The Chinese University of Hong Kong
Division of Physics

Experimental Projects Offered in 2024-25

No.	Project title	Degree	Offered by
E1	Experimental high energy physics at the Large Hadron Collider	PhD	Prof. Luis R. Flores Castillo
E2	Electronic and thermal properties of correlated electron systems under extreme conditions	PhD or MPhil	Prof. Swee Kuan Goh
E3	Magnetic fields in star formation	MPhil or PhD	Prof. Hua-Bai Li
E4	Probing stellar birth from Mauna Kea and Greenland	MPhil or PhD	
E5	Application of diamond quantum sensing in condense matter physics, materials science, and biomedicine	PhD	Prof. Quan Li
E6	Developing in/ex situ tools for mechanistic study of battery process		
E7	Topological superconductors and their applications	PhD	Prof. Yufan Li
E8	Quantum sensing using color centers in diamond	PhD	Prof. Ren-Bao Liu
E9	In-situ synchrotron characterization of photovoltaic thin films	PhD	Prof. Xinhui Lu
E10	Topics in plasmonics and metamaterials	MPhil or PhD	Prof. Daniel H. C. Ong
E11	Quantum engineering of single ultracold atoms and molecules in optical tweezers	MPhil or PhD	Prof. Dajun Wang
E12	Quantum simulation with a lattice gas of ultracold polar molecules	PhD	
E13	Interactions between plasmons and 2D excitons	PhD	Prof. Jianfang Wang
E14	X-ray and neutron scattering studies of high-temperature superconductors	PhD	Prof. Qisi Wang
E15	Biophysics: Dynamics of biological systems in space and time	PhD or MPhil	Prof. Yilin Wu
E16	Non-equilibrium physics: Dynamics of active matter in space and time		
E17	Experimental study of crystallization at single-particle	PhD or MPhil	Prof. Lei Xu
E18	Novel interfacial dynamics in ultralow-surface-tension systems		
E19	Astronomical instrumentation	PhD	Prof. Renbin Yan
E20	Astrophysics of the interstellar medium	MPhil or PhD	
E21	Manipulating light and sound in artificial topological systems	PhD	Prof. Haoran Xue

E1. Experimental high energy physics at the Large Hadron Collider (PhD)

(**Prof. L Flores Castillo**, 🖃 *castillo@phy.cuhk.edu.hk*)

Experimental High Energy Physics achieved one of its most cherished goals in recent times on July 4, 2012, when the European Organisation for Nuclear Research (CERN) announced the discovery of the Higgs boson. This achievement required the collaboration of thousands of researchers, the most powerful particle accelerator in history (the Large Hadron Collider, or ***LHC***) and two of the largest and most precise particle detectors ever built. It also led to the awarding of the 2013 Nobel Prize in Physics to Professors Peter Higgs and Francois Englert. During 2014, the LHC will undergo a large upgrade program to increase its center-of-mass energy by about 70%; this large increase will, at the same time, produce a higher number of Higgs particles and open a new mass region, previously unexplored. Students are expected to participate in the preparation work for the analysis of the 2015 data, and to have an active role in physics analyses once the new data-taking period starts. [Two students may be admitted].

Reference :

1. *"Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", Phys. Lett. B716 (2012) 1-29.*

E2. Electronic and thermal properties of correlated electron systems under extreme conditions (PhD or MPhil)

(**Prof. S. K. Goh**, 🖃 *skgoh@cuhk.edu.hk*)

Strongly correlated electron systems (SCES) represent a special class of materials in which the strong Coulomb interaction between electrons plays a prominent role. The strong interaction has resulted in a wide range of fascinating phenomena, including diverse types of magnetism, unconventional superconductivity and metal-insulator transitions. These phenomena are not only of theoretical interest, but are also of growing technological significance.

Our modern laboratory enables the growth of high purity single crystals of topical strongly correlated electron systems and their subsequent investigation under multiple extreme conditions. We are able to examine these crystals at temperatures as low as ~0.01 K, magnetic field up to 14 T and pressures at gigapascal scale (1 gigapascal = 10,000 atm). We will apply powerful probes such as magnetotransport, magnetic susceptibility, heat capacity, and quantum oscillations to study the physics of SCES under these extreme conditions. For our recent results, see references below. Highly motivated students with a strong background in solid state physics and experimental physics are invited to apply. This programme will involve strong international collaborations. The applicant must also be able to work as part of a team. [One or two students may be admitted.]

References :

1. *Swee K. Goh et al., "Trapped magnetic flux in superconducting hydrides", Nat. Phys. 19, 1229 (2023).*
2. *Wei Zhang et al., "Nodeless superconductivity in kagome metal CsV3Sb5 with and without time reversal symmetry breaking", Nano Lett. 23, 872 (2023).*
3. *Jianyu Xie et al., "Fragile pressure-induced magnetism in FeSe superconductors with a thickness reduction", Nano Lett. 21, 9310 (2021).*
4. *Y. J. Hu et al., "Detection of hole pockets in the candidate type-II Weyl semimetal $MoTe_2$ from Shubnikov-de Haas quantum oscillations", Phys. Rev. Lett. 124, 076402 (2020).*
5. *K. Y. Yip et al., "Measuring magnetic field texture in correlated electron systems under extreme conditions", Science 366, 1355 (2019).*

E3. Magnetic fields in star formation (MPhil or PhD)

(Prof. H. B. Li, ✉ *hbli@cuhk.edu.hk*)

Stars and their planets are born when giant clouds of interstellar gas and dust collapse. Astronomers still know very little about the mechanisms behind these processes. For example: why can only a small portion of a cloud collapse into stars? How are protostellar discs formed from clouds? How are disc bipolar outflows launched?

It has been proposed that magnetic fields play a role in all of the aforementioned processes. However, models including magnetic fields are very controversial. The goal of this project is to observationally test these proposals, using telescopes including the Atacama Large Millimeter/submillimeter Array (ALMA; http://www.almaobservatory.org/). [Up to two students may be admitted.]

References :

1. *"CUHK Physicist Unveils Mystery of Massive Star Formation".* [Link to Article]
2. *"CUHK Physicist and Statistician Work Together to Reveal Link Between Magnetic Fields and Birth Rate of Stars".* [Link to Article]
3. *"Magnetic Fields in Molecular Clouds—Observation and Interpretation".* [Link to Paper]

E4. Probing stellar birth from Mauna Kea and Greenland (MPhil or PhD)

(Prof. H. B. Li, ✉ *hbli@cuhk.edu.hk*)

The so-called "magnetic topology problem", i.e., how does the field topology evolve as molecular clouds form and as clouds contract to form stars, has puzzled astronomers for decades. The goal of this project is to build the next generation polarimeter for magnetic field mapping. One of the telescopes we plan to install the new polarimeter is the *James Clerk Maxwell Telescope* operated on Mauna Kea, Hawaii. The other one is the Greenland Telescope.

References :

1. *"Design and Initial Performance of SHARP, a Polarimeter for SHARC-II Camera at the Caltech Submillimeter Observatory".* [Link to Paper]
2. *"The Greenland Telescope".* [Link to Article]
3. *"The Link between Magnetic Fields and Cloud/Star Formation".* [Link to Paper]

E5. Application of diamond quantum sensing in condense matter physics, materials science, and biomedicine (PhD)

(Prof. Q. Li, ✉ *liquan@cuhk.edu.hk*)

The nitrogen-vacancy (NV) centers in diamond are extremely sensitive to any environmental parameter that affect its spin states. The atom-like nature and long coherence time at room temperature of the NV centers respectively enable excellent spatial resolution and room temperature sensing experiments, making NV based sensing attractive for a variety of applications in condense matter physics, materials science, and biomedicine. In this project, we aim at developing new sensors and protocols based on diamond NVs, to tackle key problems in nanomagnetism, thermo-plasmonics, energy storage systems, soft matter, as well as mechanics and exogenesis of cellular machinery. Students may focus on one of these directions. [Up to two students may be admitted.]

References :

1. *X Feng et al., "Association of Nanodiamond Rotation Dynamics with Cell Activities by Translation-Rotation Tracking" Nano Lett., 21, 8, 3393–3400, 2021*
2. *KW Xia, et al., "Nanometer-precision non-local deformation reconstruction using nanodiamond sensing" Nature Communications 10, 3259, (2019).*
3. *T. Zhang et al., "Hybrid nanodiamond quantum sensors enabled by volume phase transitions of hydrogels" Nature Communications, 9, 3188 (2018).*

E6. Developing in/ex situ tools for mechanistic study of battery process (PhD)

(Prof. Q. Li, ✉ *liquan@cuhk.edu.hk*)

The development of battery is like a game played in blackbox. Evolution of the materials themselves (e.g. active electrode material, electrolyte, separators etc.) and their achitectures are closely correlated with the device performance, for example, capacity retention, rate performance, cyclability, and safety. However, monitoring of the battery process is not a simple task, due to the complicated electrochemical reactions during cycling and the anhydrous/anaerobic operation requirement in most cases. In/ex situ characterizations of the battery process are key to understanding of its evolution by simulating real battery conditions. In this project, we will develop in/ex situ protocols to tackle key problems (e.g. capacity fading, thermal runaway, etc.) in designing high performance energy storage devices. [One student may be admitted.]

References :

1. *"Understanding materials challenges for rechargeable ion batteries with in situtransmission electron microscopy", Nature Communications 8, 15806 (2017) doi:10.1038/ncomms15806.*
2. *"Review—Promises and challenges of in situ transmission electron microscopy electrochemical techniques in the studies of lithium ion batteries", Journal of Electrochemical Society, doi: 10.1149/2.1451709jes.*
3. *"Revisiting the origin of cycling enhanced capacity of Fe3O4based nanostructured electrode for lithium ion batteries", Nano Energy, doi.org/10.1016/j.nanoen.2017.10.001.*

E7. Topological superconductors and their applications (PhD)
(Prof. Y. F. Li, ✉ *yufanli@cuhk.edu.hk*)

Topological superconductivity holds the key to realizing fault-tolerant quantum computing. Superconductors hosting topologically non-trivial band structure, often with unconventional pairing symmetry, may give rise to Majorana fermions. These exotic particles are famously known for being their own antiparticles, a unique property that allows construction of noise-resilient topological qubits [1]. We focus on identifying intrinsic topological superconductors (TSCs) [2,3] and exploring the topological properties in nanodevices. Topics include (1) synthesizing thin films of TSC, (2) phase-sensitive experiments for identifying the pairing symmetry, (3) fractional quantization effect in Josephson junctions, and (4) half-quantum flux qubit device with spin-triplet superconductors. Our primary experimental apparatus are ultra-high-vacuum thin film deposition, electrical transport measurements and nanofabrication. Strong background in quantum mechanics and solid state physics is preferred. [Two students may be admitted.]

References :

1. *For review articles on related topics, see for example Sato and Ando, Rep. Prog. Phys. 80 076501 (2017); Beenakker, Annu. Rev. Condens. Matter Phys. 4, 113 (2013).*
2. *Y. Li, X. Xu, M.-H. Lee, M.-W. Chu, C. L. Chien, "Observation of half-quantum flux in the unconventional superconductor β-Bi2Pd", Science 366, 238 (2019).*
3. *X. Xu, Y. Li, C. L. Chien, "Spin-triplet pairing state evidenced by half-quantum flux in a noncentrosymmetric superconductor", Phys. Rev. Lett. 124, 167001 (2020).*

E8. Quantum sensing using color centers in diamond (2 PhD)
(Prof. R. B. Liu, ✉ *rbliu@cuhk.edu.hk*)

Up to two students are to be admitted to study quantum coherence control using optically detected magnetic resonance (ODMR) of nitrogen-vacancy centers in diamond and its applications in quantum sensing. The project will involve confocal and/or wide-field microscopic imaging, optical detection of spins in diamond under control of microwave pulses, and using the ODMR to study condensed matter physics and thermodynamics at nanoscales and to sense biological processes in single live cells. Honesty, strong motivation, and hard working are must. Required is good training in quantum physics, solid-state physics, optics, and experimental physics at the undergraduate level.

References :

1. *X. Feng, et al., "Association of nanodiamond rotation dynamics with cell activities by translation-rotation tracking". Nano letters 21, 3393 (2021).*
2. *C. F. Liu, et al, "Ultra-sensitive hybrid diamond nanothermometer", National Science Review 8, nwaa194, (2021).*
3. *K. W. Xia, et al., "Nanometer-precision non-local deformation reconstruction using nanodiamond orientation sensing", Nature Communications 10, 3259 (2019).*
4. *G. Q. Liu, et al., "Coherent quantum control of nitrogen-vacancy center spins near 1000 kelvin", Nature Communications 10, 1344 (2019).*
5. *N. Wang, et al., "Magnetic criticality enhanced hybrid nanodiamond thermometer under ambient conditions", Physical Review X 8, 011042 (2018).*

E9. In-situ synchrotron characterization of photovoltaic thin films (PhD)
(Prof. X. H. Lu, ✉ *xinhui.lu@cuhk.edu.hk*)

Nowadays, most of the new-generation solar cells are made of semiconducting thin films. Fine-tuning the device fabrication parameters is one of the feasible and promising routes to further push the power conversion efficiency, however, requiring huge amount of time and research efforts. Despite fruitful results on fabrication methodologies and device performance optimization, fundamental studies on crystal structure and morphology, crystal growth and film formation mechanism are still very limited. Careful explorations on these aspects are highly desired, in order to effectively guide future directions of device optimization.The primary goal of this project is to design and carry out in-situ synchrotron characterization experiments for photovoltaic thin films in order to understand the crystallization kinetics, process-structure-performance correlation, and in turn improve the device performance and reproducibility. [Two students may be admitted.]

References :

1. *J. Mai, H. Lu, T.K. Lau, S. Peng, C. Hsu, W. Hua, N. Zhao, X. Xiao, X. Lu, "High Efficiency Ternary Organic Solar Cell with Morphology-Compatible Polymers", J. Mater. Chem. A 5, 11739-11745 (2017).*
2. *X. Lu, H. Hlaing, C-Y Nam, K.G. Yager, C. T. Black and B. M. Ocko, "Molecular Orientation and Performance of Nanoimprinted Polymer-based Blend Thin Film Solar Cells", Chem. Mater. 27, pp.60-66, (2015).*

E10. Topics in plasmonics and metamaterials (MPhil or PhD)
(Prof. D. H. C. Ong, ✉ *hcong@phy.cuhk.edu.hk*)

Recently, plasmonics and metamaterial have both be named as a new eras after photonics and electronics. They serve as an important platform for studying the fundamentals of light matter interaction by manipulating the electromagnetic waves in an unconventional manner. Their applications include making high efficient light emitting diodes (LEDs) and solar cells, ultrahigh sensitive biosensors, passive and active optical elements for photonic circuitry, optical tweezers, etc. Our group focuses on two projects. The first one studies the interaction between plasmonic systems/metamaterials and quantum dots [1]. We engineer the near-fields around the quantum dots and study how their absorption and emission properties are affected. In particular, we measure the local density of the optical states around one single quantum dot in frequency, momentum, time, and space domains by using several home-built, specially designed microscopes. Its spontaneous emission rate, chirality, photocurrent generation efficiency, etc, are then studied accordingly so that LEDs and solar cells can be implemented eventually. The second project combines plasmonic tweezers and surface enhanced Raman scattering (SERS)/surface plasmon resonance (SPR) sensing in attempt to image single molecules. In principle, this combination produces an analogy of "line of sight" method by placing the target molecules at the right position where they can be seen easily. However, since both the manipulation and the sensing require the precision at the length scale of nanometers, a full knowledge of designing the plasmonic/metamaterial systems to yield suitable hotspots for biosensing, building appropriate characterization tools, generating strong optical force for grabbing the molecules, etc, is essential [2]. These two projects involve extensive collaboration with the theoretical group in Hong Kong University of Science and Technology. [Up to two students may be admitted.]

References :

1. *M. S. Tame et al, "Quantum plasmonics", Nat. Phys. 9, 329 (2013); Z. L. Cao and H. C. Ong, "Determination of coupling rate of light emitter to surface plasmon polaritons supported on nanohole array", Appl. Phys. Lett. 102, 241109 (2013).*
2. *M. L. Juan et al, "Plasmon nano-optical tweezers", Nat. Photonics 5, 349 (2011); C. Y. Chan et al, "Dependence of surface enhanced Raman scattering (SERS) from two-dimensional metallic arrays on hole size", Appl. Phys. Lett. 96, 033014 (2010).*

E11. Quantum engineering of single ultracold atoms and molecules in optical tweezers (MPhil or PhD)

(**Prof. D. J. Wang**, ✉ *djwang@cuhk.edu.hk*)

In recent years, trapping and manipulating ultracold atoms and molecules at the single particle level have become a new frontier in quantum physics. With the help of optical tweezer and tweezer arrays, these single atoms and molecules have now been successfully exploited in quantum science and technology. In this project, built on the expertise and the series of achievements of our group in the last decade, we will realize trapping of single atoms and molecules in rearrangeable optical tweezer arrays. Starting from there, we will explore various topics including controlled ultracold chemical reactions, quantum metrology, and quantum simulation. The possibility of realized quantum gates operated on the long-range dipolar interactions will also be studied. [Up to two students may be admitted.]

E12. Quantum simulation with a lattice gas of ultracold polar molecules (PhD)

(**Prof. D. J. Wang**, ✉ *djwang@cuhk.edu.hk*)

Ultracold polar molecules can interact via the long-rang and strong dipole-dipole interaction. Theoretically, this has been found to hold great promises in a broad range of applications in quantum simulation and quantum information. However, the experimental investigation on polar molecules is lagging far behind. In this project, starting from a sample of absolute ground-state polar molecules, we will explore ways of producing a degenerate quantum gas of polar molecules. Eventually, these molecules will be loaded into optical lattices for investigating Bose-Hubbard model with true long-range interactions and quantum magnetism models with strong dipolar spin exchange interactions. This project involves advanced knowledge on quantum physics and a variety of experimental techniques. A solid background on quantum mechanics, optics and laser is required. [One student may be admitted.]

References :

1. *Mingyang Guo et al, "Dipolar collisions of ultracold ground-state Bosonic molecule", Physical Review X, 8, 041044 (2018).*
2. *Xin Ye et al, "Collisions of ultracold NaRb molecules with controlled chemical reactivities", Science Advances 4, eaaq0083 (2018).*
3. *Mingyang Guo et al, "Creation of an ultracold gas of ground-state NaRb molecules", Physical Review Letters 116, 205303 (2016).*
4. *J. L. Bohn, A. M. Rey and J. Ye, "Cold molecules: Progress in quantum engineering of chemistry and quantum matter", Science, 357, 1002-1010, (2017).*

E13. Interactions between plasmons and 2D excitons (PhD)

(**Prof. J. F. Wang**, ✉ *jfwang@phy.cuhk.edu.hk*)

Plasmonic nanostructures exhibit fascinating optical properties. They are useful for numerous applications, including optics, optoelectronics, metamaterials, solar energy harvesting, diagnostics, and medicine. Two-dimensional (2D) materials have fascinating 2D exciton-derived optical properties. Control of 2D excitons can lead to the creation of new devices, such as quantum emitters and valley polarization-based information storage and processing. We are working intensively on the use of plasmons to control the behaviors of 2D excitons. Specifically, we are fabricating hybrid nanostructures out of plasmonic components and 2D materials, investigate the interactions between plasmons and 2D excitons, and finally control the properties of 2D excitons, which particularly include the emission energy, intensity, distribution, polarization, and chirality. The project will involve nanomaterials synthesis and characterization, nanostructure fabrication, optical measurements, electromagnetic analysis and simulations. The project will require backgrounds and/or interests on optics, physics and nanomaterials. Applicants who are interested in this topic are very welcome to join us. [Up to two postgraduate students will be admitted.]

E14. X-ray and neutron scattering studies of high-temperature superconductors (PhD)

(**Prof. Q. S. Wang**, ✉ *qwang@cuhk.edu.hk*)

The broad application prospects of superconductivity have inspired tremendous research efforts. Yet, the mechanism of high-temperature superconductivity remains one of the most challenging problems in condensed matter physics. The rich interactions involving spin, orbital/charge, and lattice degrees of freedom give rise to a multitude of phases that compete or coexist with superconductivity. Understanding these interactions and their interplay is thus the key to elucidating the mechanism of high-temperature superconductivity.

X-ray and neutron scatterings are powerful probes to resolve structural, electronic, magnetic orders and their excitations. In this project, we will combine multiple x-ray and neutron scattering techniques to study cuprate, iron-based, and the recently discovered nickelate superconductors. The experiments will be carried out at international synchrotron and neutron facilities. Students will be involved in crystal growth, characterizations, and scattering experiments. [Up to two students may be admitted.]

E15. Biophysics: Dynamics of biological systems in space and time (PhD or MPhil)

(**Prof. Y. L. Wu**, ✉ *ylwu@cuhk.edu.hk*)

Life is a fascinating, far-from-equilibrium state of matter. Research in my lab lies at the interface of physics and biology: We seek to understand how living systems function, adapt and evolve. As the dominant form of life on our planet and the key players of life-Earth co-evolution, microbes have relatively simple structure, function and behavior, and thus they provide tractable systems to study the physical principles that govern living matter. In this project we will focus on the motion and self-organization of microbial systems in space and time. The systems of choice range from single cells to microbial communities, such as bacterial swarms and biofilms. Specifically, we study: 1) Collective motion and self-organization in multicellular systems; 2) Long-range communication and material transport in multicellular systems;

3) Bacterial motility in complex fluids; and 4) Growth dynamics of general living matter. We hope knowledge learned from our research will fuel the development of non-equilibrium physics (e.g. self-organization of general active matter; **see Project E16**) and will guide the engineering of novel materials that self-assemble, self-renew and are stimulus-responsive (**see project in Materials Science and Engineering from my lab**).

Our research is mainly driven by experiments, with the help of modeling and computer simulations. We fuse experimental techniques from physics, biology and other disciplines to address different questions. Students with either experimental or theoretical background are welcome to apply. Knowledge in any one of the following subjects is preferred (but NOT required): statistical physics, continuum mechanics, optics, microscopy, chemical/biological engineering, physical chemistry, molecular biology, electrical engineering, and digital image processing. [One or two students may be admitted.]

References :

1. *To learn more about our current research please visit our lab website: http://www.phy.cuhk.edu.hk/ylwu/index.html.*
2. *Wenlong Zuo & Yilin Wu, "Dynamic motility selection drives population segregation in a bacterial swarm". Proc. Natl. Acad. Sci. USA. 117(9):4693-4700 (2020).*
3. *Haoran Xu, Justas Dauparas, Debasish Das, Eric Lauga, Yilin Wu, "Self-organization of swimmers drives long-range fluid transport in bacterial colonies". Nature Communications. 10, 1792 (2019).*
4. *Chong Chen, Song Liu, Xiaqing Shi, Hugues Chaté, Yilin Wu, "Weak synchronization and large-scale collective oscillation in dense bacterial suspensions". Nature, 542, 210–214 (2017).*
5. *Ye Li, He Zhai, Sandra Sanchez, Daniel B. Kearns, Yilin Wu, "Non-contact cohesive swimming of bacteria in two-dimensional liquid films". Phys. Rev. Lett. 119, 018101 (2017).*
6. *H.C. Berg, "Motile behavior of bacteria", Physics Today 53 (1): 24-29 (2000).*

E16. Non-equilibrium physics: Dynamics of active matter in space and time (PhD or MPhil)

(Prof. Y. L. Wu, ylwu@cuhk.edu.hk)

As a new branch of non-equilibrium physics, active matter is a fast growing, interdisciplinary field focusing on systems where energy is spent locally to produce mechanical work. Active matter includes all living systems and synthetic self-driven materials. Investigations in the field will fuel the development of statistical physics in far-from-equilibrium systems, and will advance the understanding of the physics of life. The overall goal of this project is to understand the spatial-temporal self-organization of active matter. We hope knowledge obtained from this project will help to build a new paradigm for non-equilibrium physics and active matter engineering.

Our research is mainly driven by experiments, with the help of modeling and computer simulations. We fuse experimental techniques from physics and other disciplines to address different questions. Students with either experimental or theoretical background are welcome to apply. Knowledge in any one of the following subjects is preferred (but NOT required): statistical physics, continuum mechanics, optics, microscopy, chemical/biological engineering, physical chemistry, molecular biology, electrical engineering, and digital image processing. [One or two students may be admitted.]

References :

1. *To learn more about our current research please visit our lab website: http://www.phy.cuhk.edu.hk/ylwu/index.html.*
2. *Haoran Xu, Justas Dauparas, Debasish Das, Eric Lauga, Yilin Wu, "Self-organization of swimmers drives long-range fluid transport in bacterial colonies". Nature Communications. 10, 1792 (2019).*
3. *Chong Chen, Song Liu, Xiaqing Shi, Hugues Chaté, Yilin Wu, "Weak synchronization and large-scale collective oscillation in dense bacterial suspensions". Nature, 542, 210–214 (2017).*
4. *For an overview of active matter physics, see a collection of papers in Nature journals: https://www.nature.com/collections/hvczfmjfzl.*

E17. Experimental study of crystallization at single-particle level (PhD or MPhil)

(Prof. L. Xu, xuleixu@cuhk.edu.hk)

As one of the most important phase transitions, crystallization plays a crucial role in many different fields in our daily life, including science, technology, and industry. How does the disordered liquid structure transform into the ordered crystalline structure? It has been a focus of research for over one hundred years. Although the classical nucleation theory (CNT) gives a qualitative picture for the process, the microscopic picture at single-particle level remains largely missing. Using colloidal systems, we plan to experimentally tackle this important problem, focusing on the following three fundamental questions in the heterogeneous nucleation crystallization: 1. illustrate its kinetic pathways at single-particle level, and compare with the ones in homogeneous nucleation; 2. explore the influence of the nucleation sites with different sizes and curvatures; 3. study the interaction between different crystal grains, the formation of grain boundary, and the merge of grains. These three topics focus on the very basic problems in crystallization, and will provide invaluable experimental information for crystallization at single-particle level. [One or two PhD students may be admitted.]

***References** :*

1. *P. Tan, N. Xu and L. Xu, "Visualizing kinetic pathways of homogeneous nucleation in colloidal crystallization", Nature Physics 10, 73-79 (2014).*
2. *A. M.Alsayed, M. F. Islam, J. Zhang, P. J. Collings and A.. G. Yodh, "Premelting at defects within bulk colloidal crystals", Science 309, 1207-1210 (2005).*
3. *P. Schall, I. Cohen, D. A. Weitz and F. Spaepen, "Visualization of dislocation dynamics in colloidal crystals", Science 305, 1944-1948 (2004).*

E18. Novel interfacial dynamics in ultralow-surface-tension systems (PhD or MPhil)

(Prof. L. Xu, xuleixu@cuhk.edu.hk)

Novel dynamics may occur in ultralow-surface-tension systems. We would like to focus on the classical problems of droplet coalescence and snap-off in the system. In normal systems, as the connection or breakup point is approached, the Laplace pressure from the surface tension diverges, making the dynamics extremely fast and difficult to probe. In the ultralow-surface- tension system, however, the dynamics could be slowed down by several orders of magnitude. This enables a much better close-up inspection on the dynamics towards singularity, where the most interesting physics takes place.

Moreover, because of the significant reduction in the driving force (i.e., the surface tension), completely new physics may emerge: the liquid connection turns highly unstable and could easily form and break; while the previously negligible perturbations or even thermal noise could now become important. These new features may naturally induce surprising outcomes in these classical problems. [One or two PhD students may be admitted.]

References :

1. *G. Chen, P. Tan, S. Chen, J. Huang, W. Wen and L. Xu, Phys. Rev. Lett. 110, 064502 (2013).*
2. *X. Cheng, L. Xu, A. Patterson, H. M. Jaeger and S. R. Nagel, Nature Physics 4, 234 (2008).*
3. *D. G. A. L. Aarts, M. Schmidt and H. N. W. Lekkerkerker, Science 304, 847-850 (2001).*

E19. Astronomical instrumentation (PhD)

(**Prof. R. B. Yan**, 🖃 *rbyan@cuhk.edu.hk*)

Capabilities of astronomical telescopes and instrumentations set the limits for the frontiers of astronomy. New instrument capabilities always bring new discoveries. Currently, our group is developing the AMASE prototype spectrograph, which is an innovative, high spectral resolution, integral field spectrograph. When paired with a telephone lens or arrays of them, it will provide an unprecedented combination of capabilities — large angular coverage with high spectral resolution. We plan to replicate the system by large numbers and conduct a survey to spectroscopically map a quarter of the sky. The science goal is to understand the feedback of star formation and the physics of the interstellar medium. Our group is also involved in the development of instruments for other large telescopes like the Keck telescopes in Hawaii.

Students will be trained as future instrumentalist for astronomy and learn how to design astronomical instruments, how observations affect the design, and how to manage instrumentation projects. Such skills are rare to find in the community and are sought after in the job market.

Background in optical engineering, mechanical engineering, and/or electronic engineering would be ideal for this position, but is not required.

References :

1. *Renbin Yan et al., "The prototype telescope and spectrograph system for the AMASE project", Proceedings of SPIE., 11447, 114478Y (2020).*
2. *Kevin Bundy et al., "The Keck-FOBOS spectroscopic facility: conceptual design", Proceedings of SPIE., 11447, 1114471D (2020).*
3. *Niv Drory et al., "The MaNGA integral field unit fiber feed system for the sloan 2.5 m telescope", Astron. J., 149, 77 (2015).*

E20. Astrophysics of the interstellar medium (MPhil or PhD)

(**Prof. R. B. Yan**, 🖃 *rbyan@cuhk.edu.hk*)

The interstellar medium provides the material for star formation and the fuel for active galactic nuclei. It is also the sink for their feedback energy and returned material. The elemental abundance pattern of the ISM also records the history of star formation. Studying the composition and physical properties of the ISM provides critical clues for understanding galaxy evolution. This program focuses on observational studies of the ISM of external galaxies and of the Milky Way to understand the physics of the ISM and how it fits in the overall evolution of galaxies. We will use data from past and current spectroscopic surveys, from targeted multiwavelength observations using a number of optical, infrared, and radio telescopes, and combine with new data from the AMASE survey. This program could require short-term travels to observatories.

References :

1. *Xihan Ji & Renbin Yan, "Constraining photoionization models with a reprojected optical diagnostic diagram", MNRAS, 499, 5749 (2020).*
2. *Renbin Yan, "Shocks or photoionization: direct temperature measurements of the low-ionization gas in quiescent galaxies", MNRAS, 481, 476 (2018).*
3. *Renbin Yan, "Nitrogen-to-Oxygen abundance ratio variation in quiescent galaxies", MNRAS, 481, 467 (2018).*
4. *Kai Zhang, Renbin Yan, et al., "SDSS-IV MaNGA: the impact of diffuse ionized gas on emission-line ratios, interpretation of diagnostic diagrams and gas metallicity measurements", MNRAS, 466, 3217 (2017).*
5. *Renbin Yan et al., "SDSS-IV MaNGA IFS galaxy survey — Survey design, execution, and initial data quality", AJ, 152, 197 (2016).*
6. *Renbin Yan & M. R. Blanton, "The nature of LINER-like emission in red galaxies", ApJ, 747, 61 (2012).*

E21. Manipulating light and sound in artificial topological systems (PhD)

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In the past few years, the concept of band topology has been successfully introduced to classical wave systems to realize novel wave manipulation [1,2]. With topological protection, an artificial topological system can support robust wave phenomena such as backscattering-immune propagation. In this project, we will focus on the experimental realization of artificial topological systems (at microwave and audible sound frequencies) with unconventional properties, including those with non-Hermitian, nonlinear and quantum elements and featuring novel topologies such as point-gap topology, fragile topology and delicate topology. Furthermore, we will explore the applications of these novel topological states in devices like lasers and sensors. Students with background in condensed matter physics and wave physics are preferred. [One or two students may be admitted.]

References :

1. *T. Ozawa et al., "Topological photonics", Reviews of Modern Physics 91, 015006 (2019).*
2. *H. Xue et al., "Topological acoustics", Nature Reviews Materials 7, 974 (2022).*