DEPARTMENT OF PHYSICS

THE UNIVERSITY OF HONG KONG

Excellence in Teaching and Research

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For general enquiries or correspondence

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September 2019

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WELCOME

Dear Prospective postgraduate student,

I hope you find this booklet useful, both as a valuable reference and as a source of background information to help you during your postgraduate application process. We are justifiably proud of our record of distinguished and innovative research at HKU across a variety of fields in the physical sciences. These include condensed matter physics, materials science, nuclear and particle physics, quantum computing, astronomy and astrophysics. 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.

Good luck!

Prof. M.H. Xie
Head of Department of Physics, HKU
August 2019

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 research in many areas of physics. The department offers both M.Phil. and Ph.D. programs for full-time postgraduate students. Most of our researches are in condensed matter, material physics and in astrophysics. In condensed matter and related fields, our interests include correlated electron systems, topological state of matters, low-dimensional systems, surface physics, material sciences, quantum transport in nanoscale, spin and valley electronics, semiconductor physics and optics. In the field of astrophysics and astronomy, our research covers cosmological models, gamma-ray bursts, interstellar chemistry neutron stars, neutrino physics, planetary nebulae, pulsars, supernovae and their remnants, high-energy astrophysics and related projects associated with our new laboratory for space research (LSR).

- **The Facilities:**

The department houses a number of state-of-art research facilities for multi-disciplinary researches in condensed matter physics and astrophysics.

- **Theoretical Studies**

For theoretical studies, besides the central computing facility of the university, staff and students of the department have at their disposal a 100-CPU Linux computer cluster solely dedicated to research.

- **Community Service and Outreach**

The department is also involved in community service. For example, the radon analysis laboratory provides calibration services to radon and radon progeny monitors. Other specialist consulting and advising is also undertaken from time to time. Outreach is also a key factor in our activities and RPG students are encouraged to think about visiting 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 over the first 4 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.

ACADEMIC STAFF

Head & Professor

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Will join our department from January 2020
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Will join our department from January 2020

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	Dr. X. Fang	Dr. B. Fu
	Dr. X.L. Han	Dr. C. Li
	Dr. F.Z. Liu	Dr. F. Lykou
	Dr. J.A. Maki	Dr. B.B. Mao
	Dr. D. Paredes	Dr. A. Ritter
	Dr. W.Y. Tu	Dr. T.F. Yan
	Dr. W. Zheng	Dr. Z. Zheng
	Dr. B.R. Zhu	

Distinguished Visiting Professors:	Prof. K.B. Luk Prof. X.G. Wen Prof. R.S. Williams Prof. A. Zijlstra
Honorary / Visiting / Visiting Research Professors:	Prof. T. Boardhurst Prof. J. Gao Prof. H. Guo Prof. Z.J. Jiang Prof. A.K.H. Kong Prof. P.K. MacKeown Prof. D.S.Y. Tong Prof. E.G. Wang Prof. F.C. Zhang
Honorary Associate Professors:	Dr. A.M.C. Ng
Adjunct/Honorary Assistant Professors:	Dr. F.K. Chow Dr. P.W. Li Mr. H.W. Tong Mr. W.K. Wong Dr. Y. Zhang

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Technicians	Chan Wai Hung, Ho Wing Kin, Ip Kam Cheong, Lee Chin Ming
IT Technician	Lau Sai Kin
Executive Officer	Anna Wong

Clerks I	Rachel Liu, Michelle Lo, Eva Wong
Clerks II	Navis Lau
Clerical Assistant	Joe Poon
Office Attendant	Ling Wong

RESEARCH GROUPS/
CENTRE HOUSED IN DEPARTMENT OF PHYSICS, HKU

Astronomy and Astrophysics group:

1. 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 charged couple device (CCD) imager and spectrometer, and two 2.3 m diameter Small Radio Telescopes all used for teaching, training and outreach. For professional observational astrophysics research we 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. The quality of our projects and proposals leads to success in gaining such access on a regular basis. We are currently building MoUs with key strategic 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. These links will provide enhanced opportunities for our students in elite mainland research groups.

2. Theoretical Astrophysics

Academic staff: ***Prof. K.S. Cheng***
Dr. L.X. Dai
Dr. M.H. Lee (Dept. Earth Sciences - adjunct with Dept. Physics)

The major research areas are related to neutron stars and pulsars, which are rapidly spinning and magnetized neutron stars, including X-ray and gamma-ray emission mechanisms, stellar structure, stellar cooling and heating mechanisms and the internal activities, e.g. sudden unpinning of superfluid vortices. In addition to topics related to pulsars and neutron stars, we also study topics related to gamma-ray bursts, in particular the central engine problem, and high energy phenomena resulting from the stellar capture processes by supermassive black holes in the galactic center.

Dr. Dai is a high-energy astrophysicist working on topics related to the dynamics and accretion of compact objects. She also employs computer simulations to study the accretion process and jet production around black holes. as well as tidal disruption events, which is a star tidally destroyed and devoured by a supermassive black hole. Her current research interests include: 1) tidal disruption events; 2) accretion and jets around black holes; 3) general relativistic simulations for accretion and ray-tracing; 4) extreme-mass-ratio inspirals.

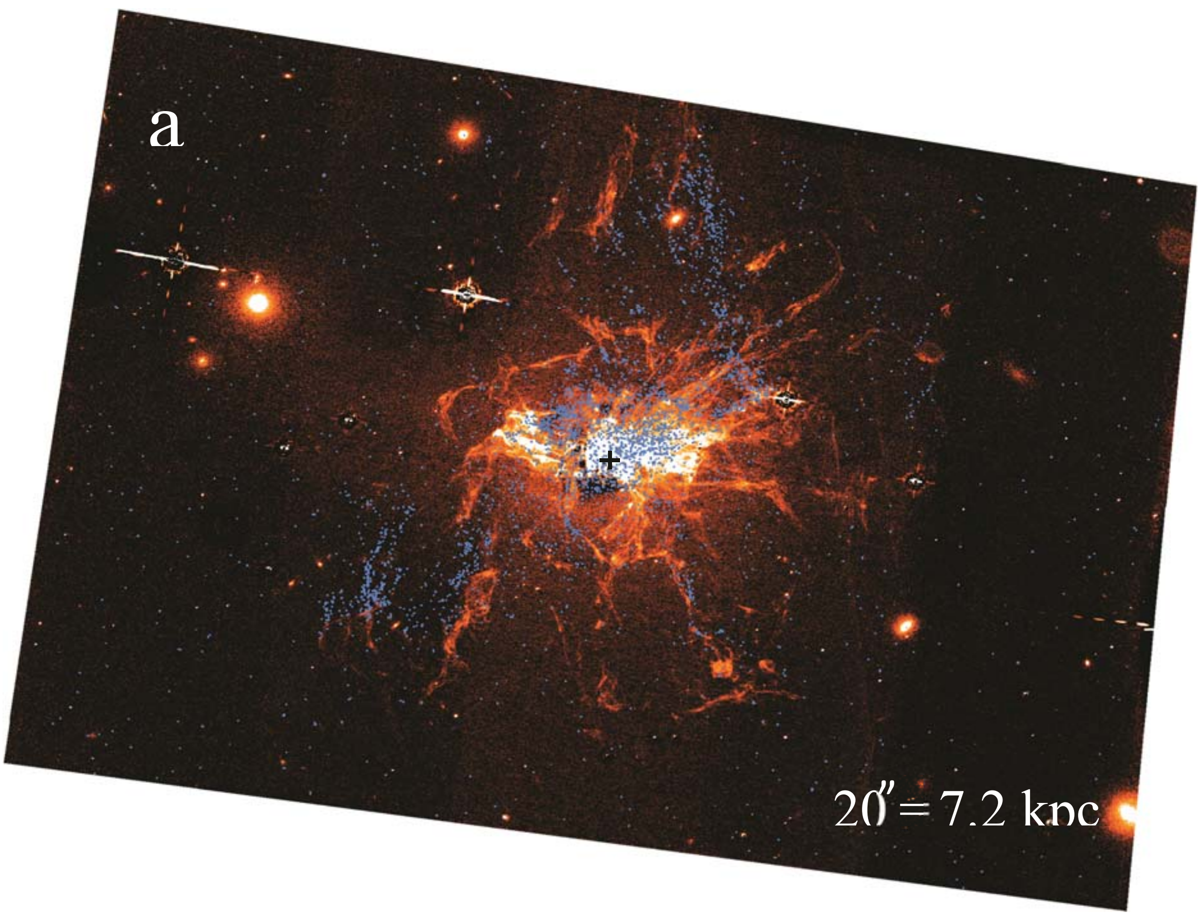
Dr. Lee is a planetary dynamicist who works on the formation and dynamical evolution of planetary bodies (planets, moons, etc.) in our Solar System and in planetary systems around other stars. He is also an expert in numerical methods for dynamical simulations of planetary systems. His current research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

3. Observational Astrophysics

Academic staff: ***Dr. J.J.L. Lim***
Dr. S.C.Y. Ng
Prof. Q.A. Parker
Dr. M. Su

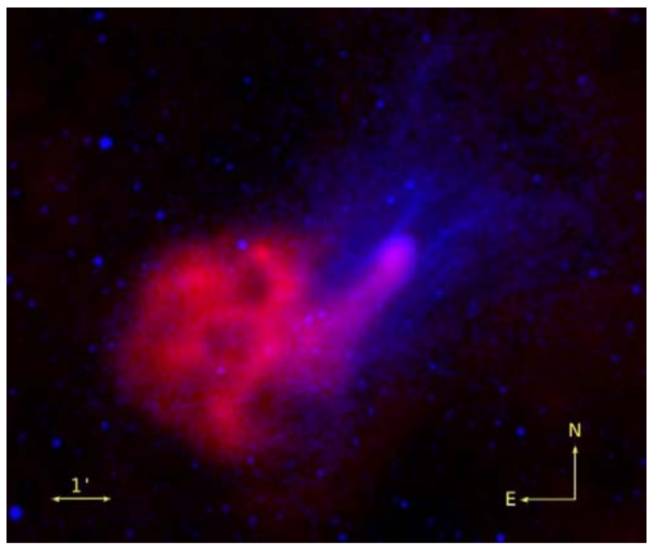
(1) Star Formation and Cooling Flows in Galaxy Clusters
Dr. Lim's research has spanned a broad range of topics, including (i) stellar coronal magnetic activity, (ii) the formation and late evolution of stars in our Galaxy, (iii) star formation and AGNs in nearby galaxies, (iv) X-ray cooling flows in galaxy clusters, and (v) astrophysical applications

of gravitational lensing, including weighing supermassive black holes, evolution of galaxies in the early Universe, as well as the nature of dark matter. The present focus of his work is on topics (iii)-(v). As an observational astronomer, Dr. Lim uses primarily radio telescopes (e.g., VLA, SMA, ALMA) and optical-infrared telescopes (e.g., CFHT, HST). Dr. Lim has mentored many graduate students, a number of whom have gone on to PhD programs in the USA and Europe, or have since become postdoctoral fellows. He collaborates with many astronomers worldwide, bringing international exposure to his students. Over the past 6 years, in collaboration with Prof. Thomas Broadhurst at Ikerbasque, Spain, Dr. Lim has built a strong group of undergraduate and graduate students working on gravitational lensing at HKU. Dr. Lim actively recruits talented undergraduate students for casual research in preparation for their capstone and graduate studies.



(2) 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 has also developed a powerful 3D modeling technique to capture the X-ray torus and jet morphology of PWNe and to measure the structure and evolution of the supernova remnant 1987A.

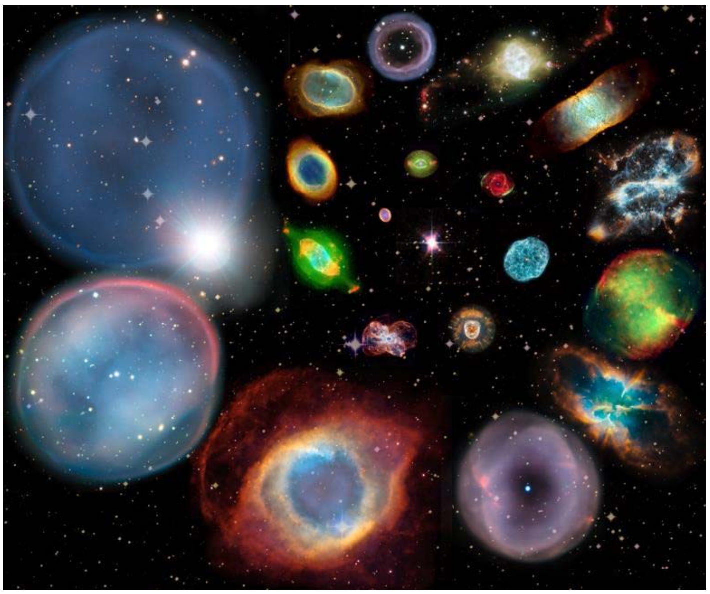
Dr. Ng's latest research focuses on the magnetic fields of neutron stars and their environments. Employing X-ray observations, he measures the surface temperature of magnetars, which are stars with the strongest magnetic fields in the Universe, to understand their extreme properties and their connection with ordinary radio pulsars. In addition, he maps the magnetic field configurations of PWNe using radio telescopes, in order to probe the cosmic ray production and transport in these systems.



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

(3) Prof. Q.A. Parker arrived at HKU in March 2015 and is intent on establishing a world-leading group in late-stage stellar evolution that includes post-AGB stars, planetary nebulae and massive star ejecta including Wolf-Rayet shells and supernova remnants. This is assisted by i) the on-going appointment of Prof. Albert Zijlstra as a Hung Hing Ying Distinguished visiting professor to HKU who is a world leader in planetary nebula; ii) the appointment of several new postdoctoral research fellows: Dr. F. Lykou, Dr. Andreas Ritter and Dr. Xuan Fang and iiii) Three PhD students. Significant contributions to this research field have been made by this

strong team including two HKU press releases (see https://www.ras.org.uk/news-and-press/2741-planetary-nebulae and http://www.scifac.hku.hk/news/any/planebulae). Exciting research opportunities exist for additional research postgraduate students to join the group. This group also has strong synergies to existing departmental expertise in late stage stellar evolution (including supernova remnants) and to the Laboratory for Space research (http://www.lsr.hku.hk).



Subject of our recent press release: A collage showing 22 individual planetary nebulae artistically arranged in approximate order of physical size. The scale bar represents 4 light years. Each nebula's size is calculated from the authors' new distance scale, which is applicable to all nebulae across all shapes, sizes and brightnesses. The very largest planetary nebula currently known is nearly 20 light years in diameter, and would cover the entire image at this scale. Credit: ESA/Hubble & NASA, ESO, Ivan Bojicic, David Frew, Quentin Parker

(4) Dr. M. Su has a broad range of research interest, including Cosmic Microwave Background to study the Universe in the very beginning and the later evolution, observational high energy astrophysics (including gamma-ray and X-ray telescopes), searching for Dark Matter particles, cosmic ray physics (both theory and observations involving both ground-based and spaceborne instruments). We are building a CMB telescope in the west part of Tibet , which is the highest observatory worldwide! We have launched the very first Chinese astronomy satellite to look for dark matter, named Dark Matter Particle Explorer (we found some hints!). He has discovered a pair of gigantic bubbles emitting high energy of gamma-ray photons using NASA's Fermi Gamma-ray Space Telescope. He is also building satellites for dedicated space science research, including a X-ray telescope using so-called Lobster-eyed type of optics to enable the largest field of view ever, a UV telescope to help to find habitable worlds in other solar systems. He is also working on the two largest payloads onboard the future Chinese space station: a 2-meter class optical telescopes, and the

High Energy Radiation Detector which is the future of the gamma-ray and cosmic-ray detection. If you are interested in studying the Universe (or the earth!) using satellites, please talk to him.

Atomic, Optical and Quantum Physics group:

1. **Quantum Computing and Information Theory**

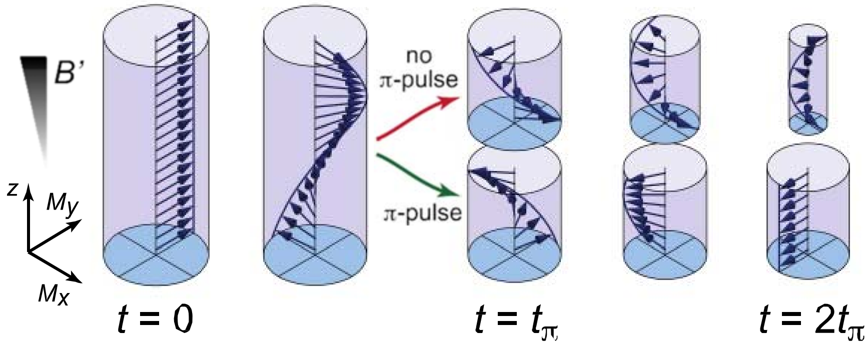
Academic staff: ***Prof. H.F. Chau***
Prof. Z.D. Wang

We focus on the theoretical study of quantum information theory and quantum computation. Our aim is to prove the security of various quantum cryptographic protocols as well as getting a better understanding of how to manipulate quantum information by quantum error-correction codes. In collaboration with researchers in HP Labs, Bristol, our group has recently proven that certain quantum key distribution scheme is unconditionally secure as well as obtained a U.S. patent on certain quantum key distribution protocols.

2. **Theoretical Atomic Physics and Degenerate Quantum Gases**

Academic staff: ***Dr. S.Z. Zhang***

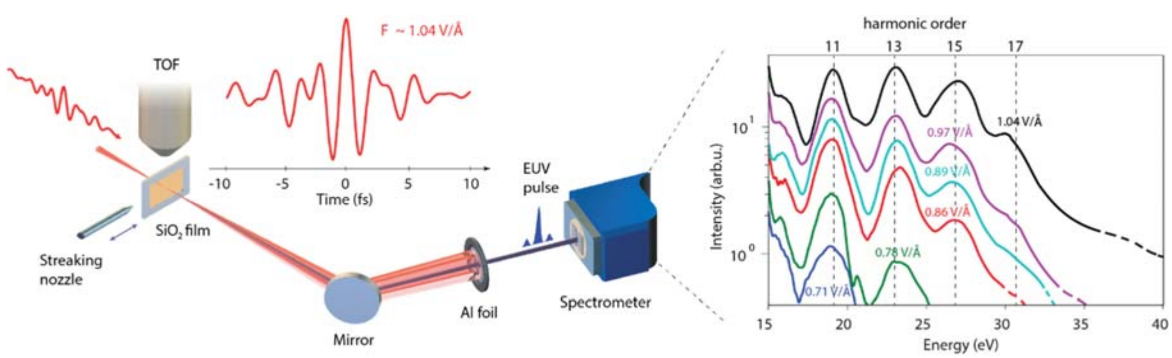
Ultra-cold atomic gases have emerged as a multi-disciplinary subject that is at the interface of modern atomic and molecular physics, quantum optics and condensed matter physics. It proves to be an excellent laboratory for investigating strongly interacting quantum many-body systems and in particular 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.



3. Ultrafast Optics and Attosecond Science

Academic staff: ***Dr. T.T. Luu***

Studying electronic processes in their native time scale requires tools that are extremely fast, i.e. as fast as hundreds of atto-second (1as = 10^{-18} s). By combining high power laser pulses and strong-field physics, creation of attosecond pulses was made possible. The tools, either extreme ultraviolet or optical attosecond 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.



Generation of coherent extreme ultraviolet radiation from laser-solid interaction: experimental apparatus and result

Experimental Condensed Matter and Material Science group:

1. Facilities

(1) Nanostructure Characterization Laboratory (***X.D. Cui***)
We focus 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.

(2) Quantum Device Laboratory (***D.K. Ki***)
We investigate quantum transport phenomena in various nano-electronic devices, realized by using state-of-art nano-fabrication and engineering techniques. To achieve this goal, we are equipped with electron-beam and optical lithography systems, different types of metal deposition chambers, reactive ion etcher, and home-made micro-manipulators to control and assemble small-size atomically thin crystals. For the transport measurement, we have two zero-field cryostats, one variable temperature insert (VTI) with 9-T superconducting magnet, and a dilution fridge with 14-T magnet (to be installed by 2020).

(3) Laser Spectroscopy Laboratory (***S.J. Xu***)
The laboratory is equipped with variable-temperature (4.2 K-300 K) photoluminescence (PL), variable-temperature (1.5 K-300 K) magneto-PL (up to 7 T) with super high spectral resolution, a confocal scanning Raman microscopy/spectroscopy system, broadband variable-temperature (8 K-330 K) emission/ absorption/ reflectance/ photocurrent spectroscopy, time-resolved PL system, and a near field scanning microscope. The existing laser sources include He-Cd laser, He-Ne laser, Ar-Kr mixed gas laser, high-energy YAG pulse laser, and semiconductor laser diode array pumped femtosecond broadband lasers.

(4) Optoelectronics and Nanomaterials Laboratory (***A.B. Djurišić***)
This laboratory is equipped with fume cupboards, tube furnaces, a spin-coater, two thermal evaporators, and an electron-beam/sputtering deposition system. Our material characterization facilities include

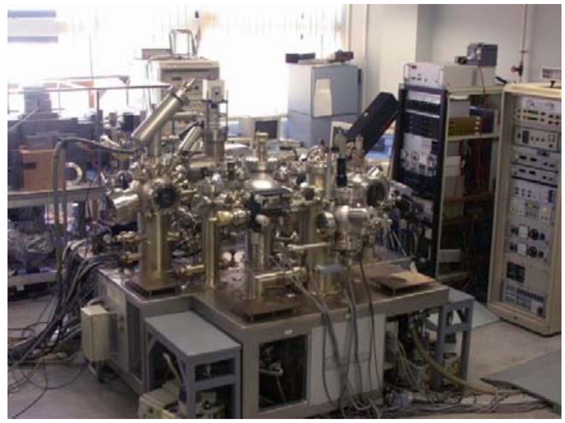
UV/Vis/NIR spectrometers for LED characterization and setups for power conversion efficiency and external quantum efficiency measurements for solar cells.

e-beam/sputter system and thermal evaporator

(5) Material Physics Laboratory (***C.C. Ling***)
Specialised equipment includes: 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.

(6) Surface Science Laboratory (***M.H. Xie***)



This includes Multi-chamber ultrahigh vacuum (UHV) systems for material synthesis and characterizations by molecular beam epitaxy (MBE), scanning tunneling microscopy and spectroscopy (STM/S), low and high-energy electron diffraction (LEED/RHEED), and ultraviolet photoelectron spectroscopy (UPS).

2. Experimental Condensed Matter

Academic staff: ***Prof. X.D. Cui***
Dr. D.K. Ki
Prof. S.J. Xu

The facilities of the experimental condensed matter group consists of a number of experimental laboratories, carrying out concerted research in various fields of condensed matter physics, including the key areas below:

(1) Experimental Solid State Physics (***X.D. Cui***)

The emphasis of this research lab is on 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.

(2) Quantum Nanoelectronic Devices (***D.K. Ki***)

We study quantum transport properties of various nano-electronic devices at low temperatures, with an aim to discover new phenomena, understand their microscopic origins, and learn to control their properties. Materials of interest include graphene and 2D materials, topological insulators and superconductors, 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.

In this context, we are currently focusing on the topics below:

(1) Quantum transport in graphene and 2D materials
(2) 'Designer' electronic heterostructures and interfaces
(3) New topological states of matter

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

(3) Novel Optical Properties of Semiconductor Nanostructures (***S.J. Xu***)

Optical properties including nonlinear optical properties, electronic structures, electron-phonon interactions, ultrafast phenomena, phonon and defect states in new semiconductor nanostructures such as self-assembled quantum dots, nanocrystals and new two-dimensional transition metal dichalcogenides are our current research interests. In addition, optoelectronic device applications of the semiconductor nanostructures are also our research interest. The materials being investigated by us include III-nitrides, SiC, traditional III-V and II-VI compound semiconductors as well as new 2D transition metal dichalcogenides. The laboratory has been already equipped by variable-temperature (4.2 K-300 K) photoluminescence system, scanning confocal micro-Raman image/spectroscopy system, variable-temperature (10 K-330 K) broadband (200 nm-1700 nm) emission/absorption/reflection spectroscopy, pump-probe based ultrafast (sub-ps) and gated integrator + boxcar averager based (20 ns to ms) time-resolved photoluminescence system, and newly-established low-temperature magneto-photoluminescence spectroscopy with super high spectral resolution. Currently, a pump-probe based fs laser source + scanning confocal microscopy system is being implemented by us, which enables us optically investigate ultrafast quantum processes and even imagine such processes occurring in individual semiconductor nanostructures.

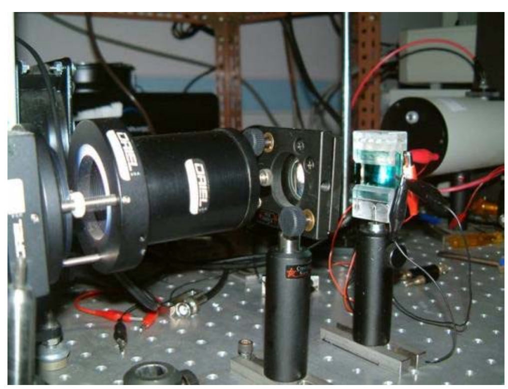
Further information of the group can be found at
http://www.physics.hku.hk/~laser

3. Materials Science

Academic staff: ***Prof. A.B. Djurišić***
Dr. C.C. Ling
Prof. M.H. Xie

The material science group conducts researches of various materials in the form of thin films and nanostructures. Examples include perovskite transition metal oxides, organic-inorganic halide perovskites, transition metal dichalcogenides, wide bandgap semiconductors (ZnO and GaN, for example), topological insulators, organic and inorganic nanocomposites. The techniques involved include various high vacuum deposition systems (e.g., sputtering, thermal and e-beam evaporation, pulse laser ablation, chemical vapor deposition, and molecular-beam epitaxy), low temperature and high B field measurement facility, x-ray and electron diffraction, scanning probe microscopy, photoelectron and Auger electron spectroscopy, temperature dependent Hall, IV and CV measurements, UV/Vis/NIR spectrometers, etc.

(1) Optoelectronics and Nanomaterials (***A.B. Djurišić***)



The 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. The laboratory is equipped with fume cupboards, 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. 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. The study of wide band gap nanostructures includes comprehensive investigation of influence of the fabrication conditions on structural and optical properties of the nanostructures, and exploring their possible use in energy and environmental applications.

(2) Defects characterization and engineering of functional materials (***C.C. Ling***)

The 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.

(3) Experimental Surface Science (***M.H. Xie***)

The surface science laboratory 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.

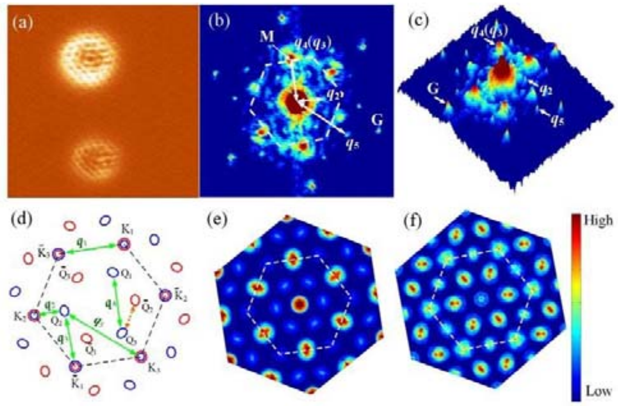


Diagram showing Intervalley Quantum Interference in epitaxial WSe_2 Monolayer

We carry out molecular-beam epitaxy (MBE) and surface studies of ultrathin layers

MBE is one of the most versatile techniques to grow materials with precise control. It allows fabrication of artificial structures by combining different materials to form the so-called "quantum wells" and "superlattices". Quantum effects and new concepts in material sciences are thus explored for modern device applications. By using STM/S and UPS, we characterize the atomic and electronic structures of film surfaces. The latter are important for the understanding various quantum effects at atomic scale.

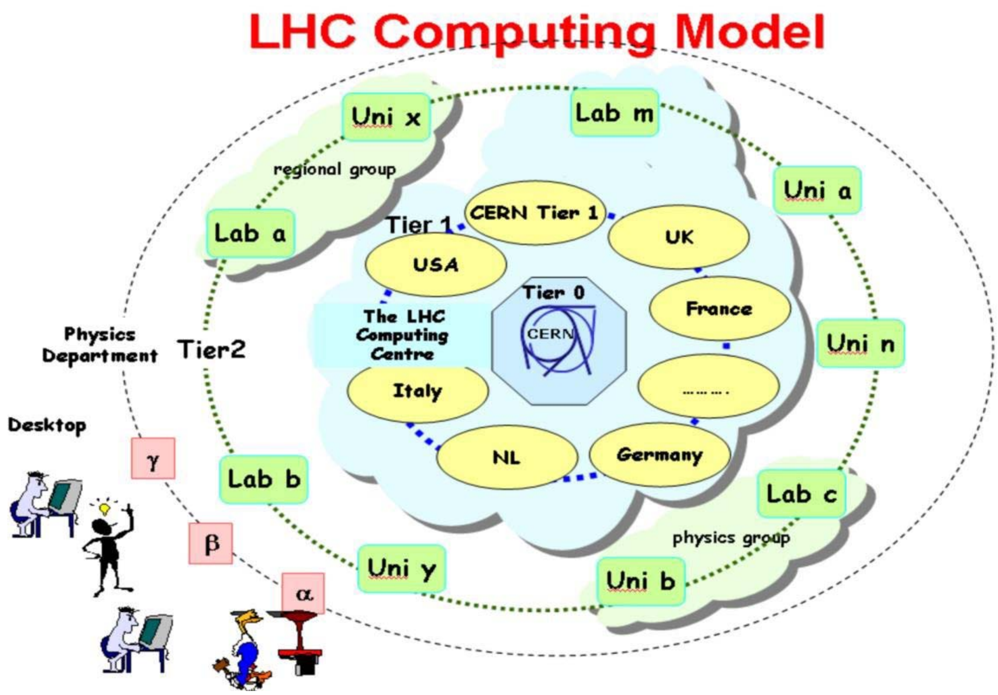
Experimental Nuclear and Particle Physics group:

1. Facilities

(1) High Energy Particle Physics Laboratory (***Y.J. Tu***)
A joint consortium for fundamental physics of the University of Hong Kong, the Chinese University of Hong Kong, and the Hong Kong University of Science and Technology, was formed in 2013. Under this umbrella, a Hong Kong cluster formally joined the ATLAS experiment at the Large Hadron Collider in June 2014. One of the missions led by the Hong Kong cluster is to build up a Tier-2 (and Tier-3) computing center in Hong Kong, which is expected to play an important role in serving both the LHC physics community and the local scientific and engineering community. The center is designed to have 1000

processing cores and 1 petabytes of disk space.

The laboratory is the part of the Tier-2 (and Tier-3) computing center for analyzing data collected by the ATLAS experiment at the LHC in CERN. The lab has access to the Worldwide LHC Computing Grid, which is the world's largest computing grid.



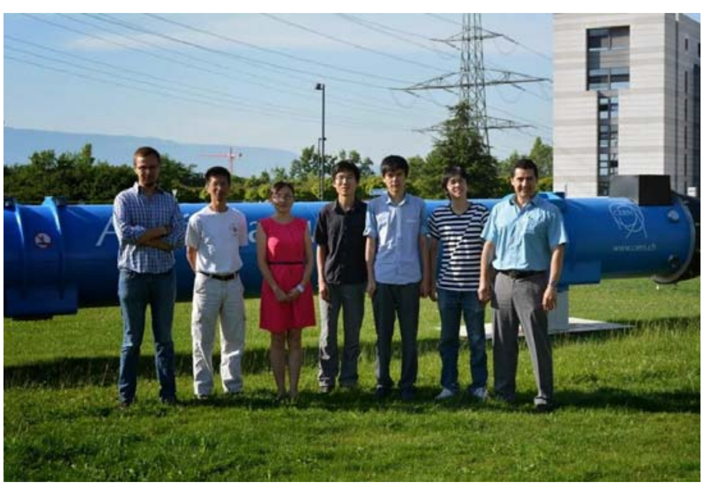
(2) Nuclear Physics Laboratory (***J.H.C. Lee***)
A cutting-edge Gamma-ray detector array and charged particle detector array, based on international collaborations, will be developed to achieve high-efficient and high-resolution measurements for the studies of nuclear structure. The arrays are designed for easy configuration and full integration with other devices to meet the detection requirements of specific major experiments, which will be performed in the Radioactive-Isotope Beams facilities worldwide such as RIKEN (Japan) and NSCL/FRIB (United States).

2. Experimental High Energy Particle Physics

Academic staff: ***Dr. Y.J. Tu***

Dr. Tu works in experimental particle physics where the goal is to understand fundamental particles and their interactions. The startup of the Large Hadron Collider (LHC), the world's largest and highest-energy particle accelerator, in 2009 opened up a new era at the high energy frontier. The unexplored energy domain of the LHC provides unique opportunities to answer fundamental questions in particle physics, such as the cause of electroweak symmetry breaking, the mass origin of particles in the Standard Model, the generation of baryon asymmetry in the Universe and the properties of dark matter. Exploring these topics could dramatically improve our understanding of nature. The recent observation of the Higgs boson in the ATLAS and the CMS experiments represents one such success. In view of this remarkable progress, the next several years will be a critical and significant period for the field development of the HEP.

With strong support from the member institutions of the Hong Kong Joint Consortium for Fundamental Physics and the Research Grants Council, Hong Kong is now participating in the LHC ATLAS experiment. The Hong Kong particle physics group is involved in several projects including searching for supersymmetric particles, and searching for beyond Standard Model heavy gauge bosons. The group is also responsible for software and hardware upgrades: software development for muon reconstruction and Phase I Phase II muon detector electronics upgrade.



A photo showing the 7 members of the ATLAS Hong Kong group.

3. Experimental Nuclear Physics

Academic staff: Dr. J.H.C. Lee

The experimental nuclear physics group is dedicated to the studies of the nuclear shell structure evolution and the nucleon correlations in nuclei. The experimental techniques include direct reactions, in-beam gamma spectroscopy and beta-decay spectroscopy. The state-of-the-art gamma-ray detector array and charged particle detector array will be constructed at the University of Hong Kong in collaboration with RIKEN (Japan) and IPN-Orsay (France). Both arrays are portable with fully integrable capability to the detection systems at the present facility RIKEN (Japan) and in the future-upgraded accelerated-based laboratories worldwide such as NSCL/FRIB (United States) and Spiral2 (France).

HKU-UCAS Joint Institute of Theoretical and Computational Physics:

Academic staff: Prof. H.F. Chau, Dr. G. Chen, Prof. G.H. Chen (Chemistry), Prof. K.S. Cheng, 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. 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", which was established in September, 2005. The purpose of the Centre is 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. The centre's honorary Director is Prof. Dan Tsui at Princeton University, Nobel Prize co-recipient in Physics in 1998. The Centre has a high level Advisory Committee (http://www.physics.hku.hk/~ctcp/). The Centre 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 Centre 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 Centre'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 center will hold two activities related to the computational and theoretical physics:

i) "Hong Kong Computational Physics Study Group"
This will be a bi-weekly activity throughout Sept-Dec 2019, planned to give series of lectures to the postdoctoral fellows and talented young graduate students in Hong Kong area on the modern computational physics techniques and their applications. The topics will 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.

ii) " Hong Kong Forum on the next generation of scientific computing and neuromorphic AI accelerator"
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.

<u>Theoretical and Computational Condensed Matter group:</u>

Academic staff: ***Dr. G. Chen***
Dr. Z.Y. Meng
Prof. S.Q. Shen
Dr. C.J. Wang
Prof. J. Wang
Prof. Z.D. Wang
Prof. W. Yao
Dr. S.Z. Zhang

Theoretical condensed matter physics is a very important area in physical sciences because not only it concerns with many fundamental subjects but also it has very wide and potentially important applications in material science, biophysical science, high technology, and even economy and finance, etc. We have a very active research group in this field. Our current research interest includes:

(1) strongly correlated electron systems;

(2) topological matters;

(3) quantum materials;

(4) quantum computing;

(5) quantum magnetism;

(6) spintronics and valleytronics;

(7) quantum transport;

(8) semiconductor optics;

(9) interdisciplinary study of cold atom physics and condensed matter physics

(10) computational approaches in quantum many-body systems

(11) scientific computing and neuromorphic AI accelerator in physics

2020/2021 POSTGRADUATE PROJECTS
DEPARTMENT OF PHYSICS
THE UNIVERSITY OF HONG KONG

The following M.Phil./Ph.D. projects are available in 2020/2021 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$16,660 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 www.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

<u>Astronomy and Astrophysics group:</u>

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 KF01: The Origin of the highest-energy particles in the universe

Supervisor: Dr. K. Fang

High-energy cosmic particles carry extreme energy that cannot be produced by man-made accelerators. They are unique messengers from distant sources such as active galactic nuclei and starburst galaxies. We will study high-energy sources using gamma-ray data from the Fermi satellite and the High Altitude Water Cherenkov telescope (HAWC), as well as high-energy neutrino data from the IceCube telescope. We will also investigate the radiative transfer of relativistic particles in cosmic environment using numerical simulation. Our work aims at understanding the origin of cosmic rays through both data and theory.

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

Supervisor: Dr. J.J.L. Lim

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

Project JJLL02: Astrophysical Applications of Gravitational Lensing

Supervisor: Dr. J.J.L. Lim

When did gas in bodies comprising primarily dark matter first turn into stars, making galaxies visible for the first time? How did the different stellar components of galaxies – in the case of galaxies like our own, central bulge, disk (in which our Sun resides), and surrounding halo – assemble over time? How did their supermassive black holes grow over time? What is dark matter, which dominates not only matter in galaxies but also matter in the space between galaxies? To address these questions, Dr. Lim, his students, and his collaborators use gravitational lensing by galaxy groups or clusters as cosmic lenses to magnify background galaxies. In this way, we able to detect and study distant, and therefore young, galaxies that would otherwise be too dim to detect and too small to resolve. We can even determine, through geometry, the distances to these galaxies, the redshifts of which are often difficult to measure because these galaxies are so faint. The manner in which the number of these galaxies change over time allows us to test predictions by different forms of dark matter. Through gravitational lensing, we also are able to study the properties of the lensing clusters, allowing us to weigh supermassive black holes in cluster member galaxies, and to search for substructure in dark matter as predicted in some models. We continue to develop different exciting astrophysical applications of gravitational lensing.

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"

Supervisor(s) for all projects include:

Prof. Q.A. Parker, Prof. A.Zijlstra (Hung Hing Ying distinguished visiting professor), Dr. Claire Lykou, Dr. Andreas Ritter, Dr Xuan Fang

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 more massive 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 ionised 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 ~3500 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): The PNe luminosity function (LMC, SMC, Bulge and local volume)

This PNLF provides the co-eval brightness distribution of a population of PNe in a given system (such as an entire Galaxy). An exponential fit to the bright end cut off of the PNLF is a potent cosmological standard candle but how and why it works so well across all galaxy Hubble types is a mystery while the detailed form and features seen in various PNLFs (so called "Jaboby dips") are hard to interpret. Access to our highly complete PNLFs across 10dex in [OIII] magnitudes for the Bulge and LMC in particular offers strong opportunities to tackle these problems.

Project QAP01(b): 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(c): Morpho-kinematic modelling of PNe and insights in bipolarity

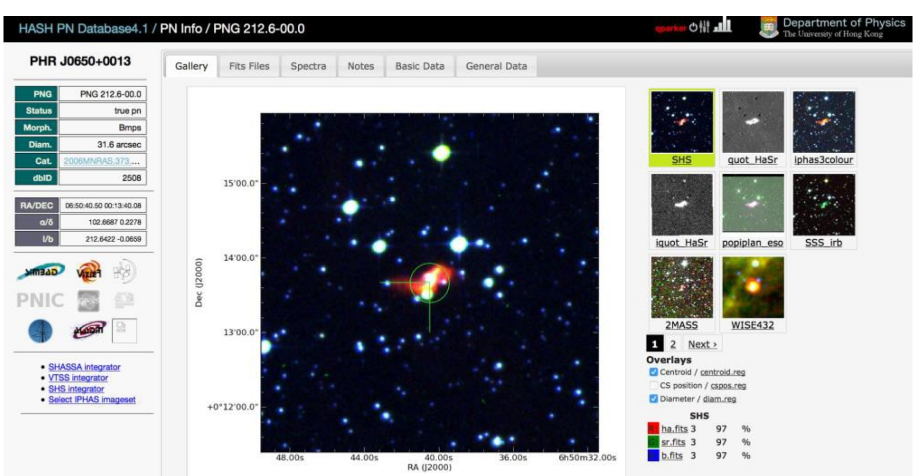
The advent of powerful integral field units (IFU) on major telescopes to perform areal point-to-point spectroscopy of resolved objects has enabled detailed 3-D data-cubes to be obtained. This has enabled both kinematic and line intensity maps to be produced for significant numbers of PNe for the first 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(d): Central stars of PNe – discovery, description and diversity

Currently less than 25% of known PNe have unequivocally identified central stars (CSPN). The availability of significant new PNe samples, new wide field surveys and particularly access to new u-band imaging from VPHAS+ and UVEX promises to dramatically improve this number. It is the characteristics of these CSPN and possible binarity that directly affects the observed properties of the ionised nebulae. This project seeks to both discover new CSPN candidates and study their properties and diversity to inform our understanding of PN shaping, expansion and evolution.

Project QAP01(e): 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 new HASH database of Planetary Nebulae – a powerful resource available to all these projects.

Project MS01: Studying the Universe using satellites
All the projects described below fall under the main topic of space science using satellites
Supervisor(s) for all projects: Dr. M. Su

We have access to some world leading space science facilities, including Chinese space station, Dark Matter Particle Explorer, CMB telescopes. We are also building our own satellites to do focused science, including X-ray telescopes, UV telescopes, gamma-ray detectors, microwave telescopes, and cosmic-ray detectors. A large range of projects are available from numerical simulation, hardware construction, data analysis, science forecast, data mining etc. Broadly speaking, if you are interested in using satellites or building your own ones, please talk to him.

Atomic, Optical and Quantum Physics group:

1. Quantum Computing and Information Theory

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.comm.utoronto.ca/~hklo/
See also https://spectrum.ieee.org/tech-talk/telecom/internet/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.

(Prof. Lo is expected to join the Department in Jan. 2020. To discuss the project with Prof. Lo, please email hklo@comm.utoronto.ca)

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.comm.utoronto.ca/~hklo/
See also https://spectrum.ieee.org/tech-talk/telecom/internet/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.

(Prof. Lo is expected to join the Department in Jan. 2020. To discuss the project with Prof. Lo, please email hklo@comm.utoronto.ca)

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.comm.utoronto.ca/~hklo/
See also https://spectrum.ieee.org/tech-talk/telecom/internet/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.

(Prof. Lo is expected to join the Department in Jan. 2020. To discuss the project with Prof. Lo, please email hklo@comm.utoronto.ca)

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.

2. <u>Theoretical Atomic Physics and Degenerate Quantum Gases</u>

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.

3. <u>Ultrafast Optics and Attosecond Science</u>

Project TTL01: Ultrafast spectroscopy of condensed matters
Supervisor: Dr. T.T. Luu

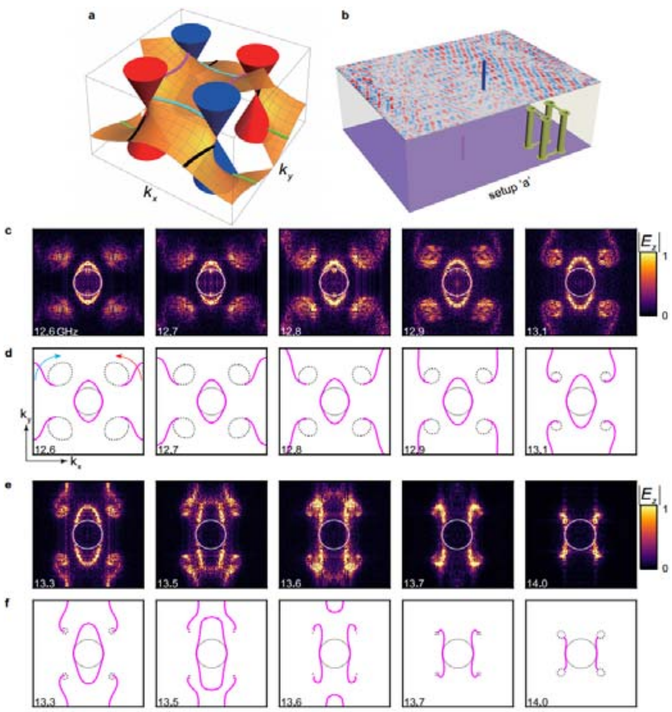
We have been actively working on and contributing to the field of high-order harmonic generation in solids and its spectroscopic applications. Once we drive a condensed matter system using a strong electric field that is beyond perturbation theory, ultrafast electronic currents, generated inside the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

4. Topological Metamaterials

Project SZ01: Scattering processes in topological Weyl metamaterials

Supervisor: Prof. S. Zhang

Topological physics concerns with exploration and implementation of non-trivial band structures in periodic systems and the related topological protection. The most well known examples are topological insulators that are insulating in the bulk but conductive on the surface. The study of topological states has recently expanded into other fields, such as cold atoms, photonics, acoustics, and mechanical systems. In particular, the development of topological systems in photonics has attracted widespread attention. The design and implementation of photonic edge/surface state in photonic structures that support topological protection immune from scattering has become a frontier research direction. While topologically protected surface states have been intensively studied in photonics, less attention has been paid to the bulk wave propagation inside the topological systems such as photonic Weyl media. This project aims to investigate the scattering of wave inside Weyl metamaterials by introducing resonant scatterers/defects into the periodic Weyl metacrystal. It is expected that due to the diminishing density of states close to the Weyl frequency, the resonant scattering cross section will diverge, leading to strong interaction between the wave and the introduced defects. This feature will further be exploited to design various photonic devices.



Experimental demonstration of ideal Weyl metamaterials and helicoid surface states. (a) Dispersion of the bulk and surface states, showing the Weyl cones and surface states. (b) measured field profile in the top surface. (c-f) Evolution of the bulk and surface equifrequency contours with increasing frequencies.

<u>Experimental Condensed Matter and Material Science group:</u>

1. <u>Experimental Condensed Matter</u>

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: Topological quantum states at artificial 2D interfaces

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 offer a great promise for realizing new types of device applications (*e.g.*, topological quantum computing). In this project, we will focus on 'artificially designing' the new topological states by creating atomically sharp interfaces between different 2D crystals where van der Waals interactions can induce new properties in the system, 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 expect this project will expand the 'zoo' of topological materials available and bring us a step closer to the realization of topological electronics

Project DKK02: New many-body physics in engineered 2D materials

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 an interesting material system with novel electronic properties that can be tuned widely in the experiments. The goal of this project is therefore to take a full advantage of such large experimental flexibilities to explore new many-body phenomena in these materials. To this end, we will realize the devices with extremely high quality in various geometries and approach as close as possible to zero Fermi energy where interactions are known to be most dominant.

Project SJX01: In-depth Investigation of Fundamental Optical and Optoelectronic Processes in Semiconductors and Luminescent Materials

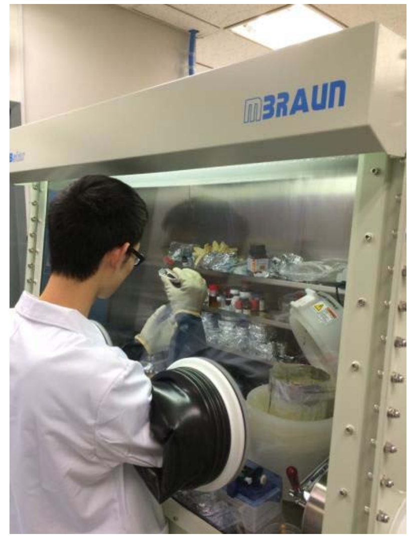
Supervisor: Prof. S.J. Xu

In this project, we employ a variety of optical spectroscopic techniques to get know more about some fundamental optical and optoelectronic processes occurring in semiconductors and luminescent materials, focusing on luminescence and energy transfer mechanisms inside the materials. We try to understand these complicated processes and phenomena in terms of a few simple principles.

2. <u>Materials Science</u>

Project AD01: Perovskite Optoelectronic Devices

Supervisor: Prof. A.B. Djurišić



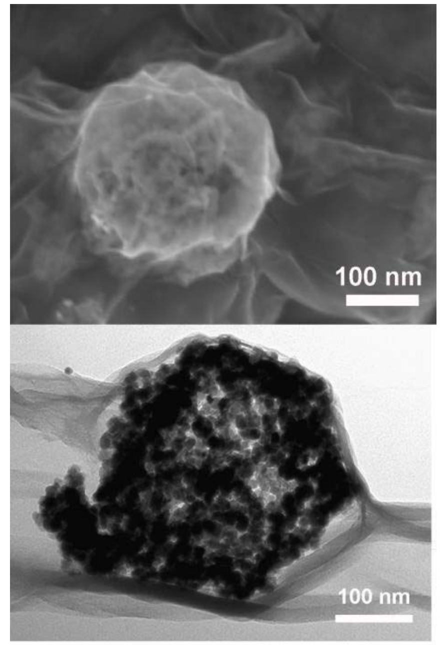
A PG student making a solar cell in a glove box

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. The objective of this project is to investigate the influence of charge transport layer doping, interface modifications and device architecture changes on the performance of solar cells. The objectives are to improve the device efficiency and stability, as well as develop devices on flexible substrates. Particular emphasis is placed on the development of novel perovskite materials for both LED and solar cells applications, and studies of the device degradation and improvement of the device stability. The student should have basic knowledge of optics and solid state physics. Some knowledge of chemistry would be beneficial.

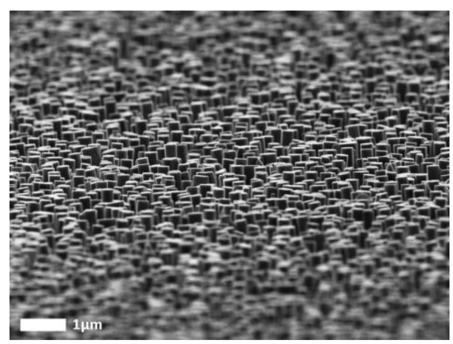
Project AD02: Wide Band Gap Nanostructures

Supervisor: Prof. A.B. Djurišić

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 dependence of structural and optical properties of wide band gap (ZnO, TiO_2, SnO_2, CeO_2 and GaN) on the fabrication conditions. The fabricated nanostructures 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. The application of prepared nanomaterials in LEDs, solar cells, photocatalysis, catalysis, sensors, or Li-ion batteries (depending on the material chosen) will also be studied.



Electron microscopy image of graphene wrapped SnO_2 hollow sphere



SEM image of ZnO nano rod

Project CCL01: Room temperature ferromagnetism in ZnO related materials

Supervisor: Dr. C.C. Ling

Dilute magnetic semiconductor (DMS) is a class of material receiving extensive attention because of its potential application spintronic, which is a new class of device based on the degree of freedom of the electron spin. For practical device applications, the Curie temperature of the DMS material has to be above the room temperature. There was theoretical and experimental results showing that room temperature ferromagnetism (RTFM) in ZnO:Tm (Tm=transition metal) could be stabilized by electron and hole mediations. It is interesting to notice that RTFM can also be achieved in non-magnetic element doped (like Cu) ZnO and undoped ZnO, which is proposed to be associated with the intrinsic defects (like V_O and V_{Zn}). However, the origins of the observed room temperature ferromagnetism are controversial and the physics is far from completely understood. The present project aims to fabricate non-magnetic element doped ZnO with RTFM and to understand the physics and the origin of the RTFM. It is also to achieve electric bias modulated magnetization in the corresponding device structure.

Project CCL02: High dielectric constant oxides via defect engineering

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 acheived 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 totally 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.

Project CCL03: Zn vacancy cluster and complex in Zinc Oxide Materials

Supervisor: Dr. C.C. Ling

Zinc oxide is a wide band gap II-VI semiconductor with a band gap of 3.4 eV. Because of its excellent electrical and optical properties, it is a potential material for a variety of applications in devices including ultra-violet optoelectronic, spintronic, photovoltaic, sensor and transparent conductive electrode. Although defects play crucial role in determining the material electrical and optical properties and there are studies involving simple point defects, not much is known in defect complex and vacancy cluster. Despite that majority of device applications involves ZnO thin film, relatively few defect studies were performed in particular in thin film focusing in optoelectronic applications. This project aims to study Zn-vacancy cluster and complex in ZnO films grown by pulsed laser deposition (PLD), focusing on how they influence the materials' electrical and optical properties as well as on manipulating the film electrical and optical properties via the defect engineering approach.

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.

Experimental Nuclear and Particle Physics group:

1. Experimental High Energy Particle Physics

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.

2. Experimental Nuclear Physics

Project JHCL01: Spectroscopy of neutron-rich Ca isotopes

Supervisor: Dr. J.H.C. Lee

We will perform in-beam gamma spectroscopy measurements of ^{56}Ca and $^{53,\ 55}$Ca at RIBF facility (RIKEN) via one nucleon knockout reactions, with the use of MINOS device coupled with DALI2 gamma spectrometer and ZeroDegree Spectrometer. The measurement of ^{56}Ca extends the systematic studies of the energies of 2_1^+ and other low-lying states beyond ^{54}Ca (N=34). The location of 2_1^+ energy of ^{56}Ca gives a direct measure of the difference between 0^+ and 2^+ two-body matrix elements in the $f_{5/2}^2$ which has not yet been determined. This new experimental data is also valuable in accessing the accuracy of the calculated $E_x(2_1^+)$ of ^{56}Ca using different effective interactions in shell-model the theories and ab-initio calculations. The spectroscopy of ^{53,55}Ca could reflect the nature of the N=34 shell closure and the contribution of the $g_{9/2}$ state. The single-particular properties (angular momentum and spectroscopic factor) of the low-lying states will be extracted from the cross sections and parallel momentum distributions of the residues.

Theoretical and Computational Condensed Matter 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 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 JW01: First Principles Calculation of Quantum Transport through Nanostructures

Supervisor: Prof. J. Wang

Currently we are interested in the field of nano-scale physics and technology. It has been demonstrated in several laboratories that many important quantum interference features such as the conductance quantization are observable for atomic wires at the room temperature. As a result, atomic device has important potential device applications and can be operated in room temperature. As theoreticians, we investigate quantum transport through atomic and molecular scale structures where a group of atoms are electrically contacted by metallic leads. Using Density functional analysis and the non-equilibrium Green's function method, we study conductance, capacitance, current-voltage characteristics, and other molecular device characteristics.

Project ZDW02: 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 WY01: Valley-spintronics in 2D materials and their van der Waals heterostructures

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 patterns formed by the inevitable lattice mismatch and twisting between the 2D building blocks in heterostructures.

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:
Introduction to basic research methods in physical science

Course Contents & Topics:
Basics of research methods will be provided for postgraduates of physical science. The following topics will be covered in the courses:
1. Research techniques: using the common problems encountered by postgraduate physics students to illustrate the modeling and problem solving skills
2. Theoretical physics: mathematical techniques, and general principles of different theories
3. Experimental physics: principles of experimental set-up
4. Data collections and analysis: statistics, probability and physical modeling
5. Mathematical modeling: models from those based on experimental data to first-principles theories
6. Presenting scientific information: written or oral presentation, the principles behind an effective presentations

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.

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 Physics of Quantum Liquids

Course Objectives:
The collective behavior of systems consisting of many particles (bosons or fermions) gives rise to new states of matter, which emerge at low temperatures where interactions are important. This course aims to introduce the students to those novel quantum states, emphasizing the general themes such as elementary excitations, broken symmetry, hydrodynamic description, and topological properties of condensed matter. Theoretical language useful in the interpretation of experiments, such as response functions, will be discussed. The emphasis will be on a selected few examples that illustrate the above concepts and techniques. The course is intended for both experimentalists and theorists.

Course Contents & Topics:
This course will concentrate on the phenomena of emergent many-body states that require not only the effects of quantum mechanics, but also that of quantum statistics to its proper explanation. Examples include: superfluidity, superconductivity and the quantum Hall states. We will emphasize on the interaction effects and discuss the primary feature brought about by the interaction. Some general themes related to these quantum states, such as elementary excitation, Ginzburg-Landau description and symmetry breaking 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, Data Analysis, and Computer Grid
2. Vacuum technology and deposition techniques
3. Raman spectroscopy and photoluminescence (PL)
4. Electrical Characterizations
5. Scanning Probe Microscopy (STM and AFM)
6. Electron and X-Ray Diffraction (LEED/RHEED/XRD)
7. Photoemission Spectroscopy (PES)
8. Scanning Electron Microscopy (SEM)
9. Transmission Electron Microscopy (TEM)
10. Low-temperature electrical measurements
11. Radiation Detection and Measurements in Nuclear Physics
12. Particle Detection in Space and Microwave Measurements with Superconducting Detector

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

REPRESENTATIVE PUBLICATIONS OF FACULTY MEMBERS

H.F. Chau

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G. Chen

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K.S. Cheng

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"High-energy Radiation from Rapidly Spinning Pulsars with Think Outer Gaps", L. Zhang and K.S. Cheng, *The Astrophysical Journal*, 487, 370-379 (1997)

"Energetic Radiation from Rapidly Spinning pulsars. I: Outermagnetosphere Gaps", Cheng, K.S., Ho, C. & Ruderman, M., *Astrophysical Journal*, 300, 500-521 (1986).

X.D. Cui

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

"Anomalously robust valley polarization and valley coherence in bilayer WS_2", B. Zhu, H.L.Zeng, J.F. Dai, Z.R. Gong and X.D. Cui, *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 111, 11606-11611 (2014)

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J.H.C. Lee

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