PHYS3999 Directed studies in physics (2026-27)

Project HFC3901: Quantum Speed Limits
Supervisor: Prof. H.F. Chau

According to the Schrödinger equation, it takes non-zero time to evolve from one quantum state to another distinct quantum state. In fact, there are fundamental limits, collectively known as quantum speed limits, on how fast such evolution can take place. In this directed study, you are going to review some of these limits. Students taking this directed study should have good command in quantum mechanics plus knowledge in either mathematical analysis or computational physics.

Only those who have come to talk the supervisor will be considered.

Prerequisites: At least 2 Bs in Quantum Physics plus either Introductory Computational Physics, Theoretical Physics or Analysis I

Corequisites: Advanced Quantum Mechanics plus either Computational Physics or Data Analysis And Modeling In Physics

Project XDC3901: Instrument development
Supervisor: Prof. X.D. Cui

The project provides a training course for students to be involved in scientific instrument development. Scientific instruments are essential for experimental physics and are usually tailor-made for specific functions. In this project, students are to developed one scientific instrument, for example cryostat for low temperature research, ultrafast photo detectors, etc. Intensive hand work training is involved through the project.

Prerequisites: none

Project LXD3901: Studying energetic events around black holes
Supervisor: Prof. L.X. Dai

Around astrophysical black holes energetic phenomena can happen. In particular, the accretion of gas onto black holes can power different types of astrophysical systems such as active galactic nuclei, gamma ray bursts, tidal disruption events, etc. General relativity is often important for the dynamics or accretion or emission happening in these systems. In this directed study, depending on the interest and expertise, the student will choose to learn about one of the following astrophysical phenomena around black holes: 1) tidal disruption event, in which a star is torn apart by a black hole; 2) corona production and reflection around black holes; 3) the shadow of black holes as observed by the Event Horizon Telescope.

Prerequisites: The student should also haven taken PHYS3653 (Astrophysics) or PHYS3650 (Observational Astronomy) or PHYS 4654 (General Relativity). Basic C++/python programming skill is needed.

Project DKK3901: Physical Properties of Fewlayer Graphene
Supervisor: Prof. D.K. Ki

Graphene, a single layer of graphite, is the thinnest material that people have ever made and it can be produced—surprisingly very easily—using sticky tapes. The method is called mechanical exfoliation and it works because the graphene layers in graphite are coupled weakly by van der Waals force such that the tape can easily pill off them. Here, we will investigate various physical properties of the graphene layers, such as their optical contrasts, Raman responses, and electric conductivities to name a few. For this, the student will first choose the specific property of interest and learn how to exfoliate graphene on silicon substrate followed by introduction to the relevant experimental techniques to study the chosen property. The student can also work on other 2D materials, such as MoS2 or WSe2, which have different physical properties.

Project HCL3901: Mass calculation for deformed relativistic Hartree-Bogoliubov theory in continuum
Supervisor: Prof. J.H.C. Lee

Mass calculation for the exotic regions is mainly based on different theories. The relativistic continuum Hartree–Bogoliubov (RCHB) is based on the covariant density functional theory, the pairing correlations, continuum effects and the relativistic Hartree–Bogoliubov (RHB) equations. The deformed relativistic Hartree-Bogoliubov theory in continuum (DRHBc) is similar to the RCHB theory, but uses the deformed RHB equations to get a better description on the deformed nuclei.

In this project, students will learn and practice using advanced code to do the mass calculation based on the DRHBc. Students can understand the effects of quadrupole deformation on the nuclei by working on the potential energy curves of the nuclei. With the calculations, the binding energy, radius, fermi energy, pairing energy and some other properties can be obtained.

Prerequisites: PHYS3851

Project KML3901: Readings in Integrable Systems and Solitons
Supervisor: Dr. K.M. Lee

Solitons or solitary waves were first observed more than one hundred years ago. Now, we understand them as a case of integrable systems in classical wave physics. In this reading project, students are expected to learn the basics of integrable systems and its application.

Prerequisites: Knowledge in partial differential equations

Project LIM3901: Astrophysical Applications of Gravitational Lensing
Supervisor: Prof. J.J.L. Lim

Over the past 6 years, I have formed an ever-growing international collaboration and assembled a group of talented undergraduate and graduate students who use gravitational lensing by galaxies and galaxy clusters to: (i) search for, and verify geometrically the distances of, infant galaxies in the early Universe; (ii) search for and weigh supermassive black holes in galaxies at early epochs; (iii) map the distribution of matter in galaxies and galaxy clusters; and (iv) test different theories for dark matter (e.g., particle vs. wave-like in their collective behavior) based upon their predictions for the luminosity function of galaxies (especially those in the early Universe), and for the positions and magnification of multiply-lensed images of background galaxies. Studies of the early Universe is the main scientific goal of the James Webb Space Telescope (JWST), for which gravitational lensing will play an integral role by providing a cosmic lens to magnify distant and therefore faint galaxies. Our work uses archival data from the Hubble Space Telescope (HST), and newly acquired proprietary data as members of programs on both the HST and the soon to be launched JWST. The first step in our work usually involves the construction of lens models for (i.e., infer the mass distribution associated with) galaxies or galaxy clusters as constrained by the positions and distances of lensed images of background galaxies that have been robustly identified – and then using the preliminary lens model to confirm uncertain or identify new lensed images of background galaxies, and adding these lensed images to refine our lens model. We generate lens models using either or both parametric and non-parametric algorithms depending on the complexity of the lensing mass, the available constraints from multiply-lensed images of background galaxies, as well as the scientific needs of our work. At the present time, one of the primary focus of our work is to compute the effects of granulations inherent in wave-like dark matter on gravitational lensing, in particular on the subtle effects they have on the positions and magnifications of background lensed images – and to compare these predictions with longstanding and newly found (by us and others) anomalies in multiply-lensed images of background galaxies or of their individual stars.

Project LIM3902: Cluster Merger Impact on Central Thermodynamics and Star Formation
Supervisor: Prof. J.J.L. Lim

The majority of elliptical galaxies are red and dead – they comprise primarily low-mass (presumably old) stars, and are no longer (and presumably have long since ceased) actively forming stars. This situation, however, is not always true of giant elliptical galaxies that lie at the centers of galaxy clusters. Such galaxies are the most massive, largest, and most luminous galaxies in the Universe: how they attained their enormous masses and sizes remain an outstanding problem in astrophysics, and have much to teach us about the cosmic growth and evolution of galaxies. Some of these galaxies harbour enormous quantities of relatively cool gas, and are actively engaged in star formation. My research team is addressing how star formation and active galactic nuclei at cluster centers are related to the thermodynamics of the intracluster medium and the cluster dynamical state.

Project CCL3901: Experimental Defect Studies of Semiconductor Materials
Supervisor: Prof. F.C.C. Ling

Defects in semiconductors play an important role in determining the electrical properties of the materials. In the present study, with the use of Hall measurement, IV measurement, CV measurement and deep level transient spectroscopy, we aim at identify the defects existing in some wide band gap semiconductors (like silicon carbide, gallium nitride or zinc oxide) and to study their influence towards the materials' electrical properties. This project involves performing the electrical measurements on the samples and also analyzing the data by constructing appropriate models.

Co-requisite and pre-requisite: PHYS3551

Project TTL3901: Introductory ultrafast optics 1: pulse broadening due to material dispersion
Supervisor: Prof. T.T. Luu

In this short-term project, the involved students will learn:

- Introduction to Fourier transform and its application in optics.
- Ultrashort laser pulses and what are these made of.
- Frequency dependent refractive index and pulse broadening due to material dispersion (linear response).

The students will learn these topics theoretically first. Afterward, they will be able to measure the pulse duration before and after passing through a given material. Their pulse durations will be then compared to theoretical simulation results. In this project, the students will not only learn experimental skills, but they will also be able to make their own numerical simulation and compare it with existing codes to see what they did well and what can be improved.

Prerequisite: Analysis I, Algebra I, Electromagnetism, Waves and Optics (optional)

Project TTL3902: Introductory ultrafast optics 2: Nonlinear Optics
Supervisor: Prof. T.T. Luu

In this short-term project, the involved students will learn:

- Introduction to Fourier transform and its application in optics.
- Ultrashort laser pulses and what are these made of.
- Nonlinear optics: perturbative response.

The students will learn these topics theoretically first. Afterward, they will be able to perform one example of nonlinear optics: second harmonic generation. The experiment will be carried out, the students will record the nonlinear response as a function of input parameters. The results will be compared with that obtained from theoretical simulations. In this project, the students will not only learn experimental skills, but they will also be able to make their own numerical simulation and compare it with existing codes to see what they did well and what can be improved.

Prerequisite: Analysis I, Algebra I, Electromagnetism, Differential Equations, Quantum mechanics, Waves and Optics (optional)

Project ZYM3901: Many-Body Simulations on Quantum Magnetism
Supervisor: Prof. Z.Y. Meng

In this project, we will learn how to construct simple microscopic models to represent the quantum magnets and their phase transitions, and then we will learn how to use modern many-body simulation techniques to solve these models and obtain the physical understanding of the mechanism behind their transitions.

Prerequisites: Quantum mechanics, Statistical physics, Solid state physics, simple python, Julia, c++ or fortran programming, recommended to participate PHYS3151 Machine learning in physics

Project ZYM3902: Machine learning on Non-Fermi-Liquid
Supervisor: Prof. Z.Y. Meng

In this project, we will touch upon the physical problem of interacting electron models, that cannot be described by Fermi-liquid theory, we will first learn the basic properties of the Fermi-liquid theory and its limitations in describing modern quantum materials, and then start to build simple models that gives rise to the phenomena beyond Fermi-liquid theory, and learn how construct numerical techniques, such as quantum Monte Carlo and machine leaning, to solve these models and obtain the understanding of Non-Fermi-Liquid behaviour.

Prerequisites: Quantum mechanics, Statistical physics, Solid state physics, simple python, Julia, c++ and fortran programming, recommended to participate PHYS3151 Machine learning in physics.

Project ZYM3903: Quantum many-body physics and artificial Intelligence
Supervisor: Prof. Z.Y. Meng

In this project, we will learn basic artificial intelligence techniques such as Regression, Classification, Principle component analysis and Neural Networks, and try to apply them on few important quantum many-body physics systems, we will try to investigate whether these modern numerical techniques could help to reduce the computational complexity of the conventional simulation methods such as Monte Carlo methods, and in this way, we can explore more interesting parameter regions that is difficult for the conventional methods.

Prerequisites: Statistical physics, Solid state physics, simple python, Julia, c++ and fortran programming, recommended to participate PHYS3151 Machine learning in physics.

Project CYN3901: High Energy Emission from Pulsars
Supervisor: Prof. S.C.Y. Ng

Massive star end their lives as violent supernova explosions. The dense cores left over could form neutron stars. Such a star is more massive than the Sun, but has a radius of only 10 km, i.e. about the size of Hong Kong Island. It is therefore extremely dense. Neutron stars also possess the strongest magnetic fields in the Universe and rotate rapidly. These result in strong radiation beams along the magnetic poles, acting as lighthouses. When the beams sweep across the Earth, an observer would detect pulsating signals, hence a neutron star is also called a pulsar. The remarkable properties of pulsars make them an ideal laboratory for testing physics under the most extreme conditions that can never be produced on Earth. In this project, we will study pulsars based on high energy observations in X-rays or gamma-rays, to understand their emission properties and interaction with the environment.

Project SQS3901: Half-Quantized Hall Effect and Novel Topological Metallic States
Supervisor: Prof. S.Q. Shen

The quantum Hall effects refer to a series of peculiar quantum states of matter in the two-dimensional electron system in a strong magnetic field at a very low temperature. Similar phenomena in quasi-two-dimensional materials in the absence of a magnetic field are named the quantum anomalous Hall effect. Recently a novel type of quantum anomalous Hall effect was discovered in magnetic topological insulator. Its Hall conductivity is only one half of quantum anomalous Hall effect. In this project, we start with the Dirac equation to explore the relation between the massless Dirac fermions and the half-quantized Hall effect in condensed matter.

Project YJT3901: Searching for New Physics at the ATLAS Experiment at the Large Hadron Collider
Supervisor: Prof. Y.J. Tu

The goal of high-energy physics is to understand the fundamental particles and their interactions. The startup of the Large Hadron Collider (LHC), the world's largest and highest-energy particle accelerator, in 2009 opened up a new era at the high energy frontier. The discovery of the Higgs boson (popularly known as ‘the God particle’) at the LHC marked the beginning of a golden age for fundamental physics. The unexplored energy domain of the LHC provides unique opportunities to answer the fundamental questions in particle physics, e.g. what is the origin of particle mass? The group is carrying out new physics searches and participating the ATLAS detector upgrade. The projects will involve simulating and analyzing data from the ATLAS experiment (searching for physics beyond the Standard Model). In particular, the project will involve the application of Machine Learning (ML) techniques and the development of ML algorithms in particle physics. Particle physics has a history of several decades of using ML techniques for data analyses. However, most of the efforts heavily relied on traditional ML techniques such as Boosted Decision Trees, where expert-designed observables or model-dependent information are necessary for efficiently detecting new physics. We are developing the techniques of novelty detection which allows the data to be analysed without a priori knowledge of the new physics.

Knowledge required: C++ and Linux programming preferred

Project ZW3901: Experimental Exploration of Molecular–2D Interfaces
Supervisor: Prof. Z. Wan

This project introduces students to the experimental study of molecular insertion into two-dimensional materials. Students will learn basic exfoliation techniques for graphene or transition metal dichalcogenides, followed by controlled intercalation of selected organic molecules. The focus will be on observing how molecular spacing and orientation affect optical contrast and Raman responses. Simple external field perturbations (e.g., gate voltage or light illumination) will be applied to probe conformational changes and their influence on electronic coupling. The project provides hands-on training in sample preparation, microscopy, and spectroscopy, serving as a mini experimental platform for understanding molecular–2D hybrid systems.

Prerequisites: Introductory Solid State Physics, Quantum Mechanics

Project CJW3901: Toy Models in Many-Body Physics
Supervisor: Prof. C.J. Wang

More is different. Physics of many-body systems is fundamentally different from that of a single body. For most of the time, it is impossible to solve many-body problems exactly. Our understanding heavily relies on approximations and toy models. In this project, students are expected to explore a many-body toy model and its generalizations, and learn some basic concepts behind the model. Examples are Ising model for phase transitions, toric-code model for topological states of matter, disordered tight-binding models for localization, etc.

Prerequisites: quantum mechanics, some knowledge in programming

Project MHX3901: A Guided Study of Thin Film growth by Molecular-beam Epitaxy
Supervisor: Prof. M.H. Xie

Molecular-beam epitaxy (MBE) is a modern and versatile thin film growth technique, which allows film thickness control down to single atomic layer. It is a technique realizing artificial materials, such as by stacking one layer of material A onto another material B, thereby creating the ABAB… 'superlattice' structures with an array of new properties. In this project, students will be exposed to the fundamentals of the surface growth processes and gain some hand-on experience of ultrahigh vacuum operations. He/she will learn some basic surface characterization techniques widely used to assist MBE of crystalline thin films.

Project YY3901: Free-electron light interaction
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. This project aims to pursue strong interaction strength between free electrons and photons and to put forward realistic designs for experimental realizations

Project YY3902: 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. This project plans to explore photonic realizations of synthetic gauge fields and their topological consequences. The student will discuss the interplay between non-Hermiticity, nonlinearity, and synthetic gauge fields on photonic platforms.

Project WY3901: Valley Physics in Monolayer 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 information processing. A paradigmatic example is spintronics based on spin of electrons. Degenerate valleys of energy bands well separated in momentum space constitute another discrete degrees of freedom for low energy carriers with long relaxation time. This has led to the emergence of valleytronics, a conceptual electronics based on the valley index. In a number of monolayer hexagonal crystals including graphene and several transition metal dichalcogenides, the conduction and valance bands have two inequivalent valleys at the corners of the 1st Brillouin zone. The low energy electrons and holes are thus described by massless or massive Dirac electrons with valley degeneracy. In this project, students are expected to learn about valley dependent physics in these emerging novel materials, and may also study feasible problems related to valley and spin control for information processing.

Prerequisites: PHYS3351 Quantum mechanics, and PHYS3551 Introductory solid state physics (or equivalent courses)
Corequisites: PHYS4351 Advanced quantum mechanics (or equivalent course)

Project SZZ3901: Physics of Very Degenerate Atomic Gases
Supervisor: Prof. S.Z. Zhang

Atomic gases at extremely low temperatures exhibit a range of fascinating phenomena, in which particle statistics and interaction play an important role. As an example, superfluidity has been seen in both Bose and Fermi variants, with the direct observation of vortex arrays and other interference phenomena associated with the phase coherence of the macroscopic quantum states. Recent experimental advances have made it possible to engineer synthetic (abelian or non-abelian) gauge fields which fundamentally changes the nature of the many-body states. These new developments bring out the prominent role played by Berry phases and make atomic gases an idea playground for understanding the topological aspects of interacting many-body systems. In this project, students are expected to learn the fundamentals of this rapidly developing field and possibly explore a few problems of current interest.

Prerequisites: PHYS3351 and PHYS3550

Project S_Z3901: Topological photonics
Supervisor: Prof. S. Zhang

Topologically ordered phases of matter, such as topological insulators and topological semimetals, represent a new class of materials with the unique ability to support protected edge or surface states. Recently it has been shown that the concept of topological order can also be transferred to photonic systems, providing a flexible one-way wave-guiding platform. In this project the students will explore the design of metamaterials and/or photonic crystals with topological orders and study the interesting topologically protected surface/edge states supported by such photonic systems.

Prerequisite: Electrodynamics, Solid-State Physics, Quantum Mechanics

Project ZDZ3901: Feedback control of lasers for experiments of cold atoms and ions
Supervisor: Prof. Z.D. Zhang

Precise control of laser beam properties is essential for the production, manipulation and detection of cold atoms and trapped ions, which are fundamental quantum systems for the study of quantum physics, quantum information processing and ultracold chemistry. In this project, students will build feedback circuits with proportional-integral-derivative (PID) controls to stabilize the intensity or frequency of laser beams. Acousto- or electro-optic modulation will be applied for laser beam control. Students will acquire hands-on experience and apply knowledges of electronics, lasers and atomic physics in modern cold atom experiments.

Prerequisites: Electronics, Lasers and Atomic Physics

Project YXZ3901: Crystal symmetry in solids
Supervisor: Prof. Y.X. Zhao

Each solid is invariant under a set of spatial transformations like rotations and mirror reflections, called the symmetries of the solid. These symmetries have nontrivial implications on the energy spectrum of the solid. In this project, students will be trained to master the elementary techniques to process the symmetry constraints, including the representation of crystal symmetries and the k.p method for low-energy effective theory. The aim is for students to appreciate the difference between projective symmetry algebras and ordinary symmetry algebras in their implications for the energy spectrum.

Prerequisite: Linear algebra, Quantum Mechanics

6 March, 2026