DEPARTMENT OF PHYSICS

THE UNIVERSITY OF HONG KONG

Excellence in Research and Teaching

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September 2021

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WELCOME

Dear prospective research postgraduate student,

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. Lixin Dai and Dr. Jenny Lee Hiu Ching 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. Hoi-Kwong Lo
Research Division Director in Physics and Astronomy
Chair Professor, HKU

Prof. Zidan Wang
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Department of Physics, HKU

Prof. Shuang Zhang
Chair Professor
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August 2021.

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. To strengthen further our research, a Research Division in Physics and Astronomy has recently been formed. 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 our Research Division. 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 Research Division 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 Division and to collaborate with other divisions/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 CrI_3, Nature 572, 497- 501 (2019)

Signatures of moiré-trapped valley excitons in $MoSe_2/WSe_2$ 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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Technicians	Chan Wai Hung, Ho Wing Kin, Ip Kam Cheong, Lee Chin Ming
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Clerks II	Navis Lau, Christa Woo
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, 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.

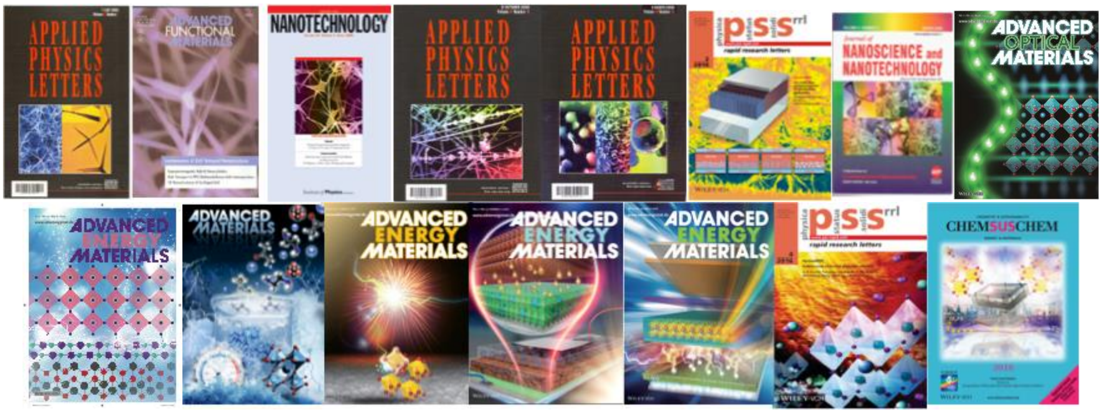
Academic staff: ***Dr. G. Chen***
Prof. X.D. Cui
Prof. A.B. Djurišić
Dr. D.K. Ki
Prof. L.J.L. Li (by courtesy)
Dr. F.C.C. Ling
Dr. Z.Y. Meng

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

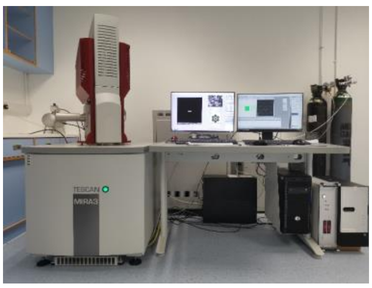
1. Experimental Condensed Matter and Material Science

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 various nano-electronic devices, realized by state-of-art nanofabrication and engineering techniques. For this, we are equipped with various nanofabrication facilities, such as electron-beam lithography system, metal deposition chambers, reactive ion etcher, and home-made micro-manipulators to assemble small-size atomically thin crystals with high precision. For transport measurements, we have two zero-field 10K CCR cryostats and one 10 mK dilution fridge with 14-T magnet (to be installed by 2020). Current research activities focus on discovering new transport phenomena, understanding their microscopic origins, and learning to control their properties. Materials of interest include graphene and 2D materials, topological insulators and superconductors, and low-dimensional Perovskite nanostructures as they not only possess interesting electronic properties but also allow us to take various experimental routes to investigate or even engineer the properties. We are also interested in bridging the gap between the fundamental researches and real-life applications.



Electron-beam writer

More details can be found at https://www.physics.hku.hk/~dkkilab/

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.

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;

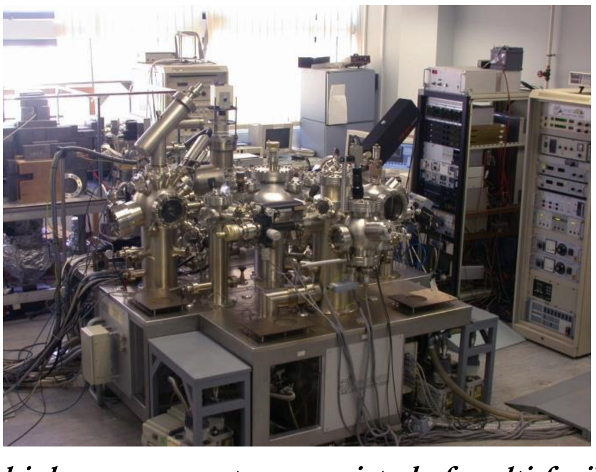
(2) Electrical and optical properties of semiconductor system: deep level transient spectroscopy, temperature dependent Hall measurement, IV and CV measurements, luminescence spectroscopy;

(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, Helmoltz 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, Helmoltz 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 hetero-structures. We use molecular-beam epitaxy (MBE), one of the most versatile techniques to grow materials with precise control, to fabricate new quantum materials and artificial structures with single atomic layer precision. We characterize the structural and electronic properties by surface tools such as scanning tunneling microscopy and spectroscopy (STM/S) and ultraviolet photoelectron spectroscopy (UPS).



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

2. Theoretical and Computational Condensed Matter

The current research interests include:

(1) strongly correlated electron systems (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);

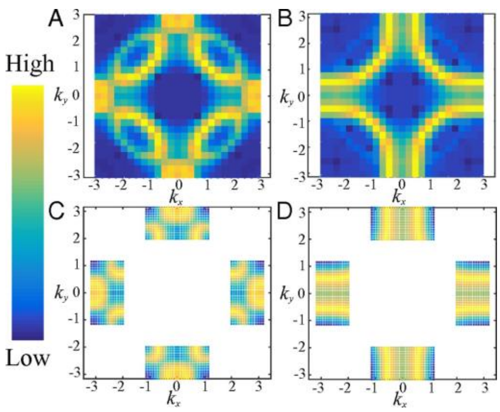
(9) interdisciplinary study of cold atom physics and condensed matter physics (S.Z.Zhang, G.Chen)

(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, 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.

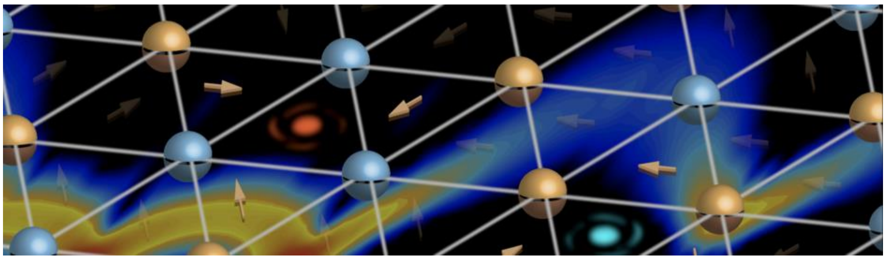
The fundamental questions, such as the paradigm beyond Landau's Fermi liquid that would eventually describe the ubiquitous observations of non-Fermi-liqud in correlated electron systems such as high temperature superconductors, 2D material and graphene heterostructures; and the paradigm beyond the Landau-Ginzburg-Wilson of phases and phase transitions, where the fractionalization and topological classifications will play the dominate role, are within the research scope of our group members. And many of them have already contributed constructively in the establishments of these new paradigms of quantum matter. For example, group members have made "Break through in understanding quantum metals", where quantum critical metallic states and signatures of non-Fermi-liquid has been concretely revealed, https://www.hku.hk/research/stories/20645/



Quantum critical metal obtained from large-scale Monte Carlo simulations

And group member have teamed with researchers from mainland China and employed quantum many-body simulations, performed on the world's fastest supercomputers (Tianhe-I and Tianhe-III protype at National Supercomputer Center in Tianjin and Tianhe-II at National

Supercomputer Center in Guangzhou), to achieve accurate model calculations for a new type of rare-earth magnet, and made predictions of the precise parameter ranges where novel topological physics can be detected in the quantum magnet, https://www.scifac.hku.hk/news/quantum-materials



Spin texture and vortex in quantum magnet TMGO when the material is inside the topological KT phase

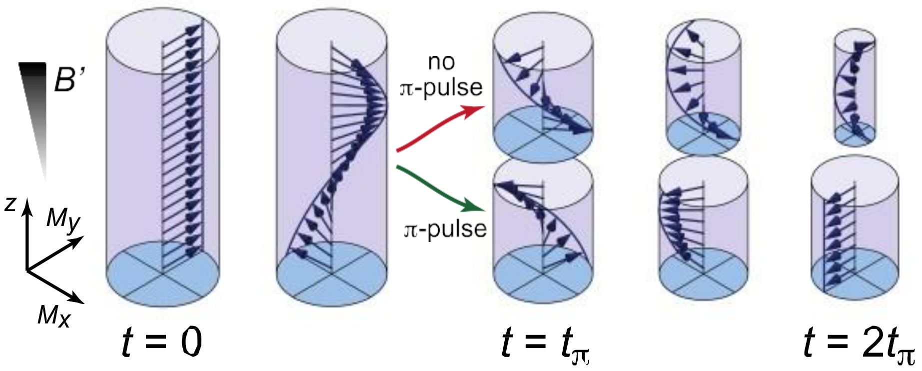
Last but not least, the new paradigm of quantum matter research with the emergent features of correlated electronic systems are inherently nonperturbative, and large-scale quantum many-body numerical simulations assisted with field theoretical analysis are becoming the most prominent and indispensable 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 our own intermediate size of high-performance computing facility, we hope to boost related developments into quantum material research.

Dr. 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, synthetic gauge fields and spin-orbit couplings in atomic gases, novel mixtures of bosons and fermions.



Transverse spin dynamics in a magnetic gradient field with or without π pulse

<u>Facilities</u>

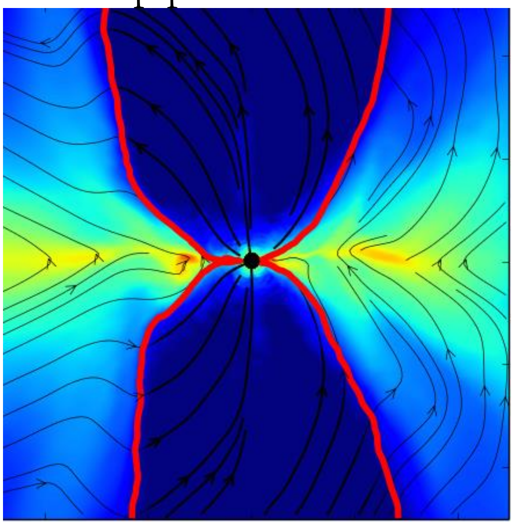
A summary of the major facilities include Multi-chamber UHV system consisted of MBE, STM, UPS, and LEED facilities, low-temperature (4K) STM, Pulsed laser deposition system, RF sputtering system and electron beam evaporators, micro-optics system for photoluminescence and Raman spectroscopy and pump-probe 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 is a theoretical astrophysicist working on high-energy processes and relativistic physics close to black holes. She works toward understanding how black hole consumes matter and produces radiation, wind and jet. She also studies tidal disruption events, which allows us to probe the environment and stars in the innermost core of galaxies as well as extreme black hole accretion physics. Besides employing theoretical calculations, she develops novel computational tools and techniques, such as general relativistic magnetodynamic (GRMHD) simulations, general relativistic ray-tracing (GRRT) simulations, and X-ray reflection and reverberation, in order to help push forward the understanding.



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

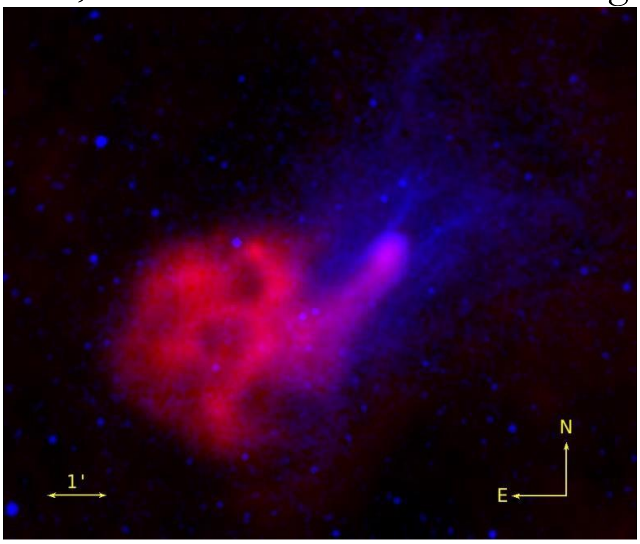
Dr. Lee is a planetary dynamicist who works on the formation and dynamical evolution of planetary bodies (planets, moons, etc.) in our Solar System and in planetary systems around other stars. He is also an expert in numerical methods for dynamical simulations of planetary systems. His current research 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.

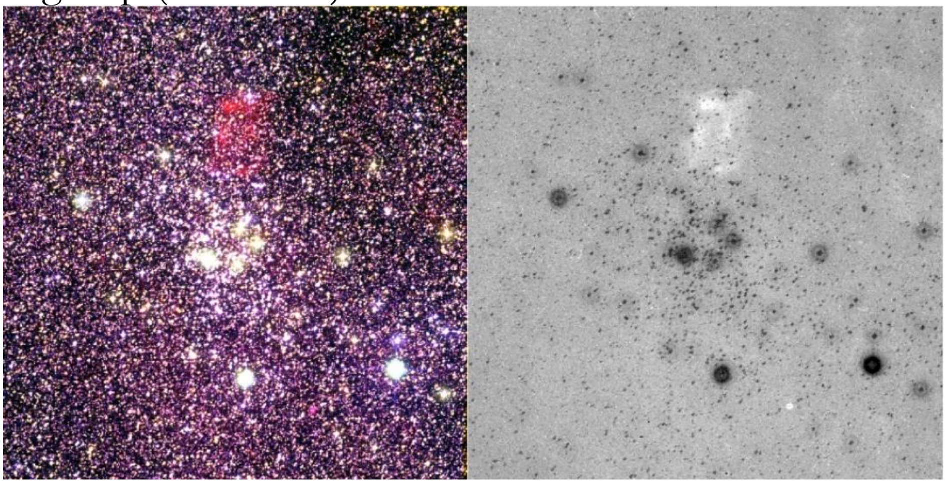
Dr. Ng's latest research focuses on the magnetic fields of neutron stars and their environments. Employing X-ray observations, he measures the surface temperature of magnetars, which are stars with the strongest magnetic fields in the Universe, to understand their extreme properties and their connection 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.



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

Further information can be found at the webpage https://www.astro.physics.hku.hk/~ncy/.

Prof. Q.A. Parker has played an important role in space research at HKU that is increasingly active across space and planetary sciences in the Mainland and globally that includes a joint science leadership of the Lobster Eye X-ray satellite launched in July 2020 (https://www.hku.hk/press/news_detail_21360.html). He has also established a world-leading group in late-stage stellar evolution and has set up the HASH research platform (hashpn.space). His group is assisted by the on-going appointment of Prof. Albert Zijlstra as a Hung Hing Ying HKU Distinguished visiting professor (a world leader in planetary nebula research at Manchester University, UK), the appointment of several postdoctoral research fellows and 4 current PhD students. Significant contributions to this research field have been made by this strong team including two recent HKU press releases for nature astronomy (see: https://www.hku.hk/press/news_detail_19632.html and https://www.hku.hk/press/press-releases/detail/18237.html. Exciting research opportunities exist for additional research postgraduate students to join the group (see below).



30 x 30 arcminute images of NGC6067 & BMP1613-5406. North-East is top left. Left: BRHa tri-colour RGB image (extracted from the online UK Schmidt Telescope SuperCOSMOS Ha Survey Ha, short-Red (SR) and broad-band 'B' images); Right: continuum-subtracted (Ha-SR) image. The PN BMP1613-5406 is identified between the red lines in the continuum subtracted image.

Facilities

Our on-campus facilities in observational astrophysics include a 40 cm diameter reflector telescope located on the top of the CYM physics building equipped with a charged couple device (CCD) imager and spectrometer, and a 2.3 m diameter small radio telescope. These are all used for teaching, training and outreach. For professional observational astrophysics research we regularly win access to a wide range of cutting-edge international telescopes via competitive peer review. These include ground based facilities such as the Gemini 8-metre Telescopes in Chile and Hawaii, the 8-metre telescopes of the European Southern Observatory in Chile, telescopes of the Beijing Astronomical Observatories and South African and Australian facilities. We also win access to space based facilities like the Hubble Space Telescope and Chandra X-Ray Observatory and data from the Fermi Gamma ray telescope. The quality of our projects and proposals leads to success in gaining frequent access on such facilities. We have also built MoUs with key strategic university partners in the Mainland such as the Kavli Institute for Astronomy and Astrophysics at Peking University, the Space and Astronomy group at Nanjing University and the microsatellites research group at Zhejiang University. Recently we have also become an associate member of the East Asian Observatory with guaranteed access to observing facilities such as the JCMT in Hawaii. These links also provide enhanced opportunities for our students in elite mainland research groups.

Quantum Information Science group:

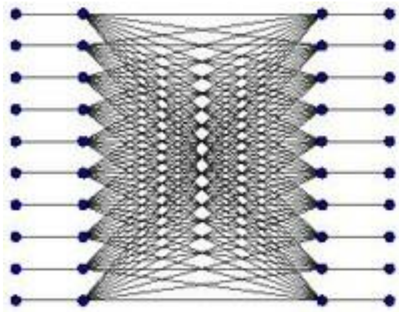
Quantum information science is the study of information processing using the laws of quantum mechanics, rather than classical physics. Quantum information processing promises to revolutionize information processing as we know it today. On one hand, quantum computing offers an exponential speed-up to 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.

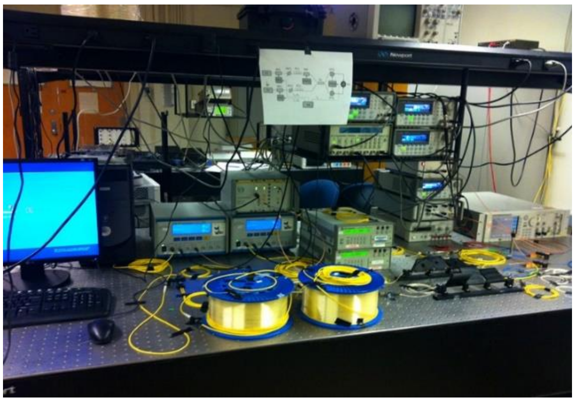
Traditionally, the quantum information science group has been strong on the theoretical side. Recently, we are expanding on the experimental side too. With the hiring of Prof. Hoi-Kwong Lo, our new Research Division Director (RDD) and Chair Professor, and a number of future hires under planning, we will be setting up an Institute of Quantum Science over the next few years.

Academic staff:	***Prof. H.F. Chau***
	Prof. G. Chiribella (by courtesy)
	Prof. H.K. Lo
	Dr. W.Y. Wang
	Prof. Z.D. Wang* (cross-listing from condensed matter physics group)
	Dr. S. Z. Zhang* (cross-listing from condensed matter physics group)

"Twin-field" quantum key distribution



All photonics quantum repeaters graph states



Prof. Hoi-Kwong Lo's lab

IBM super-conducting quantum processors

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

Prof. Giulio Chiribella is a By-Courtesy Professor in Physics and a Professor in Computer Science. He works on quantum information theory and on the foundations of quantum mechanics. He is interested in the design of new communication protocols powered by quantum resources, and in the study of the ultimate quantum limits to information processing, including precision limits for quantum measurement devices and efficiency limits for quantum computers. In quantum foundations, he investigates the interplay between the protocols of quantum information and the fundamental notions of space, time, and causal structure.

Prof. 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 metameterials – Chair Prof. S. Zhang) and light (Dr. T.T.Luu).

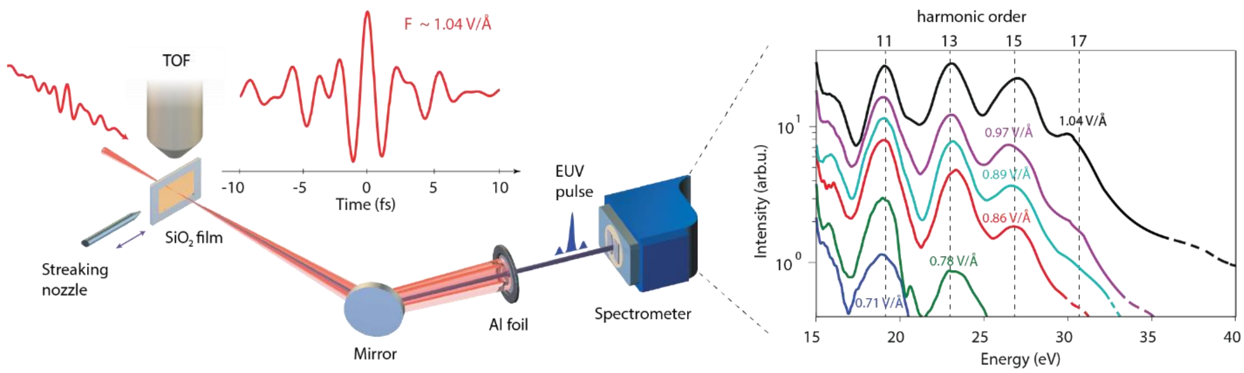
The Optics and Photonics Group is closely connected to the Quantum Information Science Group, where we can find world-class research groups on Quantum Computing and Information Theory (Chair Prof. Z.D.Wang and Prof. H.F.Chau) and Theoretical Atomic Physics and Degenerate Quantum Gases (Dr. S.Z.Zhang). Importantly, the research group of Research Division Director, 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 Pearl River Delta region; 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

Prof. S.J. Xu
Prof. S. Zhang

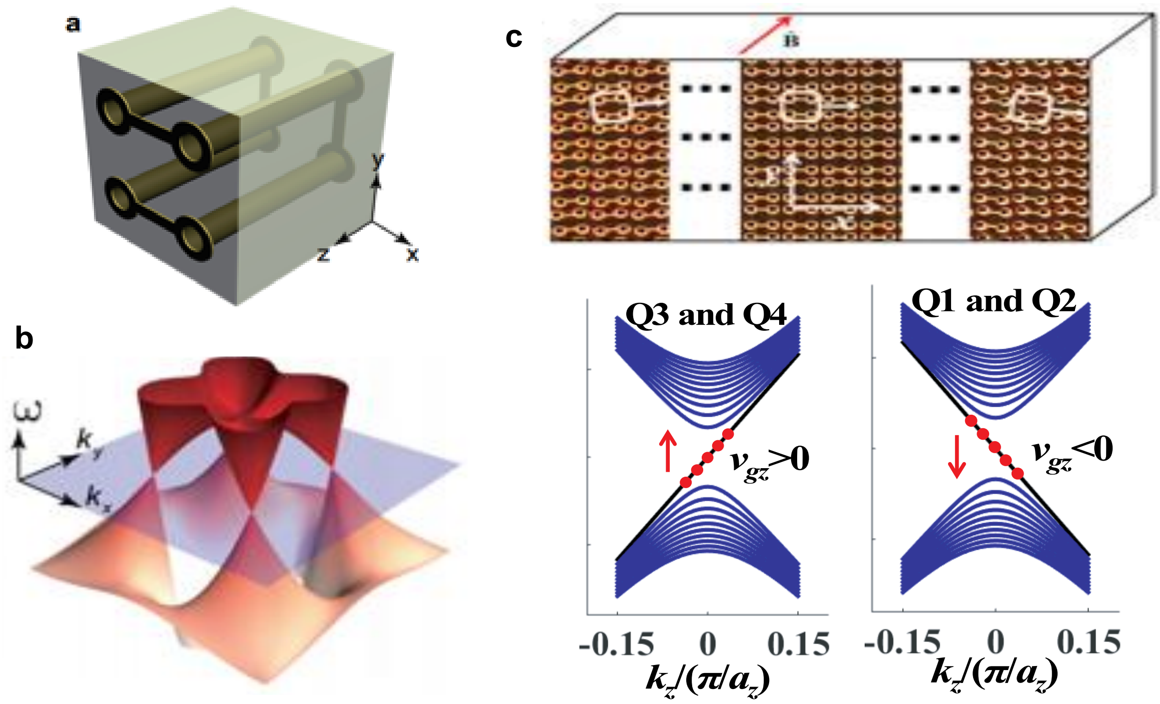
Dr. Luu's research focuses on studying light-matter interaction using manipulation of light. By creating light pulses that are extremely fast, i.e. as fast as hundreds of atto-second (1as = 10-18 s) that reside either in extreme ultraviolet or optical domain, we can study electronic process in their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



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

Prof. Xu is currently a professor with tenure in Department of Physics, The University of Hong Kong. He received his PhD degree in Electronic Engineering from Xi'an Jiaotong University in 1993. Prior to joining HKU, he was employed as research fellow by Institute of Materials Research and Engineering (IMRE), Singapore, and NSTB postdoctoral fellow by National University of Singapore earlier. SJ Xu has authored >170 peer-reviewed articles and letters with >6500 citations (Google Scholar). Under his supervision, 11 PhD and 12 MPhil postgraduate students have successfully obtained their respective degrees so far (i.e., Aug. 2020). SJ Xu's current research interests include luminescence and related phenomena, such as many-body effects and quantum interference in luminescence of wide bandgap semiconductors and nanostructures.

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:

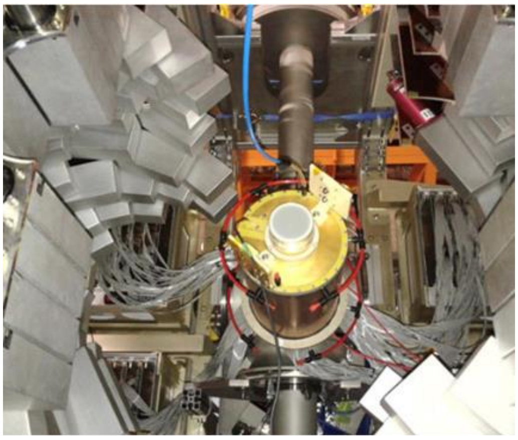
The group is established as part of the Joint Consortium for Fundamental Physics by three universities in Hong Kong – HKU, CUHK and HKUST, through which we participate in international collaborations on big science.

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

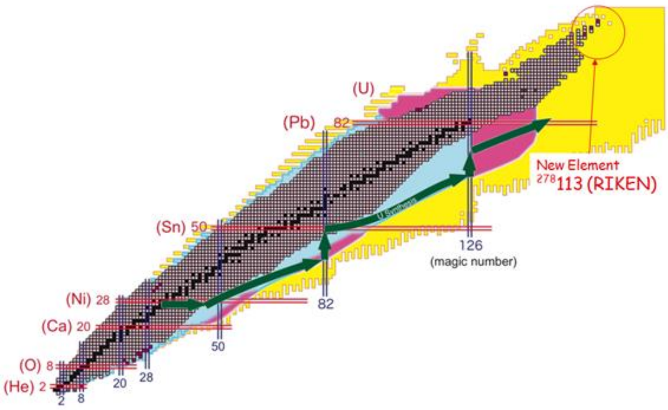
Dr. Lee is a leader of the experimental nuclear physics sub-group. Nuclear physics aims at understanding the structure of atomic nuclei and the nature of fundamental forces, addressing a big science question on how the heavy elements from Iron were synthesized in the universe which is governed by the 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

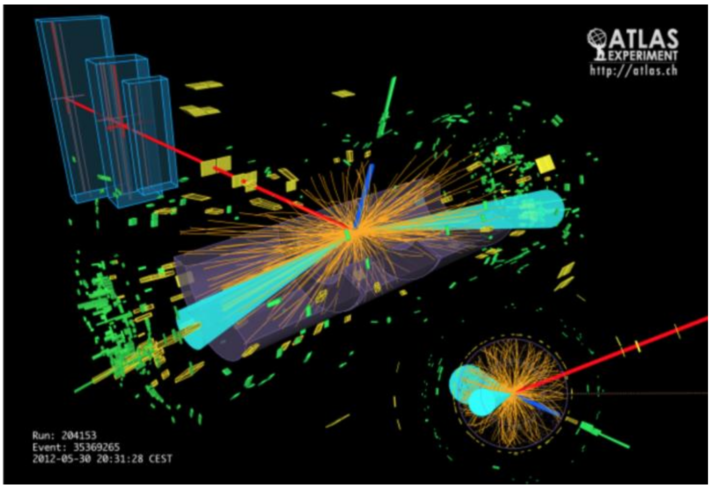


Nuclear Chat. The horizontal and vertical axes represent N and Z, respectively

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, Dr. 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

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.

In the year of 2019/2020, the joint institute has held the following activities related to the computational and theoretical physics:

i) "Beijing Summer School on Quantum Magnetism"
This is a joint activity between HKU, UCAS, IOPCAS and Fudan University, from July-August 2019. The three weeks summer school offered a curriculum encompassing the modern aspects of quantum magnetism in a coherent manner, ranging from experiment techniques (neutron scattering, crystal growth, etc), analytical methods (spin waves, field theory, etc) to numerical simulation and data analysis (quantum Monte Carlo, Tensor network renormalizaiton, etc). The summer school was highly visible and successful. The total number of the participants was around 150, including undergraduates, graduates, postdocs and junior researchers from a number of leading universities in Mainland China (Peking University, Tsinghua University, Fudan University for example), and from Hong Kong (HKU, HKUST, CUHK) and Taiwan.

ii) "Hong Kong Computational Physics Study Group"
This is a bi-weekly activity throughout Sept-Dec 2019. The purpose of that course was to promote the computational oriented research in HKU and in the area. Over 50 people including undergraduates, graduates and postdocs from HKU, HKUST, CUHK, SUSTECH and UCAS have participated in the Study Group. The topics cover exact diagonalization, quantum Monte Carlo, density matrix RG, tensor network RG, neural network and artificial intelligence. The purpose of this study group is to encourage the interaction and collaboration on the modern computational physics researches in Hong Kong area. The Study Group invited active researchers working in the frontier of these fields, and taught (including himself) two lectures (about 3 hours per time) during the week and one hands-on tutorial (about 3 hours per time) during the weekend. The

Study Group created an encouraging environment for the interactions and collaborations between the lecturers and participants.

iii) "Hong Kong Forum on the next generation of scientific computing and neuromorphic AI accelerator"
(cancelled due to the COVID-19)
This forum will involve the Faculty of Science, Faculty of Engineering, Institute of Mind and ITS in HKU. The forum is a continuation of the Hong Kong Forum hold annually at the center, and the purpose of it is to enhance the visibility of the scientific computing and AI research in HKU with special focus on their applications and inspirations on condensed matter physics and quantum material research, on the global stage.

In the year of 2020/2021, the joint institute has planned to hold the following activities related to the computational and theoretical physics. However, due to the COVID-19, these activities are rescheduled to the year of 2021/2022, depending on further development of the COVID situation.

i) "Hong Kong Computational Physics Study Group"
Due to the success of the Study Group in previous year, the center plans to continue with such new form of educational and exchange of frontier computational and theoretical condensed matter physics. The content will be more adjusted to the actual level of students in the Hong Kong area and at the same time attract more participants in the entire Southern China.

ii) "Condensed-matter Dirac/Yukawa systems: theory, numerics and experiments"
(subject to possible cancellation due to COVID)
This is an international program organized together with South Bay Interdisciplinary Science Center (https://sbisc.sslab.org.cn) at the Songshan Lake Material Laboratory (SLAB, https://www.sslab.org.cn), planned to hold in Sep. 2021 for three weeks. It will bring more than 50 leading physicists from condensed-matter and high-energy physics, to discuss the recent simultaneous progress in several sub-disciplines of physics in correlated Dirac fermions, for example, in layered graphene

heterostructures and other 2D materials as well as Gross-Neveu-Yukawa type of phases in high-energy physics. The program is intended to bring together physicists from different backgrounds including field theory, renormalization group, conformal bootstrap, quantum Monte Carlo, Tensor-network, etc, as well as experiments to further strengthen interdisciplinary collaborations, and to inspire new ideas and collaborations in the fast developing field of condensed-matter Dirac/Yukawa systems.

iii) "Workshop on precise quantum material computation"
Recently there are fast developments in combining numerical techniques such as tensor network, quantum Monte Carlo and first-principle computation and field theoretical analysis, to provide the controlled modelling and computation of the precise properties of correlated quantum material (quantum magnets, Moire materials such as twisted graphene and TMD, etc). The center members are among the key players of this international trend. We plan to organize a one-week workshop on this area, mostly like in collaboration with Chinese Academy and Fudan University, to further boost the relevant developments.

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. Applications are being called for year 2021.

2022/2023 POSTGRADUATE PROJECTS
DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG

The following M.Phil./Ph.D. projects are available in 2022/2023 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: Dr. 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: Dr. 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: Dr. 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 an 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 = S2σT/ϰ, where S=-ΔV/ΔT 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 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: Numerical investigations in the zoo of correlated topological state of matter

Supervisor: Dr. Z.Y. Meng

In this project, we will make use of large-scale quantum Monte Carlo simulations and theoretical analysis to study interacting electron systems and 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)]; to discover quantum spin liquids, representatives of topological ordered states, with our large-scale quantum Monte Carlo simulations on frustrated spin systems [such as in Phys. Rev. Lett. 121, 057202 (2018)]; and to discover the manifestation of the symmetry fractionalization and emergent gauge structures in these topological ordered phases [such as in Phys. Rev. Lett. 121, 077201 (2018), Phys. Rev. Lett. 120.167202 (2018)].

Project ZYM02: Dynamical signatures in frustrated systems and quantum magnetism

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)]. A particular interesting point is that we could calculate the magnetic spectra of frustrated magnetic systems to reveal the existing of the topological order and fractionalized excitations, 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)]. Moreover, the new types of quantum phase transitions, that are beyond the Landau-Ginzburg-Wilson paradigm of phase and matter, can be also investigated in large-scale quantum Monte Carlo simulations. 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]. We will continue our pursuit along this line to build the new paradigm of quantum phase transitions.

Project ZYM03: 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 ZYM04: Thermodynamics and dynamics in quantum magnets

Supervisor: Dr. Z.Y. Meng

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. 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.

Project ZYM05: 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 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-torrent 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

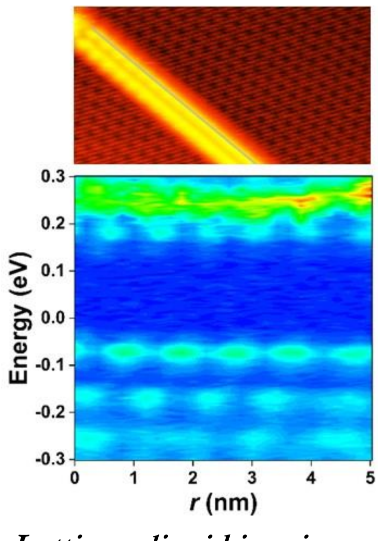
Supervisor: Prof. Z.D. Wang

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 and moiré superlattices

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: Spin dynamics in ultracold atomic gases
Supervisor: Dr. S.Z. Zhang

Recent experimental advances in the manipulation of ultra-cold alkali atomic gases have made it possible to engineer synthetic gauge fields and spin-orbit interaction for neutral atoms. Together with the possibility of modifying the inter-atomic interactions using Feshbach resonance, this has led to multitude of possibilities in the investigations of interacting quantum many-body systems. It has been suggested that the new system might support exotic excitations like Majorana fermions or exhibit high transition temperature into the superfluid state. In this project, we will investigate a few aspects of the system, including its novel spin resonance and spin diffusion behavior, which is also likely to shed light on the analogous problems in solid state physics.

Project SZZ02: 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.

Astrophysics group:

Project LXD01: Simulations of Black Hole Accretion Disks and Jets

Supervisor: Dr. L.X. Dai

Black hole accretion is the central engine that powers the most luminous sources in the universe, such as quasars and X-ray binaries. Besides radiation, winds and jets are also produced in black hole accretion. The feedback carried by radiation, winds and jets can provide feedback to the hosting galaxy and influence its formation and evolution. Besides powering persistent sources, black hole accretion can also power transient flares such as tidal disruption events and gamma-ray bursts (including the ones produced in neutron star mergers). We study the physics of black hole accretion and emission using general relativistic numerical codes. In particular, we are very interested in studying a class of accretion called super-Eddington accretion, which is believed to happen in high-redshit quasars, tidal disruption events and ultra-luminous X-ray sources. This class of accretion is under-investigated, yet it is important for understanding the formation of massive black holes and galaxies in the early universe. A lot of progress has been obtained lately on the observational front, and theoretical studies are much needed to complement the fast progress in observations. MPhil/PhD projects on this topic include: 1) design and perform new general relativistic simulations of (super-Eddington) accretion flow; 2) analyze previous simulation data and carry out radiative transfer analysis; 3) comparing data to observations (if the student is also interested in working on / is familiar with observations).

Project LXD02: Theory and Simulations Related to Tidal Disruption Events

Supervisor: Dr. L.X. Dai

Stars in the very center of a galaxy can be occasionally scattered to approach the central supermassive black hole very closely and therefore torn apart by the tidal force. As stellar materials collide and accrete onto the black hole, bright flares are produced outshining the whole galaxy. So far a few dozen of such tidal disruption events have been observed in X-ray, optical, UV, radio and mm wavebands, which have already greatly taught us about how black holes launch relativistic jets and fast winds, how extreme black hole accretion happens, etc. In the next decade, many time-domain instruments will be built / launched in order to catch transients like tidal disruption events, which will allow us to probe the demographics of supermassive black holes and do a lot of other interesting physics. MPhil/PhD projects on this topic include: 1) simulate the accretion disks and jets formed in tidal disruption events; 2) compute their light curves and spectra; 3) calculate the rates of different classes of tidal disruption events (e.g., optical, X-ray, jetted events).

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 reslensing 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 clusterswhere 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.

Project QAP01: Late Stage Stellar Evolution
All the projects described below fall under the main topic of Late stage stellar evolution and exploitation of "The new Hong-Kong/AAO/Strasbourg multi-wavelength and spectroscopic Planetary Nebulae database: HASH (see website haspn.space)"
Supervisor(s) for all projects include:
Prof. Q.A. Parker, Prof. A.Zijlstra (Hung Hing Ying distinguished visiting professor), Dr. Andreas Ritter, Dr. Snehalatu Sahu

Some scientific background to the projects listed below
Stars, the key building blocks of all galaxies, are born in collapsing gas clouds, live their lives as nuclear fusion reactors, and eventually die. Massive stars live fast and die young, exploding as supernovae after only a few million years. However, the vast majority of stars have lower mass and may live for billions of years. PNe derive from stars in the range ~1-8 times the mass of the Sun, representing 90% of all stars moremassive than the sun. PNe form when only a tiny fraction of unburnt hydrogen remains in the core. Radiation pressure expels much of this and the hot stellar core can shine through. In a few thousand years the effective temperature rises from ~5000 degrees to as high as 250,000 degrees before falling as the core fades and contracts to a so-called White-Dwarf (WD). The radiation field ionizes the final ejected shell which is called a PN as well as the faint halo of material ejected at earlier times, providing

a visible fossil record of the entire mass loss process. PNe have nothing to do with planets but acquired this name because the glowing spheres of ionized gas around their hot central stars resembled planets to early observers.

The study of PNe is crucial to understand both late stage stellar evolution, and the chemical evolution of our entire Galaxy. The ionized shell exhibits strong and numerous emission lines that are excellent laboratories for plasma physics. PNe are also visible to great distances where their strong lines permit determination of the size, expansion velocity and age of the PN, so probing the physics and timescales of stellar mass loss. We can also use them to derive luminosity, temperature and mass of their central stars, and the chemical composition of the ejected gas. Their radial velocities can trace a galaxy's kinematic properties and test whether the galaxy contains a substantial amount of dark matter. The kinematic properties of PNe in galaxy halos also give strong constraints both on the mass distributions and formation processes of giant elliptical galaxies. The PN formation rate also gives the death rate of lower mass stars born billions of years ago and they directly probe Galactic stellar and chemical. Their complex shapes provide clues to their formation, evolution, mass-loss processes, and the shaping role that may be played by magnetic fields, binary central stars or even massive planets. As the central star fades to a WD and the nebula expands, the integrated flux, surface brightness and radius change in ways that can be predicted by current hydrodynamic theory.

PNe are thus powerful astrophysical tools, providing a unique window into the soul of late stage stellar evolution. We are also in a golden age of PN discovery and Prof Parker and his team have lead programs that have more than doubled the totals accumulated by all telescopes over the previous 250 years. The scope of any future large-scale PNe studies, particularly those of a statistical nature or undertaken to understand true PNe diversity and evolution should now reflect this fresh PN population landscape of the combined sample of ~3600 Galactic PNe now available. Such studies should take into account these recent major discoveries and the massive, high sensitivity, high resolution, multi-wavelength imaging surveys now available across much of the electromagnetic spectrum. Following this motivation we provide, for the first time, an accessible, reliable, on-line "one-stop" SQL database for essential, up-to date information for all known Galactic PN. All the projects below will make use of and build on this world-leading new resource.

Project QAP01(a): PNe AGB Haloes and the Ejected Mass Budget

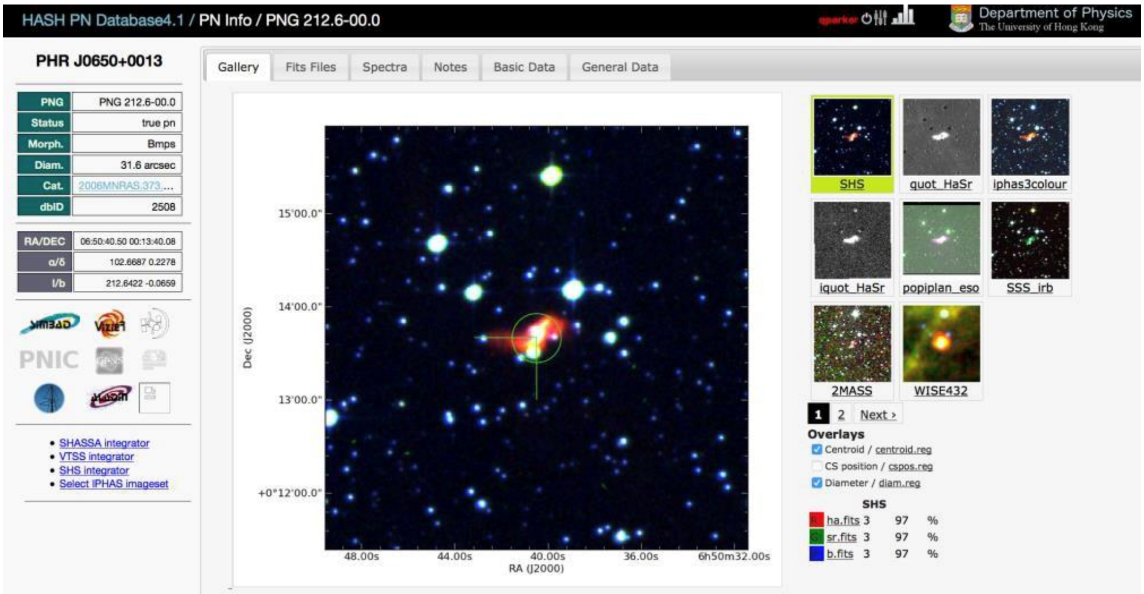
The main shells of PNe typically contain only ~0.1 Msun in ejected material while the residual core – on the way to becoming a white dwarf are only ~0.6Msun. However, the progenitor star may have had a mass of between one and up to 8 solar massess. The "missing mass" has been lost on the AGB and particularly post AGB and pre PNe phases of evolution. At least part of this is detectable in terms of so called AGB haloes. These can be extensive but of a surface brightness that could be 1/1000 times weaker than the main PN shell. Detailed study of such haloes especially in terms of abundances is currently lacking as is a proper understanding of where are the previously ejects mass is to be found.

Project QAP01(b): Morpho-kinematic modelling of PNe

The advent of powerful integral field units (IFU) on major telescopes to perform areal point-to-point spectroscopy of resolved objects has enabled detailed 3-D data-cubes to be obtained. This has enabled both kinematic and line intensity maps to be produced for significant numbers of PNe for the first time. These data can be combined with morpho-kinematic modelling with sophisticated visualisation software such as SHAPE to permit the de-projection of 2-D PNe images into more accurate 3-D representations as matched and informed by the kinematic data available from the IFU data-cubes. More accurate determinations of true PNe morphologies can be obtained particularly for bi-polar PNe where the major axis might otherwise be poorly constrained and provide insights into connections between CSPN properties, nebular characteristics binarity and morphology.

Project QAP01(c): Abundances of Planetary Nebulae, Galactic Gradients and the Local Group

Obtaining accurate abundances for PNe is a difficult enterprise. Very high S/N spectra are required for large numbers of faint emission lines in order to provide sufficient species to allow proper abundance estimates. So far only ~150 PNe have well determined abundances from a total population of over 3200 Galactic PNe. Most of these are also for the highest surface brightness PNe as these are the easiest to observe but they may not be representative of the underlying abundance patterns of most PNe. This project will attempt to improve this situation in terms of both available abundances and breadth of PNe sample selection. Results will be used to improve our understanding of nebula abundance variations as a function of PNe CSPN properties (mass and likely progenitor mass), environment and other variables.



A single page from the HASH database of Planetary Nebulae – a powerful resource available to all these projects

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 HKL01: Quantum Information and Quantum Communication Theory

Supervisor: Prof. H.K. Lo

We are in the midst of the Second Quantum Revolution. Quantum mechanics can revolutionize information processing by performing tasks that are difficult or impossible in conventional information theory. For instance, quantum computer can break standard encryption schemes such as RSA. Quantum cryptography can lead to unbreakable codes. Quantum internet enables distributed quantum information processing including blind quantum computing in the cloud. We will study the power and limitation of quantum communication and information. Our work ranges from the foundations of quantum information theory, the foundations of security, and the proposal of quantum repeaters to the design of practical protocols, their simulations and experimental implementations. This project will be on the theoretical side.

The applicant may work either independently or work closely with the experimental group. The experimental group will leverage our generous start-up funding to build the first quantum communication lab in Hong Kong. Our goal is to bring the success of the professor's research from the U. of Toronto to Hong Kong.
See https://www.scifac.hku.hk/people/lo-hoi-kwong
See also https://spectrum.ieee.org/quantum-repeater-trial-ignites-hopes-for-longdistance-quantum-cryptography-and-computation

A strong academic background in physics (or a closely related subject such as theoretical computer science) will be beneficial.

Project HKL02: Experimental Quantum Communication and Quantum Internet

Supervisor: Prof. H.K. Lo

We are in the midst of the Second Quantum Revolution. Quantum mechanics can revolutionize information processing by performing tasks that are difficult or impossible in conventional information theory. For instance, quantum computer can break standard encryption schemes such as RSA. Quantum cryptography can lead to unbreakable codes. Quantum internet enables distributed quantum information processing including blind quantum computing in the cloud. We will study the power and limitation of quantum communication and information. Our work ranges from the foundations of quantum information theory, the foundations of security, and the proposal of quantum repeaters to the design of practical protocols, their simulations and experimental implementations. This project will be on the experimental side.

The applicant will play a key role in our experimental efforts with the help of postdocs/research assistant professor. We will leverage our generous start-up funding to build the first quantum communication lab in Hong Kong. Our goal is to bring the success of the professor's research from the U. of Toronto to Hong Kong.
See https://www.scifac.hku.hk/people/lo-hoi-kwong
See also https://spectrum.ieee.org/quantum-repeater-trial-ignites-hopes-for-longdistance-quantum-cryptography-and-computation

A strong academic background and a strong interest in doing hands-on research in experimental optics will be useful.

Project HKL03: Quantum Communication and Quantum Internet (Theory or Simulation or Experiment)

Supervisor: Prof. H.K. Lo

We are in the midst of the Second Quantum Revolution. Quantum mechanics can revolutionize information processing by performing tasks that are difficult or impossible in conventional information theory. For instance, quantum computer can break standard encryption schemes such as RSA. Quantum cryptography can lead to unbreakable codes. Quantum internet enables distributed quantum information processing including blind quantum computing in the cloud. We will study the power and limitation of quantum communication and information. Our work ranges from the foundations of quantum information theory, the foundations of security, and the proposal of quantum repeaters to the design of practical protocols, their simulations and experimental implementations. This project will be on the phenomenological side.

Depending on the applicant's expertise, he/she/they can work on either theory or simulation or experiment. We will leverage our generous start-up funding to build the first quantum communication lab in Hong Kong. Our goal is to bring the success of the professor's research from the U. of Toronto to Hong Kong.
See https://www.scifac.hku.hk/people/lo-hoi-kwong
See also https://spectrum.ieee.org/quantum-repeater-trial-ignites-hopes-for-longdistance-quantum-cryptography-and-computation

A strong academic background in physics or a closely related subject will be beneficial.

Project ZDW01: Quantum Computation

Supervisor: Prof. Z.D. Wang

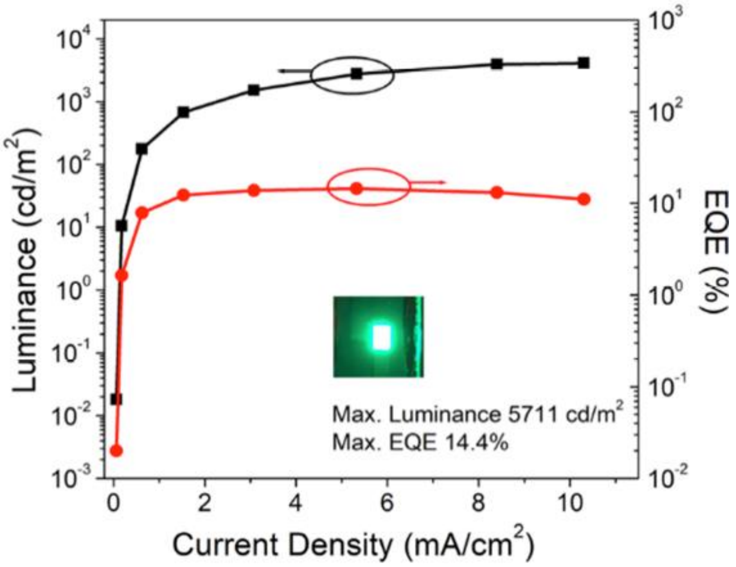
Quantum computers, based on principles of quantum mechanics, could efficiently solve certain significant problems which are intractable for classical computers. For the past several years, they have become a hot topic across a number of disciplines and attracted significant interests both theoretically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

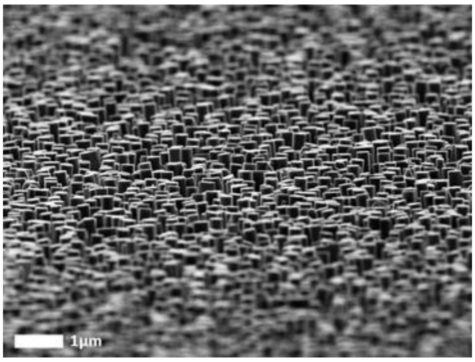
Supervisor: Prof. A.B. Djurišić

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, NiOx) 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. Luu

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 SJX01: Many-body luminescence in GaN-based quantum structures and novel luminescent phosphors

Supervisor: Prof. S.J. Xu

In the project, the roles of many-body interactions among quasi-particles, such as exciton, phonon, photon etc., in luminescence of GaN-based quantum structures and novel luminescent solid will be both experimentally and theoretically. We attempt to obtain some state-of-the-art knowledge and understanding of the many-body luminescence in these functional nitride nanostructures and solids.

Project SJX02: Optics and quantum devices of color centers in diamond

Supervisor: Prof. S.J. Xu

Some color centers such as nitrogen vacancy (NV) composite defect center in diamond have been recognized as the almost ideal building block or qubit for quantum computer. We thus investigate the optics, especially quantum optics of color centers in diamond. Besides the fundamental optics investigation, qubit devices and ultrasensitive sensor based on color centers in diamond will be exploited.

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 inhomogenous 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 Z or Z2 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, quarternion 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~100 N~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 in 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 subfields 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 basic astrophysical modeling 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: 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 select topics in condensed matter physics.

Course Contents & Topics:
The course will cover 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:
The course will cover the following topics: 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 will introduce and discuss the following topics: Boundary-value problems in electrostatics and Green 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 intends to introduce some advanced topics in the field of equilibrium statistical physics.

Course Contents & Topics:
Ensemble theory: the micro-canonical ensemble, the canonical ensemble, and the grand canonical ensemble. Quantum mechanical

ensemble theory. Theory of simple gases, ideal Bose systems, ideal Fermi systems. Statistical mechanics of interacting systems. Some topics in the theory of phase transition may be selected.

PHYS8551 Graduate Solid State Physics

Course Objectives:
To provide students with an understanding of more advanced topics in selected areas of solid state physics.

Course Contents & Topics:
Bloch theory. Nearly free electrons and tight binding model. Band structure calculations for realistic systems. The semi-classical model of electron dynamics. Ab initio total energy calculations and other advanced topics.

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. Quantum statistics and inter-particle interaction are important to explain these phenomena. This course aims to introduce the students 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. The emphasis will be on a few selected examples that illustrate the above concepts and techniques. The course is intended for both experimentalists and theorists.

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:
To introduce students to the field of general relativity. To provide conceptual skills and analytical tools necessary for astrophysical and cosmological applications of the theory.

Course Contents & Topics:
The Principle of equivalence. Inertial observers in a curved space-time. Vectors and tensors. Parallel transport and covariant differentiation. The Riemann tensor. The matter tensor. The Einstein gravitational field equations. The Schwarzschild solution. Black holes. Gravitational waves detected by LIGO.

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
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

9. Electron and X-Ray Diffraction
10. Photoemission Spectroscopy
11. Scanning Electron Microscopy, Transmission Electron Microscopy
12. Radiation Detection and Measurements in Nuclear Physic

PHYS8750 Nanophysics

Course Objectives:
This course is designed to let fresh postgraduate students know fundamental concepts and principles of nano physics, such as two-dimensional electron gas, quantum Hall effects, one-dimensional electron system, quantum wires and nanotubes, zero-dimensional electron systems, single electron effects and quantum dots.

Course Contents & Topics:
Introduction to nano physics and quantum size effect. Dimensionalities and density of states. Optical and transport properties of two-dimensional electron gas formed at heterostructures and within novel graphene monolayers with external fields. Quantum Hall Effects. Physics of one-dimensional electron systems including carbon nanotubes and semiconductor nanowires.
Fundamental physics of zero-dimensional electron systems. Single electron effects. Quantum dots and nanocrystals. Fundamental principles and applications of scanning tunneling microscopy in the study of nano physics. If time permits, the making and application aspects of nanomaterials 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 manipulaton of light propagation using structured photonic media - metamaterials, with negative refraction, super-imaging and invisibility cloaking as the most wellknown examples. These new discoveries are paving ways towards many potential applications of photonic structures, including imaging, sensing 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:

This course will begin with the interaction of light with metals, covering both propagating and localized surface plasmon polaritons. It will then provide effective-medium description of the unconventional electromagnetic properties of metamaterials, such as negative permeability and negative refraction, chirality and bi-anisotropy. It will then provide some detailed discussion on how to design the unit cells of the metamaterials based on plasmonic structures for achieving various electromagnetic properties and functionalities. This is followed by descriptions of various metamaterial devices, including superimaging lenses, invisibility cloaks, meta-lenses, metasurface holography etc. The course will next discuss the control of the nonlinear optical properties of metamaterials and metasurfaces. In the final part of this course, the metamaterial approach for designing the topological properties for light will be discussed.

REPRESENTATIVE PUBLICATIONS OF FACULTY MEMBERS

H.F. Chau

"Security of Finite-Key-Length Measurement-Device-Independent Quantum Key Distribution Using an Arbitrary Number of Decoys", H.F. Chau, *Physical Review A*, 102, 012611 (2020)

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

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

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

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

G. Chen

"Pr 2 Ir 2 O 7: when Luttinger semimetal meets Melko-Hertog-Gingras spin ice state", Xuping Yao, Gang Chen, *Phys. Rev. X* 8 (4), 041039 (2018)

"Emergent orbitals in the cluster Mott insulator on a breathing Kagome lattice", Gang Chen, Patrick Lee, *Phys. Rev. B* 97, 035124 (2018)

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

"Quantum paramagnet and frustrated quantum criticality in a spin-one diamond lattice antiferromagnet", Gang Chen, *Phys. Rev. B*, Rapid Communication 96, 020412 (2017)

"Symmetry enriched U (1) topological orders for dipole-octupole doublets on a pyrochlore lattice", Yaodong Li, Gang Chen, *Phys. Rev. B*, Rapid Communication 95, 041106 (2017)

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