DEPARTMENT OF PHYSICS

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For general enquiries or correspondence

Department of Physics
Room 518 Chong Yuet Ming Physics Building
The University of Hong Kong
Pokfulam Road
Hong Kong

Tel: (852) 3917 2360
Fax: (852) 2559 9152
Web: https://www.physics.hku.hk/

September 2025

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WELCOME

Dear prospective research postgraduate students,

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

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

We are very much in an uptrend. Both the quality and the quantity of the physics research activities at HKU have grown steadily in recent years. We are doing outstanding research in all the above research areas. For instance, Prof. Wang Yao, a Chair Professor in Physics, has published some very highly cited papers in the field of condensed matter physics. We have been winning more awards - two Croucher Senior Research Fellowships, one by Prof. Wang Yao and one by Prof. Xiaodong Cui; Prof. Shizhong Zhang received Hong Kong RGC Fellowship; Prof. Wang Yao received the 2021 (the Ninth) Nishina Asia Award; Prof. Wang Yao, Prof. Xiaobo Yin and Prof. Yi Yang received the Xplorer Prize; Prof. Shuang Zhang and Prof. Wang Yao appeared on the list of New Cornerstone Investigator Program sponsored by Tencent; Prof. Lixin Dai and Prof. Jenny Hiu Ching Lee won China's Excellent Young Scientists Fund 2021; Prof. Chenjie Wang and Prof. Yi Yang won China's Excellent Young Scientists Fund 2022. Prof. Yi Yang also won the Croucher Tak Wah Mak Innovation Awards 2024 and he was selected as the Inventor of the 2022 Innovators Under 35 (China) by the MIT Technology Review. We have been getting some of the largest research grants in Hong Kong (e.g. two out of four AoEs awarded in 2021, including one led by Prof. Wang Yao). The Department has grown steadily over the past few years, having attracted some very outstanding young scientists in the fields of condensed matter physics, ultrafast optics, and astronomy. Three Professors from the Department have appeared on the list of globally highly cited researchers over the last five years (Wang Yao, Xiaobo Yin, Shuang Zhang). In terms of citation numbers, our annual citations (ISI) increased from 18586 in 2019 to 29260 in 2024. Prof. Wang Yao and Prof. Shuang Zhang have been nominated the Fellow of the American Physical Society and Fellow of Optica, in recognition of their exceptional contributions to the field of physics. This was truly impressive!

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

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

August 2025.

INTRODUCTION

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

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

Currently, there are 26 faculty members in the Physics Department. There are four strategic research areas. They are 1) condensed matter physics and material science, 2) astrophysics, 3) quantum information science and 4) optics and photonics including atomic and molecular physics.

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

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

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

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

- **The Facilities:**

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

- **Theoretical Studies**

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

- **Scholarships and Funding Support:**

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

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

Over the last few years, our research activities have grown substantially: For instance, (i) annual research outputs increased from 278 scientific papers in 2019 to 375 in 2024; (ii) publications in Science and Nature series, and in Phys. Rev. Lett. increased from 28 in 2019 to 53 in 2024; (iii) annual citations (ISI) increased from 18586 in 2019 to 29260 in 2024. These growing publication and citation numbers demonstrate the growth in world-class research in our department. Here are some examples of recent papers being published in top scientific journals:

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

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

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

Signatures of moiré-trapped valley excitons in $MoSe_2/WSe_2$ heterobilayers, Nature 567, 66-70 (2019)

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

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

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

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

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

Signatures of Fractional Quantum Anomalous Hall States in Twisted $MoTe_2$, Nature (2023)

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

- **Community Service and Outreach**

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

- **Location of Physics Department**

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

ACADEMIC STAFF

Interim Head & Chair Professor

Prof. S. Zhang, B.S. Jilin Univ; Ph.D. UNM; FOSA, FAPS
Rm 521, Tel: 3917 7944, email: shuzhang@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/s_zhang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Chair Professors

Prof. X.D. Cui, B.S. USTC; Ph.D. Ariz State
Room 209, Tel: 3917 8975, email: xdcui@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/xd_cui/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. S.Q. Shen, B.Sc., M.Sc. Ph.D. Fudan
Room 208, Tel: 3917 8901, email: sshen@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/sq_shen/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. W. Yao, B.S. Peking; Ph.D. Calif; FAPS, FOSA
Room 529, Tel: 3917 4809, email: wangyao@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/w_yao/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. B. Zhang, B.S., Ph.D. Peking
Room 523, Tel: 3917 5932, email: bzhang1@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/b_zhang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Chair Professor (by courtesy)

Prof. X.B Yin, Chair Professor, Department of Mechanical Engineering
Haking Wong Building Room 7-26, Tel: 3910 2659, email: xbyin@hku.hk
web: https://www.mech.hku.hk/academic-staff/Yin-XB

Professors

Prof. H.F. Chau, B.Sc., Ph.D. HKU; M.IEEE.; F.Inst.P.
Room 520, Tel: 3917 1925, email: hfchau@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/hf_chau/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. J.J.L. Lim, B.Sc., Ph.D. Macquarie
Room 531, Tel: 2219 4924, email: jjlim@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/jjl_lim/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Z.Y. Meng, B.Sc. USTC; Ph.D. Uni. Stuttgart
Hui Oi Chow Science Building Room 231, Tel: 3917 7850, email: zymeng@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/zy_meng/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. M.H. Xie, B.Eng. Tianjin; M.Sc. Chinese Acad of Sc; Ph.D. Lond; DIC
Room 415C, Tel: 3917 7945, email: mhxie@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/mh_xie/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. S.Z. Zhang, B.S. Tsinghua; Ph.D. Illinois
Room 526, Tel: 3917 7943, email: shizhong@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/sz_zhang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Professor (by courtesy)

Prof. G. Chiribella, Professor, Department of Computer Science
Chow Yei Ching Building Room 304, Tel: 2859 2193, email: giulio@cs.hku.hk
web: https://www.cs.hku.hk/index.php/people/academic-staff/giulio/
& http://qift.weebly.com/

Associate Professors

Prof. L.X. Dai, B.Sc. HKUST; M.Sc., Ph.D. Stanford
Room 311J, Tel: 3910 2166, email: lixindai@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/lx_dai/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. D.K. Ki, B.Sc., Ph.D. POSTECH
Room 311C, Tel: 3910 2163, email: dkki@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/dk_ki/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. J.H.C. Lee, B.Sc. CUHK; M.S., Ph.D. Michigan State
Room 516, Tel: 3917 4616, email: jleehc@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/jhc_lee/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. F.C.C. Ling, B.Sc., M.Phil., Ph.D. HKU; C.Phys.; M.IEEE; F.Inst.P.
Room 417, Tel: 3917 5248, email: ccling@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/fcc_ling/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. S.C.Y. Ng, B.Sc., M.Phil. HKU; M.S., Ph.D. Stanford
Room 517, Tel: 3917 7947, email: ncy@astro.physics.hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/scy_ng/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Y.J. Tu, B.Sc. USTC; Ph.D. Pennsylvania
Room 419A, Tel: 3917 4662, email: yanjuntu@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/yj_tu/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. C.J. Wang, B.Sc. USTC; Ph.D. Brown
Room 311L, Tel: 3917 7847, email: cjwang@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/cj_wang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Y.X. Zhao, B.Sc. Peking; Ph.D. HKU
Room 420, Tel: 3917 2858, email: yuxinphy@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/yx_zhao/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. M.H. Lee, Associate Professor, Department of Earth and Planetary Sciences (Adjunct with Department of Physics)
James Lee Building Room 318A, Tel: 3917 4817, email: mhlee@hku.hk
web:https://www.earthsciences.hku.hk/people/academic_staff/11/?back=07f5ded7e70fa2be574db14dc869bdc9

Associate Professor (by courtesy)

Prof. B.Z Zhang, Associate Professor, Department of Earth and Planetary Sciences
James Lee Building Room 303, Tel: 2857 8251, email: binzh@hku.hk
web:https://www.earthsciences.hku.hk/people/academic_staff/63/?back=07f5ded7e70fa2be574db14dc869bdc9

Assistant Professors

Prof. M. Gu, B.Sc. NJU; M.A., Ph.D. Harvard
Room 311K, Tel: 3917 7848, email: menggu@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/m_gu/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. T.T. Luu, B.Sc. VNU; M.Sc KAIST; Ph.D. LMU
Room 311A, Tel: 3917 2364, email: ttluu@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/tt_luu/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Z. Wan, B.S. Jilin Univ; Ph.D. Purdue
Room 104E, Tel: 3917 1163, email: zhongwan@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/z_wan/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Y. Yang, B.Sc., M.Sc., Peking; Ph.D. MIT
Room 311E, Tel: 3910 2165, email: yiyg@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/y_yang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Prof. Z.D. Zhang, B.S. HUST; Ph.D. UChicago
Room 311D, Tel: 3910 2164, email: zhendong@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/zd_zhang/?back=af3a6f1ace1fc32210286eb66ab8ef53

Research Assistant Professors

Dr. Y.D. Liao, B.Sc. SCUT; Ph.D. IOPCAS
Hui Oi Chow Science Building Room 217, Tel: 3917 0013, email: ydliao@hku.hk

Dr. L. Pizzimento, B.Sc., M.Sc., Ph.D. Uniroma2
Room 419, Tel: 2859 2549, email: lpizzime@hku.hk

Dr. W.B. Rui, B.Sc., M.Sc. Nanjing; Ph.D. Max Planck Institute for Solid State Research
Hui Oi Chow Science Building Room 228, Tel: 3910 2168, email: wbrui@hku.hk

Dr. Y.P. Xia, B.Sc. HKBU; Ph.D. HKU
Room 416, Tel: 3917 8619, email: xiayp@hku.hk

Dr. D.W. Zhai, B.Sc. BIT; Ph.D. OU
Room 104C, Tel: 3917 4265, email: dzhai@hku.hk

Principal Lecturer

Dr. J.C.S. Pun, B.A., B.S. Roch; M.A., Ph.D. Harv
Room 104D, Tel: 3917 0941, email: jcspun@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/jcs_pun/?back=af3a6f1ace1fc32210286eb66ab8ef53

Lecturer

Dr. K.M. Lee, B.Sc. HKU; Ph.D. Caltech
Room 415A, Tel: 3917 2370, email: kmlee1@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/km_lee/?back=af3a6f1ace1fc32210286eb66ab8ef53

Assistant Lecturer

Dr. Judy F.K. Chow, B.Sc., M.Phil., Ph.D. HKU
Room 104C, Tel: 3917 4265, email: judychow@hku.hk
web:https://www.physics.hku.hk/people/academic_staff/teaching_staff/fk_chow/?back=af3a6f1ace1fc32210286eb66ab8ef53

Post-doctoral Fellows:

Dr. A. Amruth
Dr. Z.D. Bai
Dr. C. Banerjee
Dr. H.C. Chan
Dr. C. Chen
Dr. H.W. Chen
Dr. J.H. Chen
Dr. Y.L. Chen
Dr. Z.Y. Chen
Dr. S. Cheng
Dr. Y.H. Cheng
Dr. J.X. Dai
Dr. K.X. Feng
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Dr. R. Kar Chowdhury
Dr. J.Y. Li
Dr. X. Li
Dr. Z.F. Li
Dr. X. Lin
Dr. Z.K. Lin
Dr. Z.M. Lin
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Dr. S. Wang
Dr. X. Wang
Dr. Z.Q. Wang
Dr. H.X. Xue
Dr. K.B. Zeng
Dr. C. Zhang
Dr. J.C. Zhang
Dr. L. Zhang
Dr. T.Y. Zhang
Dr. X.D. Zhang
Dr. R.X. Zheng
Dr. C.K. Zhou

Honorary / Visiting / Visiting Research Professors:	Prof. G. Chen Prof. B.B. Chen Prof. A.B. Djurisic Prof. D.L. Feng Prof. T.L. Ho Prof. H.Z. Liang Prof. S.A. Maier Prof. A.M.C. Ng Prof. P.H. Schury Prof. T. Ishihara Prof. E.G. Wang Prof. J. Wang Prof. J.P. Xu Prof. S.J. Xu Prof. F.C. Zhang

Clerical & Technical Staff:

IT Technician	Lau Sai Kin, Wong Chi Wing
Technicians	Ai Chunhui, Chan Tak Hong, Ho Wing Kin, Ip Kam Cheong, Lai Kin Fung, Lam Ka Kin
Executive Officer	Carfulin Tam, Anna Wong
Clerks I	Mandy Tse, Queenie Yue
Clerk II	Ken Chow, Arena Liang, Anastasia Tsui, Muses Wong
Office Attendant	Ling Wong

RESEARCH GROUPS/
CENTRE HOUSED IN DEPARTMENT OF PHYSICS, HKU

Condensed Matter Physics group:

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

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

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

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

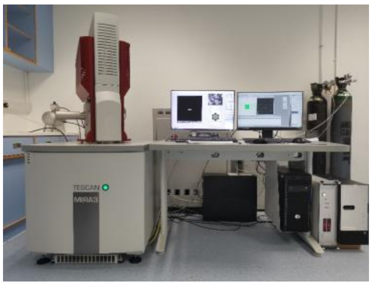
Academic staff: ***Prof. X.D. Cui***
Prof. D.K. Ki
Prof. F.C.C. Ling
Prof. Z.Y. Meng
Prof. S.Q. Shen
Prof. Z. Wan
Prof. C.J. Wang

Prof. M.H. Xie
Prof. W. Yao
***Prof. X.B. Yin** (cross-listing from Optics and Photonics group)*
Prof. S.Z. Zhang
Prof. Z.D. Zhang
Prof. Y.X. Zhao

1. Experimental Condensed Matter and Material Science

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

Prof. Ki's quantum device lab investigates quantum transport phenomena in nano-electronic devices, realized by state-of-the-art nanofabrication and engineering techniques, such as electron-beam lithography and van der Waals assembly techniques. For this, the group is equipped with a complete set of nanofabrication and engineering facilities, such as electron-beam writer, mask-free photolithography system, metal deposition chambers, reactive ion etcher, and home-made micro-manipulators to assemble atomically thin 2D crystals with high precision. There are also two atomic force microscopes (AFMs) to check and clean 2D materials' surfaces. For transport measurements, we have one zero-field 10K CCR



Electron-beam writer

14-T dilution fridge

cryostat, one 100 mK dilution fridge with 14-T magnet, one 400mK He-3 fridge with 12-T magnet, and one 1.8K 9-T PPMS. Current research focuses on discovering new transport phenomena, understanding their microscopic origins, and learning to control their properties. Materials of interest include 2D materials, topological insulators, unconventional magnets, and low-dimensional Perovskite nanostructures as they not only have interesting electronic properties but also offer large experimental flexibilities to study and engineer them. We are also interested in bridging the gap between the fundamental research and real-life applications. More details can be found at https://www.physics.hku.hk/~dkkilab/

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

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

(2) Suppressing or introducing new defects (or defect complex) to control the material properties; or to create new functionality for old materials.

(3) Defect engineering of commercial devices to enhance device performance via industry collaboration.

Current projects of the Materials Physics Laboratory include:

(a) Dielectric materials and dielectric engineering. Aim to enhance the oxide permittivity via introducing acceptor-donor defect complex. It was demonstrated the permittivity of ZnO film and ZnO ceramic can be enhanced to respectively ~200 and ~10000, whereas the enhancement is associated to the correlated barrier hopping between the acceptor-donor defect complex.

(b) Wafer scale high-k van de Waals thin film growth and phase control via defect engineering. This is the ideal material for fabricating the gate of the field effect transistor. The absence of the material daggling bond implies a good gate/channel interface thus less scattering and larger mobility. Wafer scale pure alpha phase Sb_2O_3 van de Waals films was fabricated via controlling the oxygen vacancy with resultant permittivity of ~100.

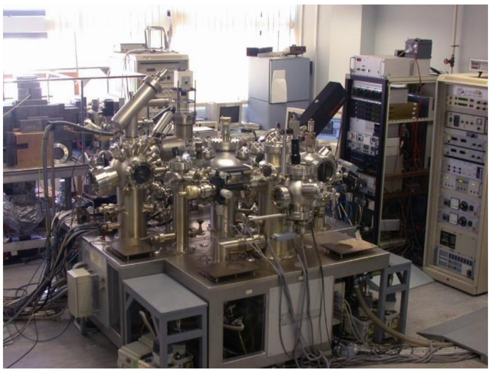
(c) Defect engineering of SiC devices for enhancing device performance. This is a collaborated project with the Mainland industry.

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

Prof. Wan's research lab is dedicated to the design and synthesis of modular hybrid superlattices based on van der Waals materials and molecular intercalants and study its quantum transport properties. By integrating 2D atomic crystals with chemically diversed molecules through scalable, low-temperature assembly routes—including chemical/electrochemical intercalation, exfoliation-coassembly, and spatially confined solid-state conversion—we construct highly tunable quantum materials with tailored structural and electronic landscapes.

Current research activities and plans span three interconnected domains: (1) Structure and Interface Design: We engineer superlattices with chiral architectures, nonlinear optical responses, and large periodicities to enable optical, mechanical, and symmetry-driven effects not accessible in conventional crystals. (2) Functional Electronic Properties: By exploiting molecular doping, ferroic order, and spin–orbit engineering, we tune interlayer coupling and induce emergent behaviors such as ferroelectricity and quantum charge transfer. (3) Emergent Quantum Phases: We explore interface-induced topological states, unconventional superconductivity, and quantum magnetism within artificially layered solids, targeting phenomena governed by Mott transitions, Berry curvature, and Chern topology. To create a new materials platform that underpins future breakthroughs in quantum information, optoelectronics, and correlated quantum physics.

The existing and incoming facility in the lab includes: chemical vapor deposition (CVD) furnaces for material growth and processing. A glove box system for preparing and handling air-sensitive samples. An atomic force microscope (AFM) and a probe station for nanoscale morphology and electronic characterization. A dilution refrigerator, as well as closed-cycle and liquid helium cryostats with optical windows for low-temperature optical and electrical transport measurements. More details can be found at: https://sites.google.com/view/hku-wan-lab/home/openings



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

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

Prof. Z.D. Zhang's research focuses on the preparation, manipulation and detection of ultracold neutral atoms, molecules and ions using laser light, external electric and magnetic fields and high finesse multimode optical cavities. Such quantum experiments inside ultra-high vacuum chambers provide a pristine and versatile platform for the exploration of quantum phases of matter and their dynamics at mesoscopic scale with the precision of atomic physics. The preparation of atoms and molecules close to absolute zero temperature also offers unique opportunities for discovering laws governing ultracold chemistry, where quantum superposition and entanglement dominates the reaction process. His recent research includes the realization of the transition from an atomic to a molecular Bose-Einstein condensate (BEC), observation of the associated quantum many-body chemical reaction process and novel quantum dynamics in periodically driven atomic BECs.

2. Theoretical and Computational Condensed Matter

The current research interests include:

(1) strongly correlated electron systems (Z.Y.Meng, C.J.Wang, S.Z. Zhang);

(2) topological matter (Z.Y.Meng, S.Q.Shen, C.J.Wang, W.Yao, Y.X. Zhao);

(3) quantum materials (Z.Y.Meng, S.Q. Shen, W.Yao, S.Z. Zhang);

(4) quantum magnetism (Z.Y. Meng);

(5) spintronics and valleytronics (W.Yao);

(6) quantum transport (S.Q. Shen, S.Z. Zhang, W.Yao);

(7) semiconductor optics (S.Q.Shen, W.Yao);

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

physics (S.Z.Zhang)

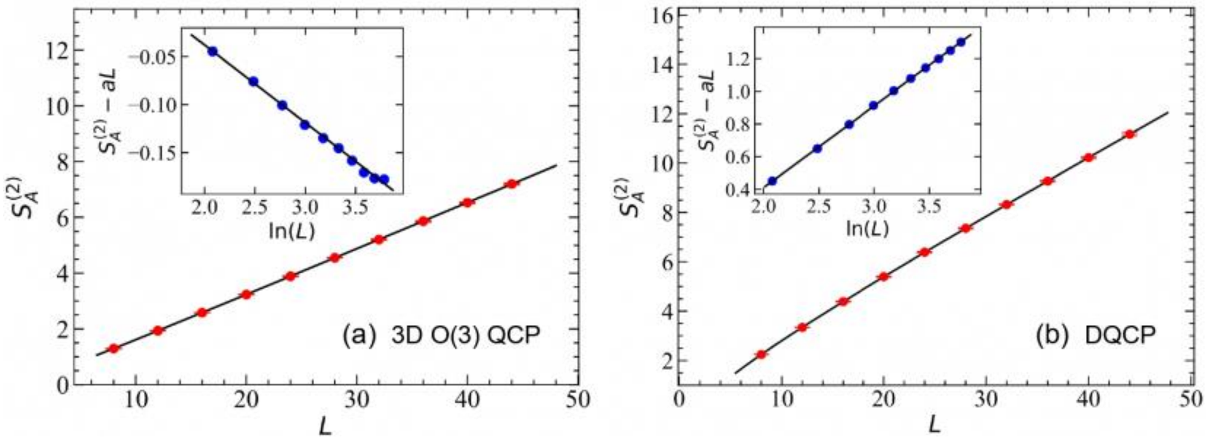
(9) computational approaches in quantum many-body systems (Z.Y.Meng, C.J.Wang)

(10) scientific computing and neuromorphic AI accelerator in physics (Z.Y.Meng)

(11) crystal symmetry (Y.X. Zhao)

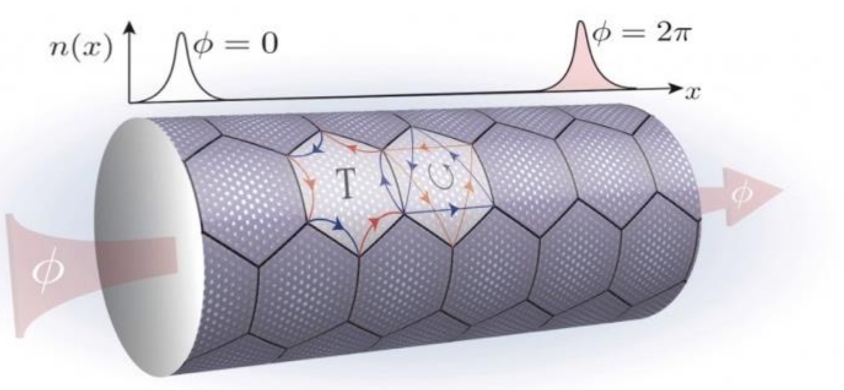
The research activities of theoretical and computation condensed matter physics cover almost the full spectrum of modern condensed matter physics research, from strongly correlated electron systems, topological state of matter, quantum computation and magnetism, transports and spin and valleytronics,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

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



Scaling of the entanglement entropy indicates the non-trivial DQCP

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



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

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

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

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

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

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

Facilities

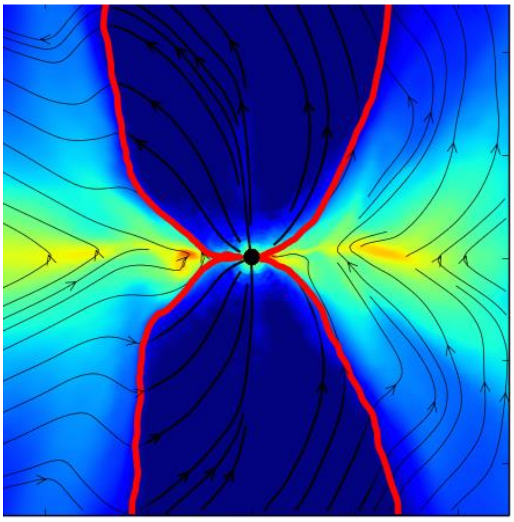
A summary of the major facilities include Multi-chamber UHV system consisted of MBE, STM, UPS, and LEED facilities, low-temperature (4K) STM, Pulsed laser deposition system, RF sputtering system and electron beam evaporators, micro-optics system for photoluminescence and Raman spectroscopy and pump-probe spectroscopic systems, Home-assembled large ultra-precise magneto-photoluminescence system, Comprehensive semiconductor parameter analyzing system, Scanning electron microscope with E-beam lithography function, Superconducting magnet, 9T with closed cycled cooling system, Ultralow temperature cryogen-free measurement system with 14-T and 12-T superconducting magnets, 9-T Physical Properties Measurement System (PPMS).

Astrophysics group:

The group's research covers the most active areas in contemporary astronomy and astrophysics, including high-energy astrophysics, multi-messenger astrophysics, stars (stellar evolution), compact objects (black holes, neutron stars, and white dwarfs), planets (exoplanets and the solar system), galaxies, active galactic nuclei, and cosmology.

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

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

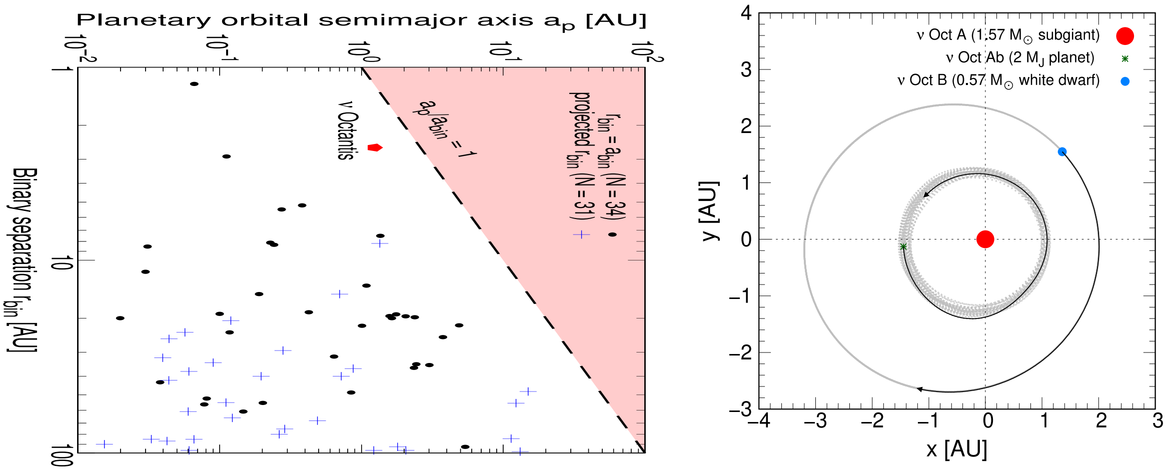


Snapshot from a state-of-the-art GRMHD simulation of a super-Eddington accretion disk around a black hole and the relativistic jet launched

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

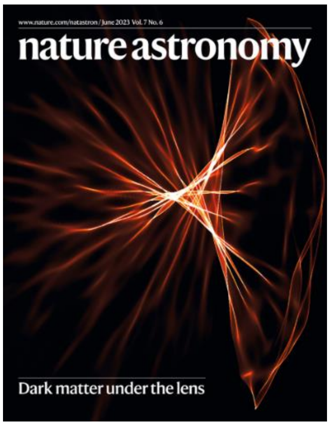
Prof. Lee is a planetary dynamicist who works on the formation and dynamical evolution of planetary bodies (planets, moons, etc.) in our Solar System and in planetary systems around other stars. He is also an expert in numerical methods for dynamical simulations of planetary systems. His current research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

System, and (4) the satellite systems of Jupiter, Uranus and Pluto-Charon.



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

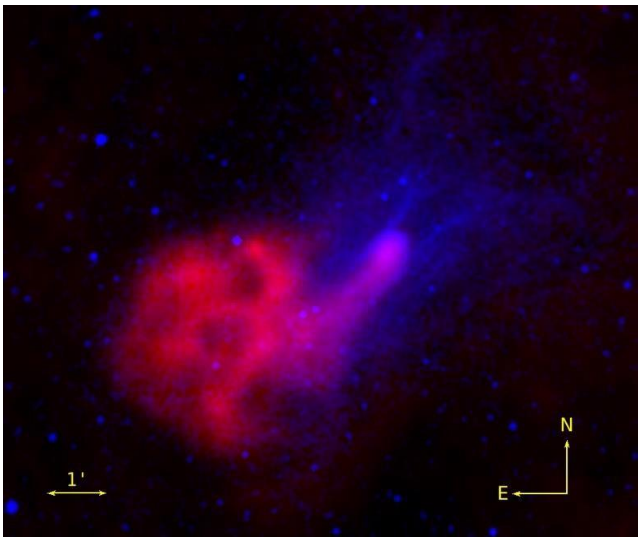
Prof. Lim is an observational astronomer whose work has made significant impact across many different fields in astrophysics, from the formation of binary star systems to the magnetospheres of Sun-like stars to the atmospheres of evolved stars, star formation and active supermassive black holes in nearby galaxies, as well as the physics of galaxy clusters. At the present time, the primary focus of his research team is on the astrophysical applications of gravitational lensing, which includes searchers for and studies of galaxies in the early Universe, although the main emphasis is on addressing the nature of Dark Matter - specifically, whether Dark Matter comprises ultra-massive particles such as WIMPs or ultra-light particles such as Axions. Prof. Lim leads a large team of postdoctoral fellows, PhD students, MPhil students, undergraduate students, and sometimes also high-school students seeking work experience. Their research work has been featured in the popular press, as well as on the cover of Nature Astronomy reporting evidence from gravitational lensing that Dark Matter may comprise ultra-light particles that display wave-like behaviour on astronomical scales.



The complex pattern of caustics created by quantum interference of ultra-light Dark Matter particles. Such particles, when concentrated into the halos of galaxies, generate gravitationally-lensed images in seeming agreement with those observed.

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

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



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

be found at the webpage https://astro.physics.hku.hk/~ncy/.

Prof. Zhang is a theoretical astrophysicist actively collaborating with observers. His research covers a wide range of topics in the area of high-energy, multi-messenger astrophysics. Research topics include black holes of all sizes, neutron stars of different species, relativistic jets launched from these systems and their interactions with the ambient medium, the physics of astrophysical transients, and applying them as cosmic probes to study cosmology and constrain fundamental physics. The research is multi-wavelength (data from the entire electromagnetic spectrum from radio all the way to TeV gamma-rays) and multi-messenger (including gravitational waves, neutrinos, and cosmic rays, besides the traditional electromagnetic radiation) in nature. The three areas that take up most of Prof. Zhang's time include gamma-ray bursts (GRBs) and their softer siblings known as fast X-ray transients (FXTs), fast radio bursts (FRBs), as well as electromagnetic/neutrino counterparts of gravitational wave events. Prof. Zhang's research has three modes: in the solo mode, he writes single-author books, reviews, and research papers; in the small-collaboration mode, he works with his students/postdocs to carry out cutting-edge theoretical, computational, and observational research projects in many frontier areas listed above; and in the large-collaboration mode, he plays a leading role in several large-collaboration teams to carry out discoveries and observations of new phenomena and provide timely theoretical guidance to these teams. Currently, he is one of the leaders of the FAST (Five-hundred-meter Aperture Spherical Telescope) FRB Key Science Project (served as PI of the Project from 2020-2025), Chair of the multi-messenger science topical panel and member of science management committee of the Einstein Probe mission, and Mission Scientist of the Chinese-French GRB mission SVOM (Space Variable Objects Monitor).

Facilities

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

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

Quantum Information Science group:

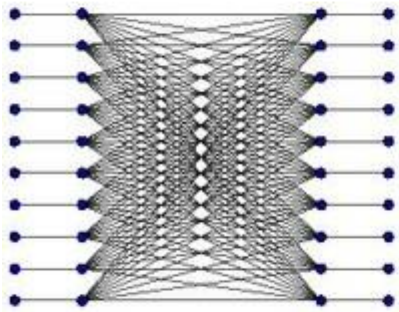
Quantum information science is the study of information processing using the laws of quantum mechanics, rather than classical physics. Quantum information processing promises to revolutionize information processing as we know it today. On one hand, quantum computing offers an exponential speed-up to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

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

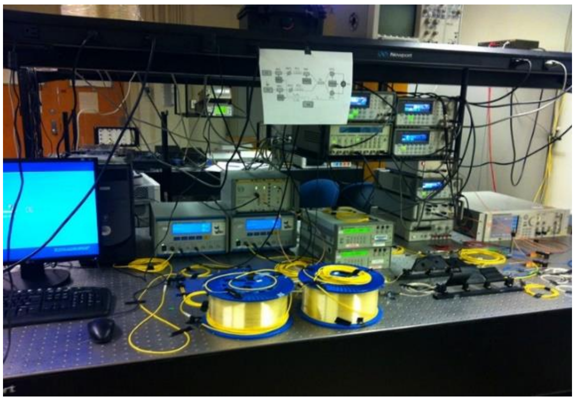
Traditionally, the quantum information science group has been strong on the theoretical side. With the recent establishment of the Institute for Advanced Quantum Study, we are going to expand in this area, both theory and experiment.

Academic staff: ***Prof. H.F. Chau***
Prof. G. Chiribella (by courtesy)
Prof. S. Z. Zhang* (cross-listing from condensed matter physics group)

"Twin-field" quantum key distribution



All photonics quantum repeaters graph states



Prof. Hoi-Kwong Lo's lab

IBM super-conducting quantum processors

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

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

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

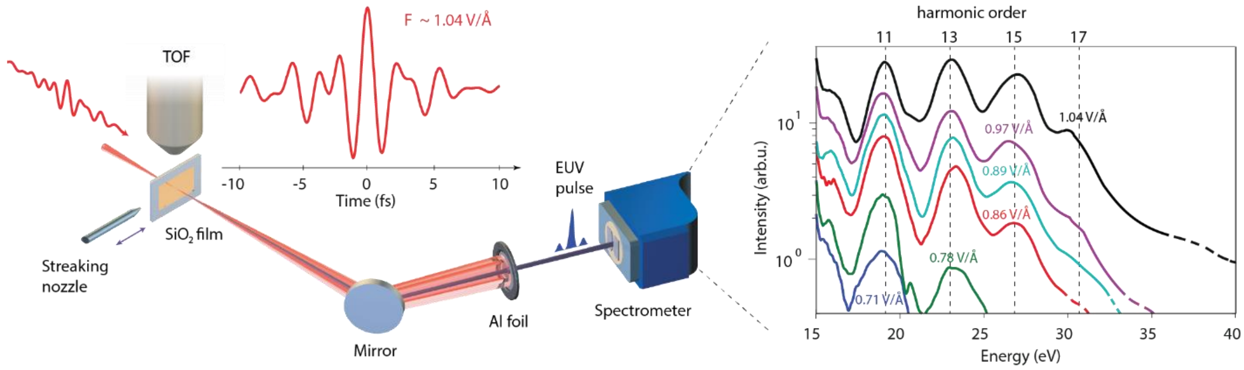
Optics and Photonics group:

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

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

Academic staff: *Prof. T.T. Luu*
Prof. Y. Yang
Prof. X.B. Yin (by courtesy)
Prof. S. Zhang

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



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

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

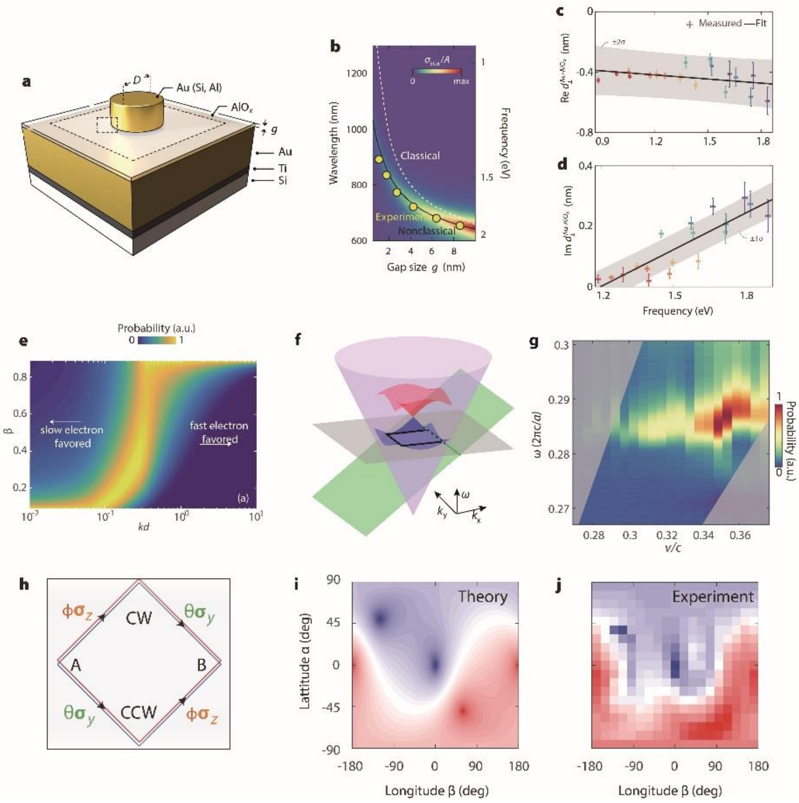
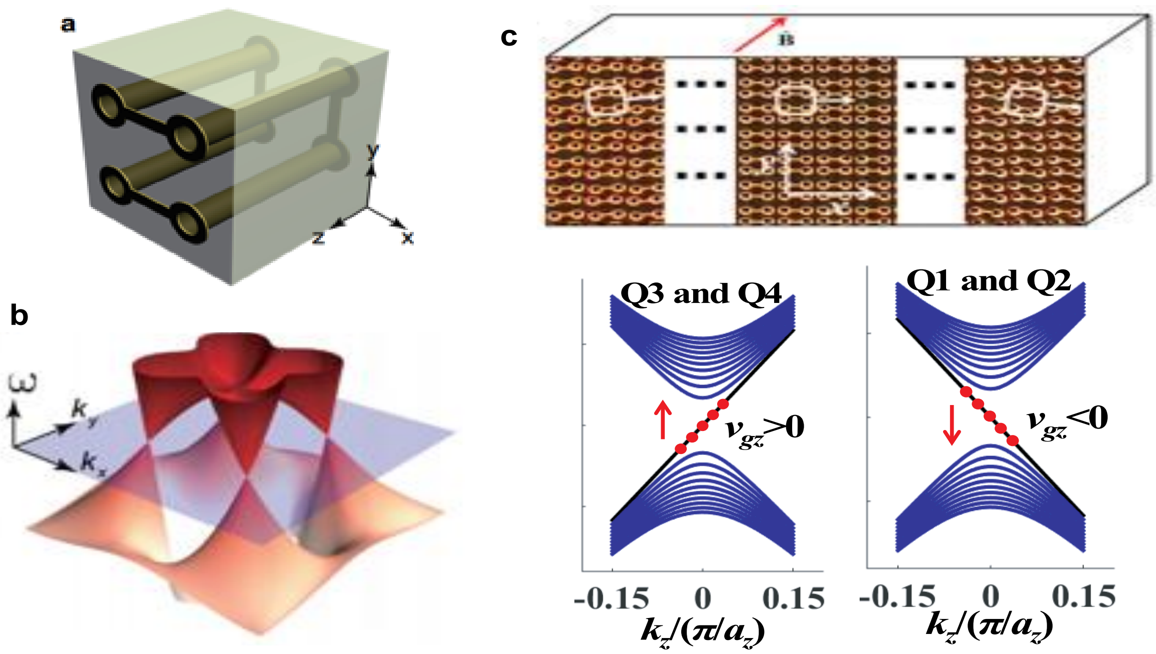


Figure. Photons interacting with material electrons, free electrons, and synthetic gauge fields. a-d. A general nanoscale electromagnetic framework and the experiment that measured its Feibelman d parameter. e-g. An upper limit to spontaneous free-electron radiation and the measured enhanced interaction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

Professor X. B. Yin's research centres on the optical and electrical characteristics of nanomaterials and metamaterials. His team has developed advanced ultrafast laser spectroscopy techniques and uncovered unique structural and excitonic parity symmetries in 2D semiconductors. They were the first to convert spin-orbit physics in solid-state systems into photonics, allowing manipulation of spin-orbit interactions of photons in optical metamaterials. Additionally, his research on optical metamaterial has led to the pioneering large-scale demonstration of passive radiative cooling, a new method for space cooling that requires no electricity. The group currently engages in a broad range of research and activities, including designing and fabricating optoelectronic devices and producing structured metamaterials for energy and sustainability solutions. Current projects involve investigating spin-orbit physics in metamaterials, developing free-space electron optics, and exploring optical technologies at the intersection of food, energy, and water resources.

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



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

Nuclear and Particle Physics group:

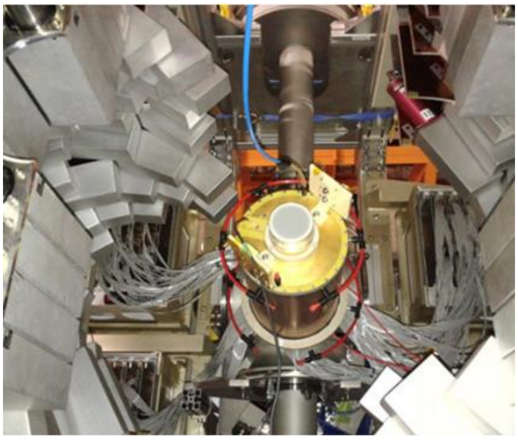
The group is established as part of the Joint Consortium for Fundamental Physics by three universities in Hong Kong – HKU, CUHK and HKUST, through which we participate in international collaborations on big science.

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

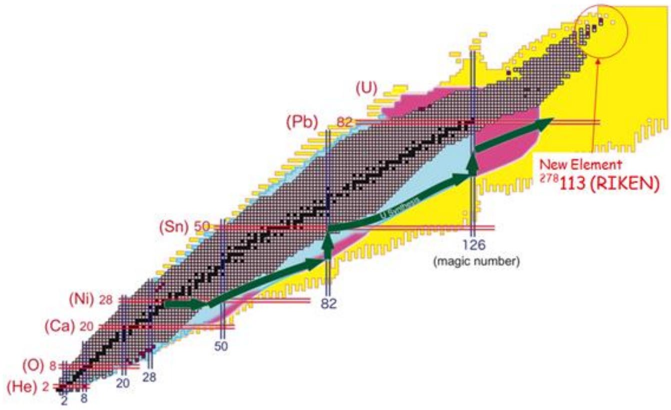
Prof. Lee is a leader of the experimental nuclear physics sub-group. Nuclear physics aims at understanding the structure of atomic nuclei and the nature of fundamental forces, addressing a big science question on how the heavy elements from Iron were synthesized in the universe which is governed by the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

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

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



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



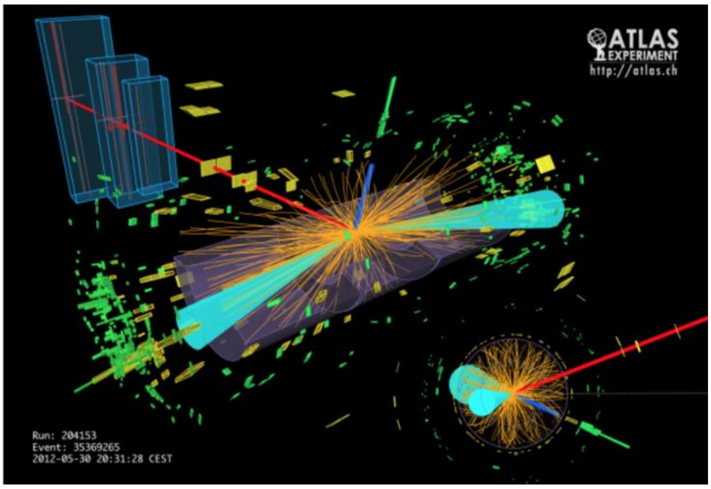
Nuclear Chat. The horizontal and vertical axes represent N and Z, respectively

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

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

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

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



A collision event at the ATLAS

State Key Laboratory of Optical Quantum Materials
光量子物質全國重點實驗室

Launched on July 1, 2025, the State Key Laboratory of Optical Quantum Materials (OQM Lab) is a world-class research hub led by The University of Hong Kong (HKU). Positioned at the forefront of photonics and condensed matter physics, the lab harnesses Hong Kong's global connectivity to drive pioneering collaborations tackling challenges in quantum information, sensing, and advanced materials. Under the leadership of HKU President Professor Xiang Zhang, the lab unites top scientists, with half from HKU's Physics Department, alongside experts from HKUST and CityU, to explore multi-degree-of-freedom light matter interactions.

Our research centers on manipulating light's properties—such as spin, orbital angular momentum, and electron's degrees of freedom, such as valley, spin — using innovative materials like metamaterials, 2D semiconductors, and moiré superlattices. These efforts fuel advancements in ultra-fast optical computing and quantum devices.

For students, the newly launched OQM Lab offers exciting opportunities to engage in groundbreaking research. Join as a postgraduate to work on projects blending theory, experiment, and application. Whether passionate about quantum physics or nanotechnology, OQM Lab empowers you to shape the future.

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

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

The institute is composed of Regular Members from the University of Hong Kong (HKU) and Associate Members from other sister institutions. Together, these members will work on cutting-edge research in quantum science and technology, with a focus on quantum information, quantum materials, and quantum AI, among other areas.
The Department of Physics at HKU is proud to have a distinguished team of members who are significantly contributing to the efforts of the institute. Our professoriate staff members include Prof. CHAU Hoi Fung, Prof. CHIRIBELLA Giulio, Prof. CUI Xiaodong, Prof. KI Dongkeun, Prof. MENG Zi Yang, Prof. SHEN Shunqing, Prof. WANG Chenjie, Prof. WANG Zidan, Prof. XIE Mao Hai, Prof. YAO Wang, Prof. YANG Yi, Prof. YIN Xiaobo, Prof. ZHAO Yuxin, Prof. ZHANG Shizhong, Prof. ZHANG Shuang, and Prof. ZHANG Xiang.

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

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

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

Full-time MPhil and PhD students who hold a first degree with second-class honours first division (or equivalent) or above are normally considered eligible to receive a Postgraduate Scholarship (HK$19,135 per month) during the normative study period. This year we expect to admit a large number of postgraduate students. Students please visit the homepage of HKU graduate school at https://gradsch.hku.hk/gradsch/ and get the information as well as application forms there.

For other details, please contact Prof. X.D. Cui (Tel. 3917 8975, email address: xdcui@hku.hk), Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong.

SPECIFIC RPG RESEARCH PROJECTS AVAILABLE WITHIN THE DEPARTMENT OF PHYSICS

Condensed Matter Physics group:

Project XDC01: Optical Properties in Emerging 2 Dimensional Materials

Supervisor: Prof. X.D. Cui

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

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

Supervisor: Prof. D.K. Ki

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

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

Supervisor: Prof. D.K. Ki

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

Project CCL01: High dielectric constant oxides via defect functionalization

Supervisor: Prof. C.C. Ling

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

Ref
[1] 'Electron-pinned defect dipoles in (Li,Al) co-doped ZnO ceramics with colossal dielectric permittivity', Dong Huang, Wen-Long Li, Zhi-Fu Liu, Yong-Xiang Li, Cuong Ton-That, Jiaqi Cheng, Wallace C. H. Choy, and Francis Chi-Chung Ling, J. Mater. Chem. A 8, 4764 (2020). Editor chosen as journal issue cover.
[2] 'High dielectric transparent film tailored by acceptor and donor co-doping', D. Huang, Y. Shi, M. Younas, R.T.A. Khan, M. Nadeem, K. Shati, M. Harfouche, U. Kentsch, Z. Liu, Y. Li, S. Zhou, A. Kuznetsov and F.C.C. Ling, Small 18, 2107168 (2022). Editor chosen as featured article.
[3] 'Wafer-scale PLD-grown high-$\varkappa$ GCZO dielectrics for 2D electronics', Jing Yu, Guoyun Gao, Wei Han, Changting Wei, Yueyang Wang, Tianxiang Lin, Yianyu Zhang, Zhi Zheng, Dong-Keun Ki, Hongyuan Zhang, Man Ho Ng, Hang Liu, Shuangpeng Wang, Hao Wang and Francis Chi-Chung Ling, Advan. Electron. Mater. 8, 2200580. Editor chosen as featured article.
[4] 'Two-dimensional molecular crystal Sb2O3 for electronics and optoelectronics', Jing Yu, Wei Han, Ruey Jinq Ong, Jing-Wen Shi, Suleiman, Abdulsalam Aji Abdulsalam, Kailang Liu, Francis Chi-Chung Ling, Applied Physics Review 11, 021326 (2024). Editor chosen as featured article.

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

Supervisor: Prof. C.C. Ling

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

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

Ref.

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

Project CCL03: Defects in functional oxides

Supervisor: Prof. C.C. Ling

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

Ref.

- 'Correlation between small polaron tunnelling relaxation and donor ionization in Ga2O3', Ying-Li Shi, Dong Huang, Francis Chi-Chung Ling, Qi-Sheng Tian, Liang-Sheng Liao, Matthew R Phillips, Cuong Ton-That, Appl. Phys. Lett. 120, 172105 (2022).
- 'Non-volatile optoelectronic memory based on a photosensitive dielectric', Rui Zhu, Huili Liang, Shangfeng Liu, Ye Yuan, Xinqiang

Wang, Francis Chi-Chung Ling, Andrej Kuznetsov, Guangyu Zhang, Zengxia Mei, Nat. Commum. 14, 5396 (2023). Editor chosen as featured article

Project ZYM01: Fundamental properties of metallic quantum critical point

Supervisor: Prof. Z.Y. Meng

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

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

Project ZYM02: Thermodynamics and dynamics in quantum magnets

Supervisor: Prof. Z.Y. Meng

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

In this project, we will employ and develop Density Matrix Renormalization Group (DMRG) and Tensor-network Renormalization Group (TRG) methods, combined with quantum Monte Carlo (QMC) calculations, to find way to calculate phase transition and thermodynamic properties of quantum many-body models, and then compare the obtained results with experimental results of promising quantum magnetic compounds which might realize quantum spin liquid states or other novel quantum many-body phases and phase transitions. These comparisons would help us to find the correct model description of the quantum magnetic systems and could eventually lead to discovery of quantum states of matter that are beyond the Landau-Ginzburg-Wilson paradigm of phases and phase transitions. Example including deconfined quantum critical point, in which the emergent spinon and gauge field are strongly coupled with each other [such as in Phys. Rev. B 98, 174421

(2018) Editors' Suggestion]. To pursue the understanding of interaction effects on topological state of matter, such as the validity of topological index in the interaction-driven topological phase transitions, the identification and classification of emergent bosonic and fermionic symmetry protected topological phases in interacting models [such as in Phys. Rev. B 93, 115150 (2016)]; to reveal the duality relations between the interaction-driven topological phase transition and the deconfined quantum critical point via numerical investigations [such as in Phys. Rev. X 7, 031052 (2017)]. We will continue our pursuit along this line to build the new paradigm of quantum phase transitions.

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

Supervisor: Prof. Z.Y. Meng

The futuristic advancement in technology will involve, to a large extent, the engineering of artificial intelligence into almost all aspects of our industry. The widespread adoption of AI is becoming increasingly challenging to 1) remain sustainable at the current power consumption rate, and 2) become comparable with human intelligence.

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

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

Supervisor: Prof. S.Q. Shen

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

Project ZW01: Tailored Quantum Phases in Hybrid Functional Superlattices

Supervisor: Prof. Z. Wan

This project explores a new class of quantum materials through the modular integration of van der Waals (vdW) atomic crystals and functional molecular intercalants. By constructing hybrid superlattices with programmable structures and interactions, we aim to investigate emergent electronic and quantum phases engineered at the atomic scale. Using scalable assembly techniques—including chemical/electrochemical intercalation and space confined conversion—these layered materials enable precise modulation of lattice symmetry, molecular chirality, and interfacial electronic structure.

A key focus is on accessing nontrivial quantum states such as Mott insulating phases, interface-induced ferroelectricity, and topological superconductivity through designed coupling across structurally distinct layers. Experimental tools including low-temperature magneto-transport and optical characterization will be used to probe spin–orbit interactions, charge ordering, and interlayer coherence. The integration of theory—via ab initio and model Hamiltonian approaches—will guide material choice and interpret emergent behavior.

By combining atomic precision in structure design with functionality encoded at the molecular level, this project aims to realize artificial quantum materials with applications in quantum sensing, information transduction, and low-dimensional correlated physics.

Project ZW02: Quantum Emergence in Molecularly Tuned 2D Unconventional Superconductors

Supervisor: Prof. Z. Wan

This project explores emergent quantum phenomena in two-dimensional unconventional superconductors via experimental construction and characterization of molecularly engineered van der Waals heterostructures. By intercalating functional organic molecules—such as those with magnetic, ferroelectric, or chiral properties—into layered inorganic superconductors (e.g., TaS_2, $NbSe_2$), we assemble hybrid superlattices with tunable symmetry breaking and interface coupling. Scalable electrochemical and chemical intercalation methods will be employed to produce low-defect, atomically precise crystalline systems exhibiting controllable periodic potential and layer alignment.

The research will leverage low-temperature magneto-transport techniques, including critical field and critical current measurements under variable temperature and magnetic field conditions, to identify unconventional pairing signatures and non-reciprocal transport behavior. Electronic transport study under gate-controlled conditions will enable direct imaging of superconducting gaps, quasiparticle interference patterns, and local density of states evolution.

Special emphasis will be placed on systems with non-centrosymmetric interfaces, where observations such as superconducting diode behavior and half-quantum flux interference may indicate the emergence of topological features. Through careful device fabrication and multi-field experimental probing, the project aims to uncover structure–electronic property relationships, and establish a versatile platform for controlling exotic superconducting states in atomically engineered materials.

Project CJW01: Topological and Quantum Critical Phases of Matter with Strong Interaction
Supervisor: Prof. C.J. Wang

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

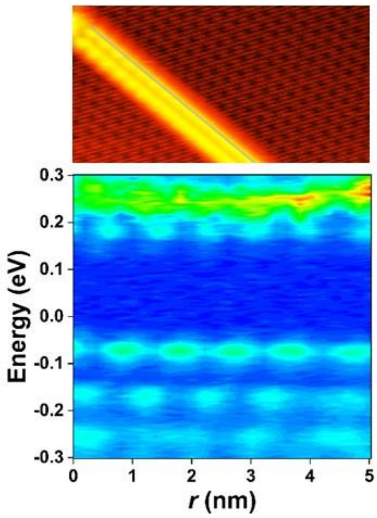
Project CJW02: Localization Physics
Supervisor: Prof. C.J. Wang

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

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

Supervisor: Prof. M.H. Xie

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



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

optoelectronic, spin- and valley-tronic applications. In this project, ultrathin films of 2D materials and their heterostructures will be fabricated by molecular beam epitaxy and characterized by the surface tools, such as electron diffraction (LEED/RHEED), scanning tunneling microscopy and spectroscopy (STM/S), ultraviolet photoemission spectroscopy (UPS), etc. Attention will be paid towards the physics related to low dimensionality, quantum confinement, localization and electron interaction in 2D films and heterostructures.

Project WY01: Valley-spintronics in 2D materials
Supervisor: Prof. W. Yao

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

Project WY02: Moiré superlattice physics in van der Waals structures
Supervisor: Prof. W. Yao

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

Project SZZ01: Transport properties of strongly interacting systems
Supervisor: Prof. S.Z. Zhang

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

Project ZDZ01: All-optical trapping of ultracold ions in a multimode optical cavity
Supervisor: Prof. Z.D. Zhang

We are developing an all-optical trapping scheme for ultracold ions in programmable and deep micro-traps formed by the superposition of degenerate transverse modes within a multimode optical cavity. This eliminates the issue of micromotion of ions in conventional radiofrequency driven Paul traps, thus enabling controllable collisions between ions and neutral atoms in the ultracold single partial wave regime. The same concentrated modes in the cavity also allow local and efficient readout of ionic quantum states. This apparatus promises a new paradigm for the exploration of quantum many-body physics, ultracold chemistry and quantum information processing.

Project ZDZ02: Exploration of impurity physics with ultracold ions and Rydberg atoms in degenerate quantum gases
Supervisor: Prof. Z.D. Zhang

This project investigates impurity physics by studying the interactions of ultracold ions or Rydberg atoms with quantum degenerate gases. By embedding impurities such as ions and Rydberg atoms into ultracold atomic environments, the research aims to understand the fundamental many-body phenomena, including polaron formation, impurity-induced correlations and collective excitations. The study employs advanced laser cooling and trapping and spectroscopic techniques to manipulate and monitor impurity dynamics within Bose-Einstein condensates and degenerate Fermi gases. Insights gained from this work have significant implications for quantum simulation, condensed matter analogs, and the development of hybrid quantum systems. Ultimately, the project seeks to deepen our understanding of impurity behavior in strongly interacting quantum environments, contributing to the broader field of quantum many-body physics.

Project ZDZ03: Quantum chemistry with ultracold atoms, molecules and ions strongly coupled to a high-finesse optical cavity
Supervisor: Prof. Z.D. Zhang

This project explores the forefront of quantum chemistry through the strong coupling of ultracold atoms, molecules, and ions with a high-finesse optical cavity. By integrating rich quantum systems within a cavity quantum electrodynamics (QED) framework, the research aims to investigate and manipulate fundamental chemical interactions at the quantum level. The setup enables precise control and detection over electronic, vibrational, rotational and photonic states, facilitating the study of bond formation, energy transfer, and reaction dynamics in an ultracold quantum regime. This work promises to open new pathways for understanding and controlling state-to-state quantum chemistry.

Project YXZ01: Non-standard symmetry classes of solids
Supervisor: Prof.. Y.X. Zhao

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

Project YXZ02: Topological classifications of projective symmetry classes
Supervisor: Prof.. Y.X. Zhao

The most fundamental notion of symmetry protected topological matter is that: Symmetry determines possible topological classifications. So far, topological classifications of non-interacting fermions have been completely solved for the tenfold Altland-Zirnbauer symmetry classes and thoroughly investigated for 230 space groups. Recently, we have applied the idea of projective symmetry to extended crystal symmetry classes. The aim of this project is to classify topological phases under certain projective crystal symmetry classes, and thereby to discover novel topological phenomena embodying intrinsic projective symmetry.

Project YXZ03: Quantum anomalies in non-linear sigma models
Supervisor: Prof.. Y.X. Zhao

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

Project XBY01: Electron Microscopy and Spectroscopy in Air
Supervisor: Prof. X.B. Yin

Focused electron beam technology has been extensively used for nanoscale imaging, spectroscopy, and material. In this project, we aim to develop an electron beam instrument capable of operating in air, at ambient atmospheric pressure (1 atm) for imaging and fabrication. This is enabled through a vacuum-sealing and electron-permeable membranes, which encapsulates the entire electron optics column and isolates it from the surrounding environment. This development will result in a focused electron beam tool for nanoscale imaging and cathodoluminescence spectroscopy studies of materials, regardless of their physical state (solid or liquid) or electrical properties (conductive or insulating, organic or inorganic). In addition to this core development, various related topics and projects are under exploration, including interface assembling at the liquid-vapor and liquid-liquid interfaces, correlated light and electron imaging, in situ observation of interface phase transitions (e.g., condensation or ice nucleation at the water surface) with reactive flows, in situ imaging of electrochemical cells or batteries, and electron beam-guided or induced thin film growth and/or etching. All were not possible under a conventional electron microscope.

Astrophysics group:

Project LXD01: Black Hole Accretion Disk & Jet Simulations

Supervisor: Prof. L.X. Dai

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

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

Project LXD02: Theory/Simulations of Tidal Disruption Events

Supervisor: Prof. L.X. Dai

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

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

Project LXD03: Black Hole X-Ray Reflection & Reverberation
Supervisor: Prof. L.X. Dai

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

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

Project MG01: The Initial Mass Function In Early-Type Galaxies
Supervisor: Prof. M. Gu

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

the IMF variation is still an open and crucial question. The following independent projects on this topic are available for PhD/ MPhil students:
1). Stellar IMF measurement with near infrared spectroscopy
2). The local IMF variation from stellar population synthesis modeling and dynamical constraints

Project MG02: Environmental Impact on Galaxy Evolution
Supervisor: Prof. M. Gu

The environment affects galaxy quenching and star formation activity, leaving imprints on their stellar populations. For example, a measurement of the relative abundance between alpha-elements and iron in early-type galaxies can be used to indicate the past star formation timescales due to its sensitivity to the time delay between type II and type Ia supernova. Previous studies revealed massive galaxies are older, more metal-rich, and more α–enhanced. A direct way to study the environmental dependence is to observe and compare satellite galaxies in the same groups and clusters. Another way to explore the topic is to compare the inner and outer region of massive galaxies, and even the intra-cluster light, to compare the stellar components dominated by in-situ and ex-situ processes. The following independent projects on this topic are available for PhD/ MPhil students:
1). Environmental Dependence of Stellar and Gas-phase Chemistry in Groups and Clusters at redshift 0.1
2). Origin of Stellar Halo & the ICL in Massive Galaxy Clusters

Project MHL01: Dynamics and Origins of Planetary Systems
Supervisor: Prof. M.H. Lee (Adjunct with Department of Physics)

Extrasolar planet searches have now yielded thousands of planets around other stars. The discoveries include planetary systems with two or more detected planets and planets in binary star systems. Multiple- planet systems and, in particular, those with planets in or near orbital resonances provide important constraints on the formation and dynamical evolution of planetary systems. We are investigating the current dynamical states and origins of resonant planetary systems and planets in binary star systems. In addition, there are projects related to the formation and dynamical evolution of the planets and their satellites in our Solar System. Prior knowledge of classical mechanics and numerical methods would be an asset.

Project JJLL01: Astrophysical Applications of Gravitational Lensing

Supervisor: Prof. J.J.L. Lim

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

Project JJLL02: Link between ICM Thermodynamics and BCG Activity

Supervisor: Prof. J.J.L. Lim

The thermodynamics of the intracluster medium (ICM) encode both the physical properties and evolutionary history of galaxy clusters. At cluster cores, however, the ICM thermodynamics are deemed to be locally dictated by a close balance between cooling owing to radiative loss (in X-rays) and reheating by an active galactic nucleus (AGN) in brightest cluster galaxies (BCGs) - constituting our most cherished example of AGN regulation of gas cooling and star formation. Yet, paradoxically, BCGs displaying the most powerful AGN jets preferentially reside in clusters possessing the densest and coolest ICM at their cores; moreover, such clusters preferentially host BCGs displaying star formation fuelled by molecular gas, attesting to effective ICM cooling that ought to leave less-dense and warmer ICM at cluster cores. From detailed study of a small sample of cluster, we have found the ICM thermodynamics and BCG star formation are strictly related to the cluster dynamical state: the results implicate cluster mergers for disrupting dense-cool cores and generating turbulence to provide additional pressure support, after which a progressively denser and cooler core develops as the cluster dynamically relaxes and the ICM again approaches hydrostatic equilibrium. Once a sufficiently dense and cool is re-established, effective ICM cooling resumes - despite AGN reheating - to sustain persistent star formation in BCGs, creating a pathway for the stellar growth of these giant galaxies. We are currently expanding our study to many more clusters to test the broad applicability of our preliminary findings.

Project CYN01: Mapping the Magnetic Fields of Pulsar Wind Nebulae

Supervisor: Prof. S.C.Y. Ng

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

Project BZ01 - Fast radio bursts: physical mechanisms and as a tool to study cosmology

Supervisor: Prof. B. Zhang

Fast radio bursts (FRBs) are bright radio bursts originating from cosmological distances. They are one of the remaining enigmas in contemporary astrophysics. Discovered in 2007 and confirmed in 2013, tremendous progress has been made in recent years to understand the physical origins of these events, as well as using FRBs as cosmological probes to study the universe and fundamental physics.

This project aims to study the physical mechanisms of FRBs using observations or theoretical modeling, and to use FRBs as cosmological beacons to study the universe. Depending on the physical training and personal interest of the students, the project can be channeled into three sub-directions: 1. Performing theoretical modeling of FRBs, their sources, and their environments; 2. Analyzing the observational data from China's Five-hundred-meter Aperture Spherical Telescope (FAST) to study the properties and classifications of FRBs; 3. Making use of FRBs as cosmological probes.

References:

- B. Zhang, "The physics of fast radio bursts", 2023, Reviews of Modern Physics, 95 (3), 035005
- B. Zhang, "The physical mechanisms of fast radio bursts", 2020, Nature, 587, 45-53

Project BZ02 - Gamma-ray bursts, fast X-ray transients, and electromagnetic counterparts of gravitational waves

Supervisor: Prof. B. Zhang

Gamma-ray bursts (GRBs) are the most luminous explosions in the universe since the Big Bang. Some are related to the core collapse of massive stars upon death, while others are gravitational wave (GW) sources that signal mergers of two neutron stars. This is still an active area of research, especially with the successful launch and operation of the Chinese-French GRB satellite SVOM. Fast X-ray transients (FXTs) are new types of high-energy transients whose mysteries are being unveiled recently with the observations made by China's space mission Einstein Probe (EP). We now know that at least some FXTs are the softer and less energetic version of GRBs, but some others might have novel origins. In particular, there might be FXTs associated with GWs.

This project aims to use a multi-wavelength (from radio to gamma-ray electromagnetic emission) and multi-messenger (combining gravitational waves with electromagnetic signals and possibly neutrino signals) approach to study the physical origin of FXTs and their connections to GRBs and GWs. Depending on the physical training and personal interest of the students, the project can be channeled into two sub-directions: 1. Performing theoretical modeling of GRBs, FXTs, or electromagnetic counterparts of GWs; 2. Analyzing the observational data from the EP mission or the SVOM mission in collaboration with large mission teams to study the physical properties of FXTs and GRBs.

References:

- B. Zhang, "The physics of gamma-ray bursts", 2018, Cambridge University Press, DOI: 10.1017/9781107027619
- P. Kumar & B. Zhang, "The physics of gamma-ray bursts & relativistic jets", 2015, Physics Reports, 561, 1-109
- H. Sun et al. "A fast X-ray transient from a weak relativistic jet associated with a type Ic-BL supernova", 2025, Nature Astronomy (https://www.nature.com/articles/s41550-025-02571-1)

Quantum Information Science group:

Project HFC01: Quantum Information Theory

Supervisor: Prof. H.F. Chau

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

Optics and Photonics group:

Project TTL01: Ultrafast spectroscopy of condensed matters

Supervisor: Prof. T.T. Luu

We have been actively working on and contributing to the field of high-order harmonic generation in solids and its spectroscopic applications. Once we drive a condensed matter system using a strong electric field that is beyond perturbation regime, ultrafast electronic currents, generated inside the materials, give rise to the generation of coherent, intense extreme ultraviolet radiation in the form of high-order harmonics. Careful observation of these harmonics and the related time-resolved measurements would allow us to study very interesting electronic properties and dynamics of the involved system. In this project, we will first construct a state-of-the-art experimental apparatus (involving high power laser pulses and its applications in nonlinear optics) that would not only allow us to do attosecond streaking measurements (direct measurement of light waves) but also generate high-order harmonics from novel condensed materials. Direct spectroscopic applications will follow immediately.

Project TTL02: Generation of intense few-cycle laser pulses

Supervisor: Prof. T.T. Luu

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

Project YY01: Nonclassical optical responses at the extreme nanoscale

Supervisor: Prof. Y. Yang

Classical electromagnetism lacks electronic length scales, rendering its failure at the extreme nanoscale. A general and unified framework for nanoscale electromagnetism—amenable to both analytics and numerics, and applicable to multiscale problems—was recently presented [Nature 576, 248 (2019)]; it reintroduces the electronic length scale to the Maxwellian framework via surface-response functions known as Feibelman d parameters. This project aims to measure the d parameters of various interfaces of photonic and plasmonic prominence in different electromagnetic regimes. In the visible regime, this project will establish the measurement protocol of d parameters via measuring the scattering properties of judiciously designed photonic systems and quasi-normal-mode perturbation analysis. In the infrared towards Terahertz regimes, this project will measure the proximity effect of metals on the dispersion of highly confined plasmons and phonon polaritons (e.g. in graphene, hexagonal boron nitride, and other 2D materials) to extract the d parameters using scanning near-field scattering measurements. Moreover, the consequences of d parameters in nonlinear optics, surface chemistry, and optoelectronics will also be discussed.

Project YY02: Interaction between light and free electrons

Supervisor: Prof. Y. Yang

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

Project YY03: Photonic synthetic gauge fields

Supervisor: Prof. Y. Yang

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

Project XBY01: Spin-Orbit Coupling at Metamaterial

Supervisor: Prof. X.B. Yin

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

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

Supervisor: Prof. S. Zhang

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

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

Supervisor: Prof. S. Zhang

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

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

Supervisor: Prof. S. Zhang

Most of the demonstrated topological invariants belong to Z or Z2 classes, which belong to the Abelian homotopy groups. They are usually manifested as the Chern numbers or the winding numbers in topological physics. Very recently, non-Abelian topological charges (for example, quarternion charges for three-band systems) were proposed for nodal links and Weyl points in non-interacting metals, which exhibit highly interesting braiding topological structures and trajectory dependent node collisions. Prof. Zhang's group recently experimentally demonstrated the presence of such non-abelian topological charges in biaxial hyperbolic media, which host nodal links in the Brillouin zone formed by three bands - two transverse modes and one longitudinal mode. This system provides an exciting platform for studying interesting phenomena associated with non-abelian topological charges, such as braiding, nodal collision, and admissible nodal link transformations. In this project we will investigate these interesting non-abelian topological phenomena based on a series of judiciously engineered optical metamaterials with modified nodal link configurations.

Nuclear and Particle Physics group:

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

Supervisor: Prof. J.H.C. Lee

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

Project YJT01: Searching for Supersymmetry at the Large Hadron Collider

Supervisor: Prof. Y.J. Tu

The Standard Model (SM) works beautifully to predict and explain various experimental results. However, the SM has many open questions thus it is believed not a complete theory. Among many models, supersymmetry (SUSY) is the most promising candidate for new physics. SUSY predicts a partner particle for each particle in the SM. These new particles would solve a major problem in the SM, hierarchy problem - The masses of the W, Z particles are 10^16 smaller than that of the Planck mass. SUSY also provides good dark matter candidate and a solution to the baryon asymmetry of the universe. We will search for super particles decaying into SM leptons plus missing transverse energy. Such experimental signatures have rich interpretations in various new physics scenarios, e.g. in SUSY, when the charginos and neutralinos (mixtures of superpartners of the gauge bosons and the Higgs bosons) produced via electroweak interactions and decay into the W, H plus the lightest neutralino or gravitino (Dark Matter candidate), where W, H further decay, the final state will contain leptons plus missing transverse momentum. The same final states also appear in the Heavy Higgs association production. Therefore, the projects are not only key searches for SUSY, but also good probes for Dark Matter and beyond the SM Higgs physics.

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

Supervisor: Prof. Y.J. Tu

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

POSTGRADUATE COURSES OFFERED BY DEPARTMENT OF PHYSICS, HKU

PHYS8950 Postgraduate Seminar

Course Objectives:

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

Course Contents & Topics:

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

PHYS8001 Selected Topics in Computational Modelling and Data Analysis in Physics

Course Objectives:

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

Course Contents & Topics:

Topics include:

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

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

PHYS8002 Advanced Topics in Theoretical Physics

Course Objectives:

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

Course Contents & Topics:

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

PHYS8201 Basic Research Methods in Physical Science

Course Objectives:

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

Course Contents & Topics:

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

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

PHYS8202 Special topic in Physics: Quantum Many-Body Computation (First Semester 2025)

Course Objectives:

Modern computational approaches are playing increasingly important roles in the advances of condensed matter physics and quantum material research, particularly in quantum many-body systems, where strong correlations among multiple degrees of freedom, including electronic, spin, lattice, and orbital, have rendered conventional methods inadequate. In recent years, a new trend of research, combining modern computational methods, such as exact diagonalization, quantum Monte Carlo, tensor network, neural network and artificial intelligence, and modern theoretical approaches such as quantum field theory and symmetry analysis as well as topological techniques, has emerged and enabled scientists to thoroughly and in an interdisciplinary manner, investigate the highly entangled quantum phases of matter, 2D moire materials, lightmatter interaction, quantum simulators and Rydberg atom arrays, etc.

Considering these rapid developments and their lack of systematic introduction and education to senior undergraduate and graduate students and researchers in HKU and even the GBA area, this course is designed to cover the advanced topics in quantum many-body computation and theoretical understanding in strongly correlated electron systems and quantum materials. Based on the frontier research type exercises, course projects and group discussion, as well as the platform-free cloud computing environment offered by the teacher https://quantummc.xyz/teaching/, we plan to teach senior undergraduate and graduate students and junior researchers in HKU and other institutions in Hong Kong, in condensed matter, quantum material, particle physics as well as astrophysics, the basic and live knowledge of modern quantum many-body computation, such that they can apply them into their research works in the corresponding areas.

Course Contents & Topics:
Topics include: Basic data analysis methods such as error analysis, chi-square analysis and regression approaches; basic random number generators and stochastic processes; basic introduction of application of AI in quantum physics research.

Hartree-Fock mean-field theories for quantum many-body models such as Hubbard model and Heisenberg model on different lattices, to understand the various LandauGinzburg-Wilson types of symmetry-breaking phases and phase transitions (with algorithm note and platform-free cloud computation code under the path https://quantummc.xyz/teaching/mean-field/);

Exact Diagonalization with symmetry and quantum number implemented for quantum spin systems and field theory with topological term, to understand the basics of modern quantum phase transitions. (with algorithm note and platform-free cloud computation code under the path https://quantummc.xyz/ed/);

Quantum Monte Carlo algorithms for interacting fermion and spin/boson lattice models and quantum entanglement measurements, to understand the basic concept of quantum phase transitions and gradually cover the unconventional quantum matter beyond Landau-Ginzburg, and to teach how to implement the modern computational algorithm in 2D material and quantum simulator research (with the algorithm note and platform-free cloud computation code under the path https://quantummc.xyz/dqmc/);

Density Matrix Renormalization Group and Tensor network methods, dynamic and thermodynamic computations for quantum many-body systems, to teach how to compute the experimentally relevant quantities such as transport, specific heat and spectroscopies in quantum magnetism and 2D materials. (with the algorithm note and platform-free cloud computation code under the path https://quantummc.xyz/teaching/dmrg/)

PHYS8351 Graduate Quantum Mechanics

Course Objectives:

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

Course Contents & Topics:

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

PHYS8352 Quantum Information

Course Objectives:

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

Course Contents & Topics:
Topics include: Quantum computer; quantum algorithms; quantum error correction; quantum information processing; quantum entanglement and quantum cryptograph.

PHYS8450 Graduate Electromagnetic Field Theory
Course Objectives:
The aim of this course is to provide students with the advanced level of comprehending on the theory of classic electromagnetic field, enabling them to master key analytical tools for solving real physics problems.

Course Contents & Topics:
This course will introduce and discuss the following topics: Boundary-value problems in electrostatics and Green's Function method; electrostatics of media; magnetostatics; Maxwell's equations and conservation laws; gauge transformations; electromagnetic waves and wave guides.

PHYS8550 Graduate Statistical Mechanics
Course Objectives:
This course covers advanced topics in equilibrium statistical physics.

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

PHYS8552 Condensed Matter Physics
Course Objectives:
This course introduces many-body physics in quantum matter. Systems consisting of many particles (bosons or fermions) display novel collective phenomena that individual particles do not have, for example, ferromagnetism and superfluidity. It aims to introduce students the

general principles behind these phenomena, such as elementary excitations, spontaneous symmetry breaking, adiabatic theorems, emergent topological phases of matter, etc. Theoretical language useful in the interpretation of experiments, such as linear response theory and response functions, will be discussed. This course is intended for both experimentalists and theorists. While there are no official prerequisites, students who would like to take this course are assumed to have sufficient knowledge on quantum mechanics and statistical mechanics.

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

PHYS8653 Selected topics in high energy astrophysics and cosmology

<u>Course Objectives:</u>
The aim of the course is to offer an advanced introduction to cosmology as well as some current topics in high energy astrophysics. It may be taken as a self-contained course or as background to research work in astrophysics or cosmology.

<u>Course Contents & Topics:</u>
Topics include: 1) astrophysics: radiation mechanisms in high energy astrophysics, review and applications of general relativity, physics of astrophysical black hole systems; 2) cosmology: the big bang and expansion of the universe, the metric of the universe, galaxy structure and formation; cosmic microwave background; 3) recent hot topics in astrophysics and cosmology research.

PHYS8654 General Relativity

Course Objectives:

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

Course Contents & Topics:

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

PHYS8656 Topics in astrophysics

Course Objectives:

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

Course Contents & Topics:

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

PHYS8701 Physics Experimental Techniques

Course Objectives:

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

Course Contents & Topics:

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

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

PHYS8750 Physics of Nanoelectronics

Course Objectives:

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

Course Contents & Topics:

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

PHYS8751 Device Physics

Course Objectives:

The growth in the past 70 years of modern electronics industry has had great impact on society and everyday life, the foundation of which rests upon the semiconductor physics and devices. This course aims at presenting a comprehensive introductory account of the physics and operational principles of some selected and yet classic semiconductor devices, microelectronic and optoelectronic. The text is primarily designed for postgraduates but can be of interest to senior undergraduates in physics, electrical and electronic engineering and materials science. Students are assumed to have acquired some basic knowledge of quantum mechanics, statistical mechanics, and solid state physics, though a review of the physics of semiconductors will be given in the beginning of the course.

Course Contents & Topics:

This course begins by giving a review of solid state physics, particularly of the physics of semiconductors. It is then followed by discussions of the fundamentals and practical aspects of PN-junctions and rectifying diodes, amplifying and switching devices like bipolar and field-effect transistors (e.g., MOSFET), light-emitting and detection devices such as LEDs, laser diodes, and photodetectors. If time allows, a brief discussion of some special devices will be presented.

PHYS8852 Photonics and Metamaterials

Course Objectives:

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

Course Contents & Topics:

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

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H.F. Chau

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“The Physics of Accretion Discs, Winds and Jets in Tidal Disruption Events”, Dai, J.L., Lodato, G., Cheng, R., *Space Science Reviews*, 217, 12 (2021)

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M. Gu

"Lensed Type Ia Supernova “Encore” at z = 2: The First Instance of Two Multiply Imaged Supernovae in the Same Host Galaxy", J. D. R. Pierel, A. B. Newman, S. Dhawan, M. Gu, B. A. Joshi, T. Li, S. Schuldt, L. G. Strolger, S. H. Suyu, G. B. Caminha et al., *The Astrophysical Journal Letters*, 967, L37 (2024)

"The MASSIVE survey – XIX. Molecular gas measurements of the supermassive black hole masses in the elliptical galaxies NGC 1684 and NGC 0997", P. Dominiak, M. Bureau, T.A. Davis, C.P. Ma, J.E Greene, M. Gu, *Monthly Notices of the Royal Astronomical Society*, 529, pp. 1597–1616 (2024)

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D.K. Ki

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Kelly, Fengwu Sun, Masamune Oguri, Hayley Williams, Rogier Windhorst, Adi Zitrin, Katsuya T. Abe, Wenlei Chen, Liang Dai, Yoshinobu Fudamoto, Hiroki Kawai, Jeremy Lim, Tao Liu, Ashish K. Meena, Jose M. Palencia, George F. Smoot, and Liliya L.R. Williams, *The Astrophysical Journal Letters*, 978, L5 (2025)

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“Measurement of the Berry curvature of solids using high-harmonic spectroscopy”, TT Luu, HJ Wörner, *Nature communications*, 9 (1), 1-6 (2018)

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“Evolution of entanglement entropy at SU(N) deconfined quantum critical points”, Menghan Song, Jiarui Zhao, Meng Cheng, Cenke Xu, Michael M. Scherer, Lukas Janssen, Zi Yang Meng, *Sci. Adv.*, 11, eadr0634 (2025)

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J.C.S. Pun

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