

DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG



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WELCOME

Dear prospective research postgraduate students,

We hope you find this booklet useful, both as a valuable reference and as a source of background information to help you during your research postgraduate application process. We are very proud of our record of distinguished and innovative research at HKU across 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 the last few 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 (e.g. two Croucher Senior Research Fellowships, one by Prof. Wang Yao and one by Prof. Xiaodong Cui; Dr. Shizhong Zhang received Hong Kong RGC Fellowship; Dr. Lixin Dai, Dr. Jenny Lee Hiu Ching, Dr. Chenjie Wang, and Dr. Yi Yang won China's Excellent Young Scientists Fund 2021). 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 three years (Wang Yao, Lance Li, Shuang Zhang). In terms of citation numbers, our annual

citations (ISI) more than doubled from 7014 in 2015 to 17825 in 2020. 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. Zidan Wang
Head and Chair Professor
Department of Physics, HKU

August 2022.

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 27 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 will be building up an Institute of Quantum Science. 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 176 scientific papers in 2014/15 to 250 in 2019/20; (ii) meanwhile, publications in Science and Nature series, and in Phys. Rev. Lett. increased from 18 to 27; (iii) annual citations (ISI) increased from 7014 in 2015 to 17825 in 2020. 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:

Monolayer semiconductor nanocavity lasers with ultralow thresholds, Nature 520, 69-72 (2015)

Valley-polarized exciton dynamics in a 2D semiconductor heterostructure, Science 351, 688-691 (2016)

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, Vol.594, 195-201 (2021)

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

- **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. B. Fu	Dr. F.X. Guan
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Dr. C.J. Huang	Dr. R. Kar Chowdhury
Dr. C.K. Li	Dr. C. Li
Dr. M.C.A. Li	Dr. Z.Z. Lin
Dr. B.W. Ma	Dr. S.J. Ma
Dr. P.S. Pal	Dr. D.K. Paredes Hernandez
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Dr. A.A. Syed	Dr. R. Wang
Dr. X. Wang	Dr. Y.P. Xia
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Dr. Z. Yan	Dr. Y.J. Yang
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Dr. C. Zhang	Dr. J.C. Zhang
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Distinguished Visiting Professor:

Prof. A. Zijlstra

**Honorary /Visiting /
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Prof. J. Gao
Prof. S.A. Maier
Prof. D.S.Y. Tong
Prof. E. Wang
Prof. J. Wang
Prof. S.J. Xu
Prof. F.C. Zhang

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IT Technician

Lau Sai Kin

Technicians

Chan Wai Hung, Ho Wing Kin, Ip Kam Cheong

Executive Officer

Anna Wong

Clerks I

Carfulin Tam, Mandy Tse, Eva Wong

Clerk II

Ken Chow, Andy Lau

Office Attendant

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. G. Chen*
- Prof. X.D. Cui*
- Prof. A.B. Djurišić*
- Dr. D.K. Ki*
- Prof. L.J.L. Li (by courtesy)*
- Dr. F.C.C. Ling*
- Dr. Z.Y. Meng*

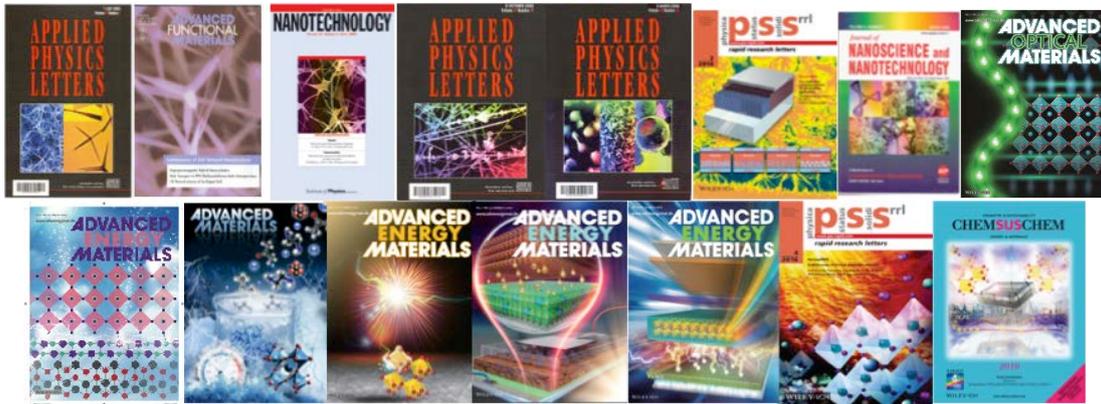
Prof. S.Q. Shen
Dr. C.J. Wang
Prof. Z.D. Wang
Prof. M.H. Xie
Prof. W. Yao
Dr. S.Z. Zhang

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, two thermal evaporators 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.



Dr. 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, and one 400mK He-3 fridge with 12-T magnet (to arrive in October 2022). Current research activities focus 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 possess interesting electronic properties but also offers large experimental flexibilities to study and engineer them. We are also interested in bridging the gap between the fundamental research and real-life applications.



Electron-beam writer



14-T dilution fridge

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/>

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

- (1) Defects in semiconductors: characterizations and identifications, defects influence on materials electrical, optical and magnetic properties, defect control, defects at semiconductor junctions;
- (2) Electrical and optical properties of semiconductor system: deep level transient spectroscopy, temperature dependent Hall measurement, IV and CV measurements, luminescence spectroscopy;
- (3) Positron annihilation spectroscopic study of vacancy type defects: These research activities are performed with the

positron beam line located at the electron LINAC ELBE, Helmholtz Zentrum Dresden Rossendorf, Germany.

- (4) Defects in functional oxides and wide band-gap materials: Tailoring electrical, optoelectronic, and magnetic properties of these materials via defect engineering.

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, pico-ammeter, electrometer, and etc.; Photoluminescence system: 30 mW HeCd laser, 500 mm monochrometer, PMT and CCD detecting system; UV-visible spectrophotometer; Radio frequency magnetron sputtering system; Pulsed laser deposition system; Chemical vapor deposition system; Electron beam evaporator; Thermal evaporator; Tube furnace and box furnace. Big “off campus” equipment accessible to our students and staff: Positron beam time at the electron LINAC ELBE in the Center for High-Power Radiation Sources, Helmholtz Zentrum Dresden Rossendorf (HZDR), Germany for positron annihilation spectroscopic (PAS) study.

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 heterostructures. 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

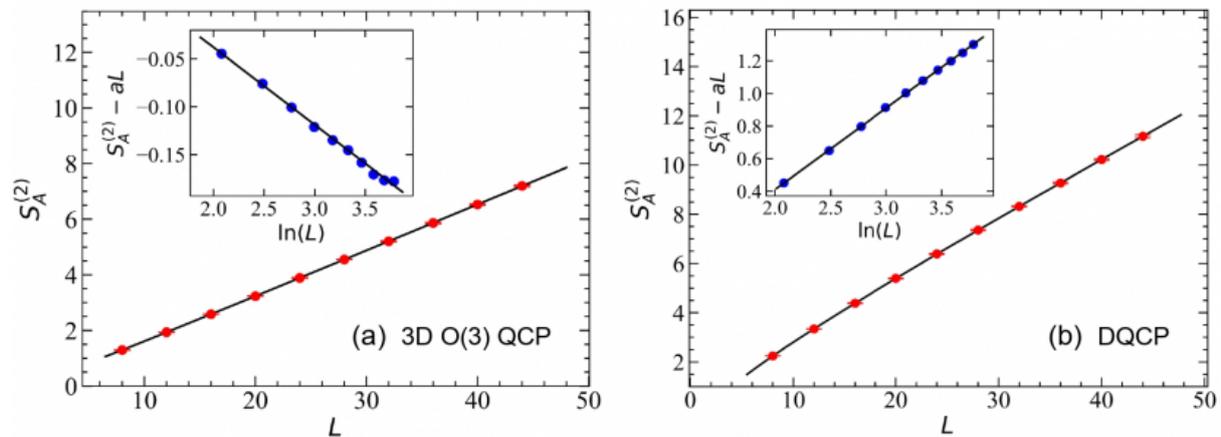
The current research interests include:

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

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,

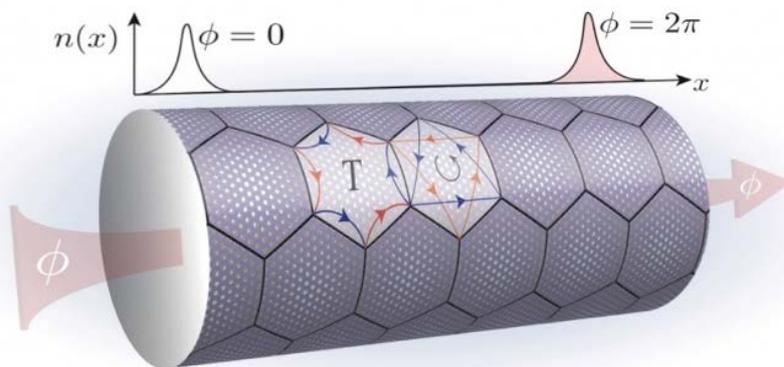
Z.D.Wang, S.Q.Shen), the frustrate magnetism and theoretical explanation of strongly correlated experiments (G.Chen), the model construction and their quantum many-body solutions towards the new paradigms of quantum matter (Z.Y.Meng), quantum computation and quantum Simulation (Z.D.Wang), cold atomic gases (S.Z. Zhang) and novel transports in 2D materials and novel mechanisms (S.Q.Shen, W.Yao), etc. In all these fields, we have made great impact and participating and leading the research directions at a global level.

Dr. 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>



Scaling of the entanglement entropy indicates the non-trivial DQCP

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. Chen is a theoretical condensed matter physicist. His research areas

cover a wide range of topics in strongly correlated condensed matter physics, including, but not limited to, frustrated magnetism, non-Fermi liquid, spin liquid, Kondo physics, topological orders and phases, spintronics, ultracold atoms, non-linear optics, thermal transports, quantum hall effects, fermion sign problem for numerics, and composite systems with multi-flavor degrees of freedom, etc.

Dr. Wang is a theorist working on condensed matter physics. His recent research focuses on fundamental theories of topological phases of quantum matter, such as interplay between symmetry and topology, bulk-boundary correspondence, quantum anomaly, symmetry fractionalization, etc. He has also worked on quantum transport, fractional quantum Hall liquids, Luttinger liquids, and fluctuation theorems in non-equilibrium statistical mechanics.

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.

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.

Dr. 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.

Facilities

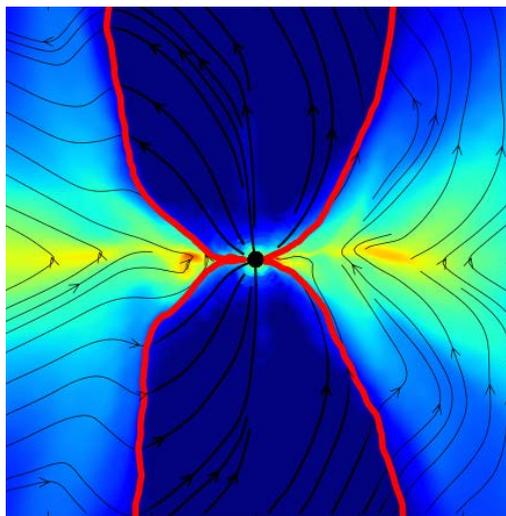
A summary of the major facilities include Multi-chamber UHV system consisted of MBE, STM, UPS, and LEED facilities, low-temperature (4K) STM, Pulsed laser deposition system, RF sputtering system and electron beam evaporators, micro-optics system for photoluminescence and Raman spectroscopy and pump-probe 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.

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: *Dr. L.X. Dai*
 Dr.M.H. Lee(Dept. Earth Sciences
 adjunct with Dept. Physics)
 Dr. J.J.L. Lim
 Dr. S.C.Y. Ng
 Prof. Q.A. Parker

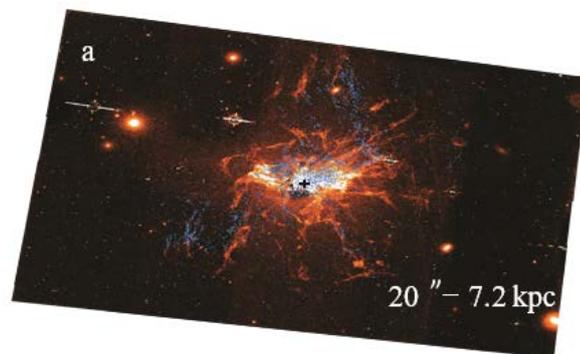
Dr. Dai works on theoretical and computational high-energy astrophysics. She focuses on studying relativistic phenomena around astrophysical black holes, including tidal disruption events, jets, active galactic nuclei, gravitational waves, etc. Besides employing theoretical calculations, she develops several novel computational tools and techniques, such as general-relativistic magneto-hydrodynamic (GRMHD) simulations, general-relativistic ray-tracing (GRRT) simulations, and X-ray reflection and reverberation.



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

Dr. 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.

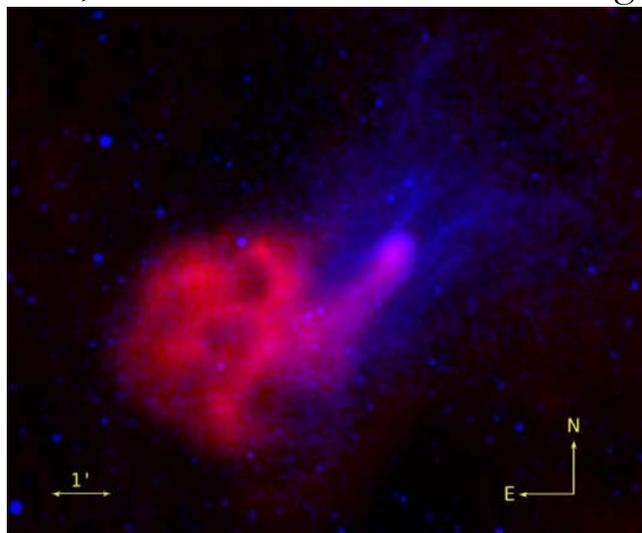
Dr. Lim is an observational astronomer who has worked on a broad range of topics in astrophysics, addressing outstanding issues related to objects from the Sun to galaxies in the early Universe, and spanning wavelengths from radio to X-rays. One of his current research focus involves galaxy clusters, in particular the origin and nature of cool gas in their central giant elliptical galaxies, the nature and history of star formation from this cool gas, and whether the cool gas fuels the supermassive black holes at the centers of these galaxies. He is the Program Coordinator of an RGC/CRF grant to infer the neutrino mass from the spatial clustering and abundance of galaxy clusters, in collaboration with an international team of astronomers using data from a forthcoming sky survey known as JPAS. Over the past 6 years, in collaboration primarily with Prof. Tom Broadhurst, a visiting Research Professor, Dr. Lim has assembled a prominent group working on the astrophysical applications of gravitational lensing, focusing in particular on identifying the nature of dark matter.



Newly born star clusters (each indicated by a blue dot) produced by gas in the nebula (red filaments) associated with the giant elliptical galaxy in the Perseus galaxy cluster. These star clusters are destined to evolve into globular clusters. The gaseous nebula originates from cooling of the surrounding intracluster gas that emits in X-rays.

Dr. 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.

Dr. 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 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://www.astro.physics.hku.hk/~ncy/>.

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

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.

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. Recently, we are expanding on the experimental side too. With the hiring of Prof. Hoi-Kwong Lo, our Chair Professor, and a number of future hires under planning, we have been establishing an

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. Hoi-Kwong Lo joined our Department in July, 2020, bringing it decades of international research experience from the University of Toronto and elsewhere. Prof. Lo work on both the theory and experiment of quantum communication, particularly quantum cryptography. Topics of interest include the design of new cryptographic protocols, parameter optimization of protocols, experimental implementations of novel protocols, quantum hacking and counter-measures, chip-based quantum key distribution (QKD), all photonics quantum repeaters and quantum key infra-structure (QKI).

Dr. Wenyuan Wang is a theorist and currently a Research Assistant Professor in the group of Prof. Hoi-Kwong Lo. His main research interest is quantum communication, with a focus on quantum key distribution (QKD). Dr. Wang studies the design, security proof and optimization of QKD protocols. He is also interested in combining computational techniques with the field of quantum information, such as semidefinite programming (for numerical security proofs), high-performance computing, as well as machine learning, in e.g. designing better and more optimized QKD protocols in practical settings.

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](#)) and light ([Dr. T.T.Luu](#)).

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 \(Dr. S.Z.Zhang\)](#). Importantly, the research group of [Chair Prof. H.K.Lo](#) uses optical technologies for revolutionizing quantum information processing. 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](#), [Dr. 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.

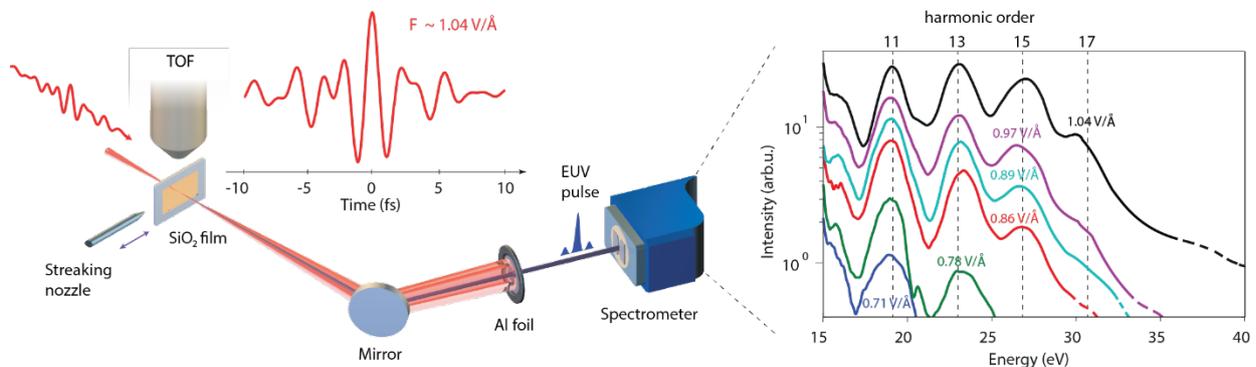
Academic staff:

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

Dr. T.T. Luu

Dr. Y. Yang
Prof. S. Zhang

Dr. 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

Dr. 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.

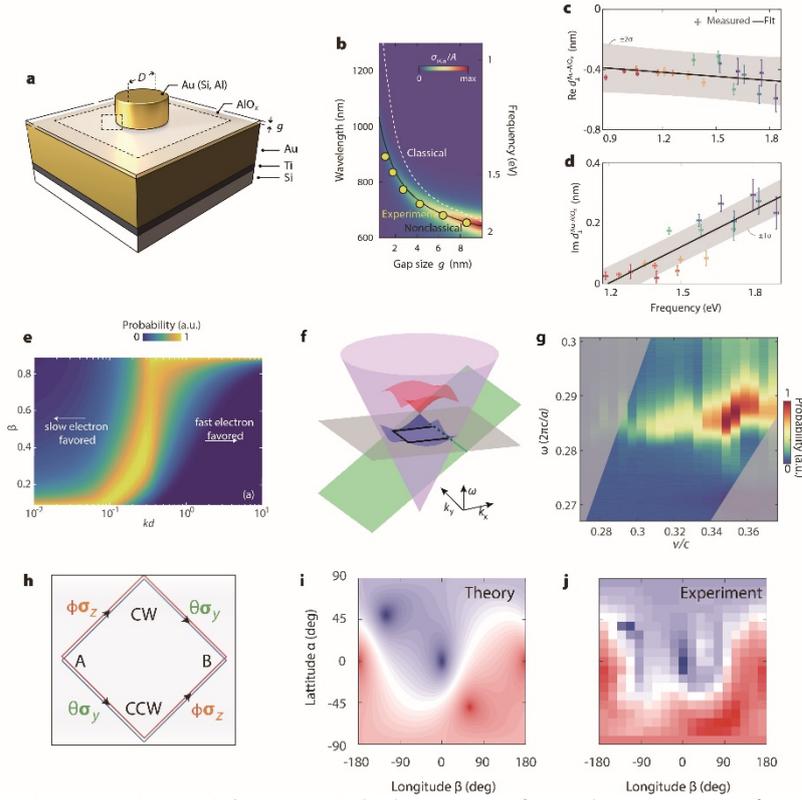
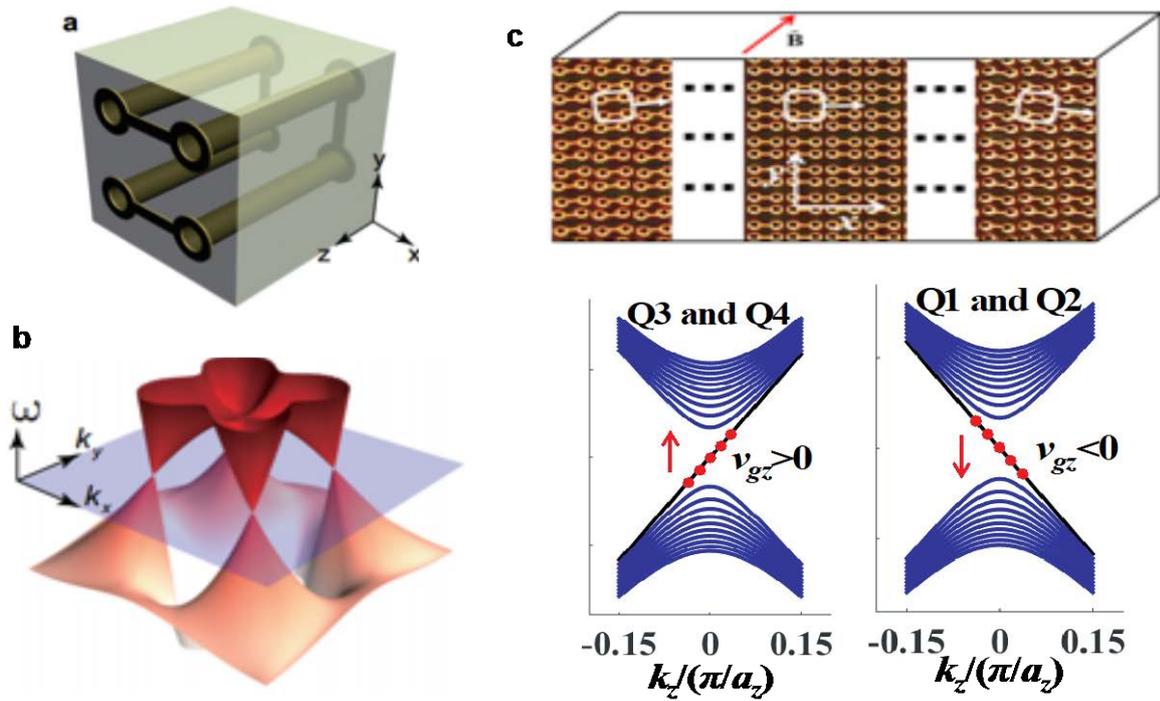


Figure. *Photons interacting with material electrons, free electrons, and synthetic gauge fields. a-d. A general nanoscale electromagnetic framework and the experiment that measured its Feibelman d parameter. e-g. An upper limit to spontaneous free-electron radiation and the measured enhanced interaction 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.*

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 recent 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.



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:

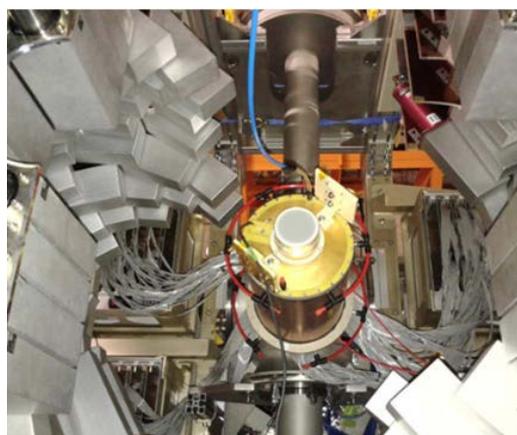
The group is established as part of the Joint Consortium for Fundamental Physics by three universities in Hong Kong – HKU, CUHK and HKUST, through which we participate in international collaborations on big science.

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

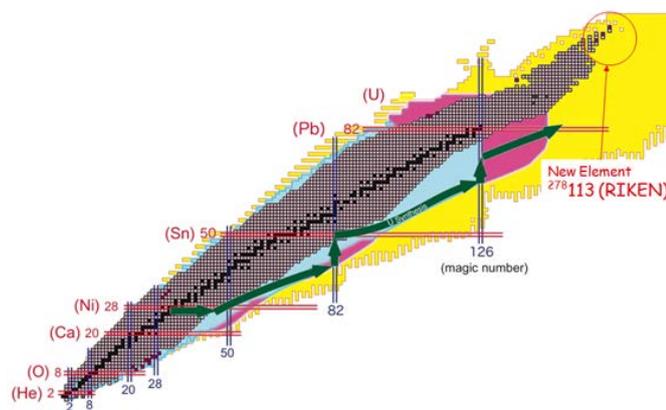
Dr. Lee is a leader of the experimental nuclear physics sub-group. Nuclear physics aims at understanding the structure of atomic nuclei and the nature of fundamental forces, addressing a big science question on how the heavy elements from Iron were synthesized in the universe which is governed by the 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. Collaborations with IMP on detector developments and physics experiments have been initiated with the IMP-HKU Joint Laboratory of Nuclear Sciences established in HKU.



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



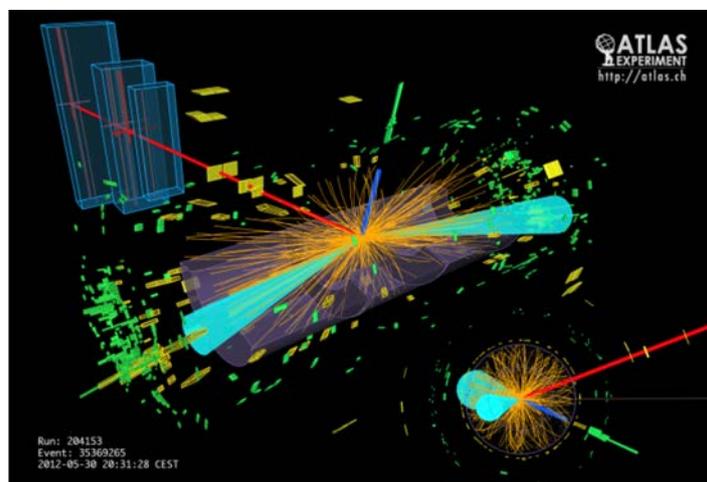
Nuclear Chart. The horizontal and vertical axes represent N and Z, respectively

Dr. 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 Charginos and Neutralinos in Supersymmetry, 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 I, one of the important upgrade projects is to introduce a new tracking and trigger device in the inner layer of the forward muon spectrometer, New Small Wheel (NSW). We work on upgrading electronics of the NSW, which makes us one of the most active groups on commissioning the NSW electronics at CERN. 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, which is expected to serve the LHC physicists. Meanwhile, we have access to the Worldwide LHC Computing Grid, which is the world's largest computing grid.



A collision event at the ATLAS

HKU-UCAS Joint Institute of Theoretical and Computational Physics:

Academic staff: Prof. H.F. Chau, Prof. G. Chen, Prof. G.H. Chen (Chemistry), Prof. G. Chiribella (Computer Science), Dr. M.H. Lee (Earth Sciences), Dr. Z.Y. Meng, Dr. S.C.Y. Ng, Prof. S.Q. Shen, Dr. Y.J. Tu, Dr. C.J. Wang, Prof. Z.D. Wang, Prof. W. Yao, Dr. S.Z. Zhang, Prof. S. Zhang

The Department of Physics houses the “HKU-UCAS Joint Institute of Theoretical and Computational Physics at Hong Kong”, formally known as the “The Centre of Theoretical and Computational Physics (CTCP)”. CTCP was established in September, 2005, with the purpose to enhance academic excellence in this area in Hong Kong and to serve as a platform for fostering collaboration between scientists in Hong Kong and abroad. Prof. Dan Tsui at Princeton University, Nobel Prize co-recipient in Physics in 1998, has served as CTCP’s honorary Director. In 2019, CTCP was retitled to “HKU-UCAS Joint Institute for Theoretical and Computational Physics at Hong Kong”, to join force with KITS at UCAS to further enhance the collaboration on academic activities on theoretical and computational physics. The sister branch, “HKU-UCAS Joint Institute for Theoretical and Computational Physics at Beijing”, is housed by KITS.

The Joint Institute includes 15 faculty staff members as listed above. These members have been working in condensed matter physics, computational material sciences, quantum information, cold-atom physics and astrophysics. Most of these subfields are related to each other and cover many cutting edge researches related to today’s science and tomorrow’s technology.

The Joint Institute exists to: (1). To invite scientists including distinguished scientists who have collaborated with or are potential collaborators of local scientists to Hong Kong to initiate or to carry out collaborative researches; (2). To organize lectures or public lectures given by distinguished visitors; (3). To train outstanding postdoctoral fellows and young talented graduate students to collaborate with Joint Institute’s visitors and the team members to carry out first class researches; (4). To

coordinate with similar centres or institutes in Pacific Rim region and in the world to regularly organize high level international conferences and/or workshops to establish itself as the magnet of research activities in these research areas in the region.

Daniel Tsui Fellowship. The Fellowship is to provide opportunities for outstanding young physicists in China including the mainland and Taiwan, or in Singapore, within 15 years receiving Ph. D., to carry out research at the joint institute.

**2023/2024 POSTGRADUATE PROJECTS
DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG**

The following M.Phil./Ph.D. projects are available in 2023/2024 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\$18,030 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 GC01: Spin-orbit-coupled correlated materials

Supervisor: Prof. G. Chen

The discovery of topological insulator and semimetal has pushed the spin-orbit coupling to the forefront of modern condensed matter physics. As we know, topological insulator and semimetal with protected surface states are non-interacting electron band structure physics. It is naturally to understand the effect of the correlation on top of the non-trivial band structure topology. Besides this theoretical motivation, the 4d/5d transition metal compounds with iridium, osmium, even 4f rare-earth compounds are natural material systems to explore such phenomena. This is a field where both theoretical ideas and experimental efforts converge. In spin-orbit-coupled correlated material, we have discovered and/or proposed novel quantum phases of matter and the unconventional multipolar orders. We will continue to explore the rich and fascinating behaviors of quantum materials with both strong spin-orbit coupling and strong correlation.

Project GC02: Frustrated and quantum magnetism

Supervisor: Prof. G. Chen

Frustration in condensed matter physics usually means competing interactions that cannot be optimized simultaneously. When frustration meets with quantum mechanics in quantum many-body systems, it not only enhances the effect of the quantum fluctuations but also enriches the quantum phenomena. Various exotic and quantum phases such as the quantum spin liquid with emergent excitations and gauge structures are proposed.

In last 1-2 decades, the field of frustrated quantum magnets has grown rapidly. Many quantum magnets have been discovered, studied and characterized. Frustration often but not always comes in the form of geometrical frustration. That is the reason that many existing frustrated

quantum magnets come in the form of geometrical lattice such as triangular, kagome, FCC, pyrochlore, hyperkagome lattices. Our work is to provide physical and realistic models to describe the interaction between the microscopic degrees of freedom, and give explanation and prediction of interesting experimental phenomena.

Project GC03: Ultracold atoms on optical lattices

Supervisor: Prof. G. Chen

Ultracold atomic and molecular systems provide another but very different fertile ground for looking for novel quantum phenomena. The most distinct and exciting part in this field is the tunability of experimental parameters and the new probing methods (that are special to the atomic systems). Both (especially the former) are often very difficult in a regular solid state system. For example, magnetic or optical Feshbach resonance can vary the effective interaction from weak to strong in a continuous fashion. A well-known application is the unitary boson or fermion gas with infinite scattering length that will be discussed in the next section. The $SU(N)$ Heisenberg model and Hubbard model are a very good example of quantum many-body problems that can be realized in ultracold atomic and molecular systems but are almost impossible in solid state systems. We propose a novel chiral spin liquid phase for a $SU(N)$ Hubbard model on an optical lattice. In cold atom systems, new experimental probes (like noise correlation, quenched measurement, etc) are available. We want to understand the experimental consequence of the various quantum phases in these new measurements. In general, we are interested in the many-body problems that can be realized in cold atom systems and also support interesting experimental consequences.

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: Dr. 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: Dr. 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 DKK03: Perovskite Thermoelectrics

Supervisor: Dr. D.K. Ki

Thermoelectric materials generally refer to those with a large figures of merit, $ZT = S^2\sigma T/\kappa$, where $S = -\Delta V/\Delta T$ is the Seebeck coefficient, σ and κ is the electrical and thermal conductivity, respectively. They have attracted considerable interests as they can directly convert heat into electricity or vice versa via various phenomena, such as Seebeck, Peltier, and Thomson effects. Many efforts have been made to find the materials with a sufficiently large ZT , i.e., those with a larger Seebeck coefficient, higher electrical conductivity, and lower thermal conductivity, simultaneously, which is difficult as the three parameters are closely related and cannot be tuned independently. Here, working together with the experts in Perovskite materials (Prof. Aleksandra B. Djurišić in Physics and Dr. Jitae Kim in Mechanical Engineering), we aim to explore various Perovskite nanostructures realized in zero, one, and two dimensions to investigate their thermoelectric properties and find a way to enhance the ZT further by using state-of-art engineering techniques developed in our group.

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: Dr. 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 $>10^4$ with low dielectric loss <0.1 have been achieved in acceptor-donor co-doped oxides, and was speculated to be associated with the electron-pinning defect complex. 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 transparent capacitive device with the transparent high-k oxide films.

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

Supervisor: Dr. 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.

Project CCL03: Defects in functional oxides

Supervisor: Dr. C.C. Ling

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

Project ZYM01: Fundamental properties of metallic quantum critical point

Supervisor: Dr. 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: Dr. 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: Dr. 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

A topological insulator is a novel topological state of quantum matter which possesses metallic edge or surface states in the bulk energy gap. The edge or surface states consist of an odd number of massless Dirac cones, and result in quantum spin Hall (QSH) effect, which is analogous integer quantum Hall effect. The physical properties of this kind of insulator are unchanged by smooth modifications to their geometry and are robust against non-magnetic impurities and interactions. The edge states and surface states are robust against the nonmagnetic impurities. The primary objective of this proposal is to explore novel topological quantum materials, and to investigate quantum transport in topological insulators,

metals and superconductors. Quantum transport and quantum phenomena will be investigated in various forms for the purpose of application.

Project CJW01: Topological Phases of Matter with Strong Correlation

Supervisor: Dr. 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 two general aspects of topological phases: (i) fundamental theories of topological phases, in particular in higher dimensions and (ii) search of anyons in experimental systems such as fractional quantum Hall liquids and quantum spin liquids. More specifically, we will investigate the deep interplay between symmetry and topology --- two key fundamental concepts in modern physics --- in various quantum systems. Also, we study quantum transport properties for detecting experimental topological systems. When it comes to realistic models, we also plan to perform numerical studies, e.g., using algorithms based on tensor network states.

Project ZDW01: Topological Metals/Semimetals and Quantum Simulations

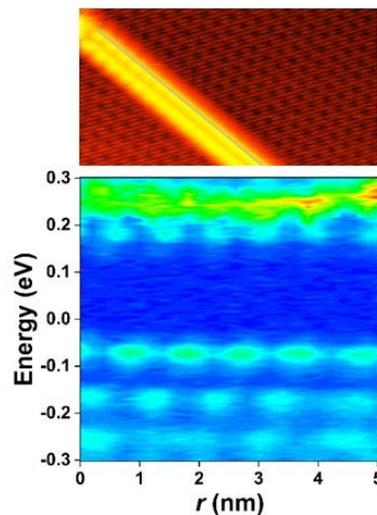
Supervisor: Prof. Z.D. Wang

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,



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.

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

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: Dr. 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 XBY01: Electron Microscopy and Spectroscopy in Air

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

Focused electron beam has been broadly used for nanoscopic imaging, spectroscopy and processing of materials in the past decades. Yet we are witnessing translational breakthroughs in the field including the Nobel Prize-winning cryogenic electron microscopy and in situ electron microscopy enabled by the integrated liquid cells. We aim to develop a focused electron beam system that can be operated in air, at a 1-atm ambient condition. It is enabled by a vacuum-sealing and electron-permeable thin membrane, which seals the entire electron optics column and isolates it from the ambient. The development will enable a first-of-its-kind focused electron beam tool for nanoscopic imaging and cathodoluminescence spectroscopy studies of materials, regardless of their condition — solid or liquid, conductive or insulating, organic or inorganic. In addition to the development, various topics and projects are under exploration including interface assembling at the liquid-vapour interface and liquid-liquid interface, correlated light and electron imaging, interface phase transitions (eg. condensations or as simple as how ice nucleates at the water surface) with reactive flows, in situ imaging of an electrochemical cell or battery, and electron beam guided/induced thin film growth and/or etching.

Astrophysics group:

Project LXD01: Black Hole Accretion Disk & Jet Simulations

Supervisor: Dr. 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 tidal disruption events. 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 have been using state-of-the-art general relativistic numerical codes to investigate a few different black hole accretion systems, which currently includes tidal disruption events, ultra-luminous X-ray sources and other newly discovered black hole transient 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 emissions and compare with observations.

Project LXD02: Theory/Simulations of Tidal Disruption Events

Supervisor: Dr. 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 will be launched to catch transients such as tidal disruption events, which will allow us to detect thousands of such events and bring many 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) connect theoretical studies of tidal disruption events to next-generation time-domain missions.

Project LXD03: Black Hole X-Ray Reflection & Reverberation

Supervisor: Dr. L.X. Dai

The novel technique of X-ray reflection and reverberation has proven to be very powerful in helping us study 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, and investigate the properties of black hole and 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) output results into packages and tools for X-ray observers.

Project MHL01: Dynamics and Origins of Planetary Systems

Supervisor: Dr. 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: Dr. 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. 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: Dr. 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.

Project CYN01: Mapping the Magnetic Fields of Pulsar Wind Nebulae

Supervisor: Dr. 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 Sakauri 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

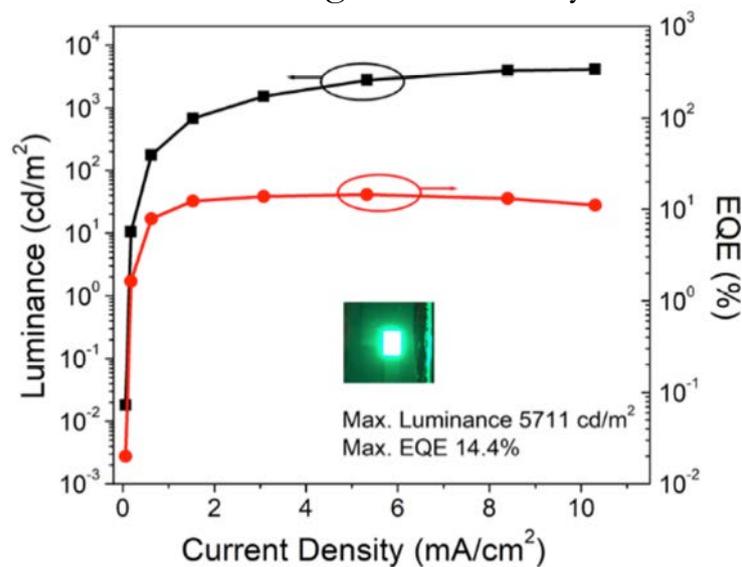
Quantum computers, based on principles of quantum mechanics, could efficiently solve certain significant problems which are intractable for classical computers. For the past several years, they have become a hot topic across a number of disciplines and attracted significant interests both theoretically 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

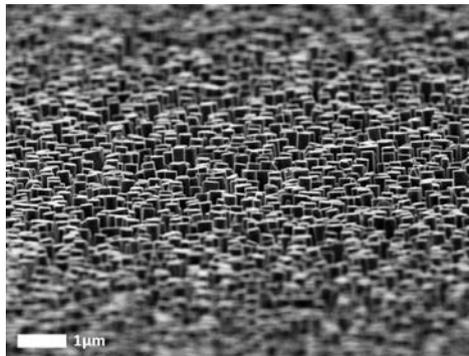
Recent advances in organometallic halide perovskite solar cells have resulted in increasing interest in next generation solar cell based on these materials. In spite of great interest for practical applications, there are still a number of unanswered questions concerning their fundamental properties 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: Dr. 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: Dr. T.T. Liu

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: Dr. 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: Dr. 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. 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: Dr. 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: 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 challenge us with the question of how today's modern optics, nano-optics and advanced optical materials can transform some of the traditional approaches. The projects include high-entropy ultra-high temperature materials for concentrated solar systems, spectral-shifting thin films for augmented photosynthesis, passive radiative cooling materials and systems that dissipate heat and harvest energy from cold space, and materials and systems that leverage solar water interactions for purifications, condensations, and more. Each project typically can involve the materials and optics design, prototyping, demonstration, system integration, and, in certain cases, scalable manufacturing of the designed functional materials.

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, quaternions 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: Dr. 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 nucleo-synthesis. 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: Dr. 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: Dr. 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.

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 cryptograph.

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 Friedmann equation.

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

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

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“Dirac's “magnetic monopoles” in pyrochlore ice U(1) spin liquids: Spectrum and classification”, Gang Chen, *Phys. Rev. B* 96, 195127 (2017)

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“X-Ray Fluorescence from Super-Eddington Accreting Black Holes”, Thomsen L.L, Dai J. L., Ramirez-Ruiz E, Kara E., Reynolds C., *The Astrophysical Journal Letters*, 884, L21 (2019)

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“Energetic constraints on electromagnetic signals from double black hole mergers”, Dai, L., McKinney, J., & Miller, M. C., *MNRAS Letters*, 470, 92 (2017)

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