims to introduce students the general principles behind these phenomena, such as elementary excitations, spontaneous symmetry breaking, adiabatic theorems, emergent topological phases of matter, etc. Theoretical language useful in the interpretation of experiments, such as linear response theory and response functions, will be discussed. This course is intended for both experimentalists and theorists. While there are no official prerequisites, students who would like to take this course are assumed to have sufficient knowledge on quantum mechanics and statistical mechanics.

Course Contents & Topics:

This course will focus on the phenomena of emergent many-body states that require not only the effect of quantum statistics but also that of inter-particle interaction. Examples include: Ferromagnetism, Fermi liquid, superfluidity, superconductivity, and the quantum Hall states. Some general themes related to these quantum states, such as elementary excitation, Ginzburg-Landau description, spontaneous symmetry breaking, and topological phases of matter will be discussed.

PHYS8654 General Relativity

Course Objectives:

This course serves as a graduate level introduction to general relativity. It provides conceptual skills and analytical tools necessary for astrophysical and cosmological applications of the theory.

Course Contents & Topics:

Topics include: The principle of equivalence; inertial observers in a curved space-time; vectors and tensors; parallel transport and covariant differentiation; the Riemann tensor; the stress-energy tensor; the Einstein gravitational field equations; the Schwarzschild solution; black holes; gravitational waves detected by LIGO, and Freidmann equation.

PHYS8656 Topics in astrophysics

Course Objectives:

This course covers high energy processes, basic theory of stellar structure and evolution, and introduction to compact objects. It follows a vigorous mathematical treatment that stresses on the underlying physical processes.

Course Contents & Topics:

Topics include: Radiation mechanisms; stellar structure equations; polytropic model; elementary stellar radiation processes; simple stellar nuclear processes; stellar formation; late stage of stellar evolution; supernova explosion; compact stellar; cosmic rays; if time permits, additional selected topics will be covered.

PHYS8701 Physics Experimental Techniques

Course Objectives:

This course provides a detailed account of some common experimental techniques in physics research. It introduces the basic working principles, the operational knowhow, and the strength and limitations of the techniques.

Course Contents & Topics:

This course will discuss and train students of the following techniques:

1. Noise and Data Analysis
2. Computer Grid

3. Raman spectroscopy and photoluminescence (PL)
4. Temporal characterization of ultrashort laser pulses
5. Chirped Pulse Amplification - Technique to amplify laser pulses
6. Cryogenics and low-noise electrical measurements
7. Nanofabrication techniques
8. Scanning Probe Microscopy (STM and AFM)
9. Electron and X-Ray Diffraction (LEED/RHEED/XRD)
10. Photoemission Spectroscopy (PES)
11. Transmission Electron Microscopy (TEM)
12. Radiation Detection and Measurements in Nuclear Physics

PHYS8750 Nanophysics

Course Objectives:

This course is designed to deliver fundamental concepts and principles of nano physics to fresh postgraduate students, mostly focusing on the transport properties of the low-dimensional electronic systems under external electric and/or magnetic fields.

Course Contents & Topics:

The course will cover various topics in nano physics, such as zero-, one-, and two-dimensional electronic gas systems, quantum dots, graphene and 2D materials, semiconductor heterostructures, quantum Hall effects, Coulomb blockade effects, single electron effects, field effect transistors, phase-coherent interference effects, and more. While most discussions will be made based on experimental findings, the basics of the relevant theories will also be covered using the tight-binding model, basic quantum mechanics, and Landauer-Büttiker formula. The principles and applications of nano fabrication and low-temperature measurement techniques will also be discussed.

PHYS8751 Device Physics

Course Objectives:

The growth in the past 70 years of modern electronics industry has had great impact on society and everyday life, the foundation of which rests upon the semiconductor physics and devices. This course aims at presenting a comprehensive introductory account of the physics and

operational principles of some selected and yet classic semiconductor devices, microelectronic and optoelectronic. A brief introduction on the processing technology of the devices will also be given. The text is primarily designed for postgraduates but can be of interest to senior undergraduates in physics, electrical and electronic engineering and materials science. Students are assumed to have acquired some basic knowledge of quantum mechanics, statistical mechanics, and solid state physics, though a review of the physics of semiconductors will be given in the beginning of the course.

Course Contents & Topics:

This course begins by giving a review of solid state physics, particularly of the physics of semiconductors. It is then followed by discussions of the fundamentals and practical aspects of PN-junctions and rectifying diodes, amplifying and switching devices like bipolar and field-effect transistors (e.g., MOSFET), light-emitting and detection devices such as LEDs, laser diodes, and photodetectors. It will end by a brief discussion of special devices, e.g. charge-couple device (CCD), negative conductance microwave device (e.g., Tunnel and Gunn diodes) and also integrated circuits.

PHYS8852 Photonics and Metamaterials

Course Objectives:

In the last two decades, tremendous progress has been made in the manipulation of light propagation using structured photonic media - metamaterials, with negative refraction, super-imaging and invisibility cloaking as the most well-known examples. These new discoveries are paving ways towards many potential applications of photonic structures, including imaging, display, holography, and information processing. This course aims at providing the fundamental understanding of the interaction of light with structured media whose unit cells are much smaller than the wavelength of light, and the design and functionalities of various metamaterial-based photonic devices. The course text is primarily designed for senior undergraduate students and postgraduate students and requires some knowledge on electromagnetism and optics. On the other hand, it will also be of interest to graduate students since it includes some most recent results in the field of metamaterials and

nanophotonics.

Course Contents & Topics:

Topics include: Modeling of interaction of light with periodic structures, gratings, photonic crystals; coupled mode theory; interaction of light with metals, covering both propagating and localized surface plasmon polaritons; effective-medium description of the unconventional electromagnetic properties of metamaterials, such as negative permeability and negative refraction, zero refractive index, hyperbolic metamaterial, chirality and bi-anisotropy; design of the unit cells of the metamaterials based on plasmonic structures for achieving various electromagnetic properties and functionalities; transformation optics and invisibility cloaks; metamaterial devices, including super-imaging lenses, meta-lenses, metasurface holography etc.; nonlinear optical properties of metamaterials and metasurfaces; photonic systems with Parity-time symmetry; metamaterial approach for designing the topological properties for light.

REPRESENTATIVE PUBLICATIONS OF FACULTY MEMBERS

H.F. Chau

“Reducing the Impact of Adaptive Optics Lag on Optical and Quantum Communications Rates from Rapidly Moving Sources”, K. S. Chan and H. F. Chau, *AIP Advances*, 13, 055201 (2023)

“Application of an Improved Version of McDiarmid Inequality in Finite-Key-Length Decoy-State Quantum Key Distribution”, H. F. Chau and K. C. J. Ng, *New Journal of Physics*, 22, 023011 (2018)

“Unconditionally Secure Key Distribution in Higher Dimensions by Depolarization”, H.F. Chau, *IEEE Transactions on Information Theory*, 51, 1451-1468 (2005)

“Unconditional Security of Quantum Key Distribution over Arbitrarily Long Distances”, H.K. Lo and H.F. Chau, *Science*, 283, 2050-2056 (1999)

“Is Quantum Bit Commitment Really Possible?”, H.K. Lo and H.F. Chau, *Physical Review Letters*, 78, 3410-3413 (1997)

X.D. Cui

“In-Plane Electric-Field-Induced Orbital Hybridization of Excitonic States in Monolayer”, Bairen Zhu, Ke Xiao, Siyuan Yang, Kenji Watanabe, Takashi Taniguchi, and Xiaodong Cui, *Phys. Rev. Letters*, 131, 036901 (2023)

“Manipulating spin-polarized photocurrents in 2D transition metal dichalcogenides”, L. Xie, X. Cui, *Proceedings of the National Academy of Sciences*, 113, 14, 3746-3750 (2016)

“Anomalous robust valley polarization and valley coherence in bilayer WS₂”, B. Zhu, H.L.Zeng, J.F. Dai, Z.R. Gong and X.D. Cui, *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 111, 11606-11611 (2014)

“Optical signature of symmetry variations and spin-valley coupling in atomically thin tungsten dichalcogenides”, H. Zeng, G.B. Liu, J. Dai, Y. Yan, B. Zhu, R. He, L. Xie, S. Xu, X. Chen, W. Yao and X.D. Cui, *Scientific Reports*, 3, 1068 (2013)

“Valley polarization in MoS₂ monolayers by optical pumping”, H.L. Zeng, J.F. Dai, W. Yao, D. Xiao and X.D. Cui, *Nature Nanotechnology*, 7, 490-493 (2012)

L.X. Dai

“Detecting Population III Stars through Tidal Disruption Events in the Era of JWST and Roman”, Kar Chowdhury R., Chang J.N.Y., Dai L., Natarajan P., *The Astrophysical Journal Letters*, 966, L33 (2024)

“The Effects of Gas Angular Momentum on the Formation of Magnetically Arrested Disks and the Launching of Powerful Jets”, Kwan T.M., Dai L., Tchekhovskoy A., *The Astrophysical Journal Letters*, 946, L42 (2023)

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