4th grade, 2026
Themes of
Graduation Research-Experiments and
Graduation Research-Theoretical Studies

●On the 4th grade assignment to laboratories

Note that the maximum number of G30 students who are accepted to each laboratory is 2.

【Graduation Research-Experiments】

A student who selects the experimental course is assigned to an experimental laboratory and performs experiments for a year about one of the themes that the laboratory provides.

The number of students that each laboratory accepts in 2026 is as follows.

Particle Physics		Astrophysics		Condensed Matter Physics		Biophysics	
F	2	A	6	I	4	D	4
N	6	Uir	4	J	4	G	4
Φ	6	Uxg	6	V	1	K	2
μ	2			Y	4		
				O	4		

Heliospheric and Geospace Physics*	
AM	7
CR	
SS_E	
(SS_T†)	
SW	

†SS_T laboratory is a theoretical laboratory.

*The laboratories (AM, CR, SS_E, SS_T, and SW) on the Heliospheric and Geospace Physics accept a total of 7 students. The wish of students for the assignment of laboratories in this field is reflected as much as possible. However, if there is a bias in the number of applicants, it may be adjusted. Within the above limit on the total number of students, CR and SS_T can accept 5 students at maximum, and the other laboratories can accept 3 students.

AM, CR, SS_E, and SW laboratories are experimental laboratories, and SS_T laboratory is a theoretical laboratory.

【Graduation Research-Theoretical Studies】

A student who selects the theoretical course is assigned to a theoretical laboratory and studies for a year about a theme related to the researches of the laboratory.

The number of students that each laboratory accepts in 2026 is as follows.

B	6	QG	4	Ω	2
C	4	R	4	SS_T	Accept as Heliospheric and Geospace Physics
E	9	Sc	6		
H	4	St	4		
P	4	Ta	4		

Themes of
Graduation Research-Experiments in 2026

Particle Physics

●F laboratory (Fundamental Particle Physics Laboratory)

Since 1980's, we have been carrying out researche for elementary particles physics with nuclear emulsion, which can individually record tracks of elementary particles in sub-micron accuracy. In 2000, for example, we succeeded in detecting tau neutrino for the first time in the world and established the existence of muon neutrino to tau neutrino oscillation in 2015.

The following are the themes of our current studies. We are also making efforts to develop and improve detectors related to particle physics and astrophysics to promote these themes.

F-1 Study of neutrino physics

The existence of neutrino mass was confirmed by the observation of neutrino oscillation. However, many characteristics are still unknown such as absolute value and hierarchy of mass. Does a right-handed neutrino exist? Is the neutrino Majorana particle? Is the CP-violating phase in the lepton sector non-zero? Tackle these challenging issues.

F-2 Directional dark matter detection

NEWSdm is the experiment for dark matter (WIMPS) search with ultra-fine grain nuclear emulsion, which is possible to detect the very short trajectory of the recoil atom caused by collisions between atomic unclei and dark matter. The goal is to demonstrate its existence and incoming direction of dark matter. This experiment is being started at Gran Sasso Laboratory in Italy. We also promote experimental research to explore the possibilities of dark matter candidates other than WIMPS.

F-3 Balloon-borne gamma-ray telescope

Unknown gamma-ray sources exist in Universe such as galactic center gamma-ray excess. To investigate these objects, we promote the GRAINE project, which is balloon-borne gamma-ray telescope with the world's largest diameter ultra-high resolution nuclear emulsion telescope.

We are currently analyzing the Australian flight data in May 2023 and are aiming to observe at the world's highest resolution of gamma-rays imaging. We are also developing emulsion telescopes with the aim of achieving even higher sensitivity and resolution.

F-4 Development of particle detectors based on technologies including nuclear emulsion's

We will progress with development of detectors based on nuclear emulsion technology.
Example 1) Detection of unknown short-range force: detection and measurement of wavefunctions of neutrons using ultra-fine grained nuclear emulsion.
Example 2) Development of automatic readout system for nuclear emulsion (speeding up, improvement of image detection)
Example 3) Production of nuclear emulsion from chemical substances and its development.

●N laboratory (High Energy Physics Laboratory)

N-1, N-2, N-3, N-4 Experimental Particle Physics

The goal of particle physics is the understanding of fundamental principles of elementary particles and their interactions. According to the Standard Model (SM), six quarks and six leptons are the fundamental constituents of the matter, and their interactions are mediated by the gauge bosons such as the photon and the W bosons. The SM explains the origin of particle masses by the Higgs mechanism. The N laboratory contributed to the verification of the SM; we confirmed the Kobayashi-Maskawa theory that explains the asymmetry between particles and antiparticles, and more recently discovered the Higgs boson. Now, the researches at the N laboratory focus on the searches for physics beyond the SM. We promote “Super B-Factory Experiment”, “LHC-ATLAS Experiment”, and “Muon g-2/EDM Experiment”. Our research would answer some of the fundamental questions in the Universe, e.g. “What is the Dark Matter?” and “How is the present matter-dominated Universe produced?”.

The courses prepared for the fourth-grade students are shown in the following.

N-1 Super B-Factory Experiment

The B-factory experiment uses the KEKB collider located at the High Energy Accelerator Organization in Japan. The N laboratory played a leading role in the observation of CP violation in B meson decays, which verified the Kobayashi-Maskawa mechanism. Now, we are searching for physics beyond the SM via precision measurements of the B-meson and tau-lepton decays at the Super-KEKB collider, which provides 30 times higher luminosity than the KEKB. Research topics for students include analyses of data obtained at KEKB and Super-KEKB colliders and their simulation studies. The researches utilize high-quality computers owned by the N laboratory.

N-2 LHC-ATLAS Experiment

The LHC-ATLAS experiment is held at CERN located at Geneva, Switzerland. Proton-proton collisions are provided with the highest energy in the world. The N laboratory played a leading role in the development and the operation of the muon detectors, which were essential for the observation of the Higgs boson. We measured the top quark properties, studied the origin of muon mass, and searched for supersymmetric particles. Further searches for physics beyond the SM are ongoing. The students are expected to learn the basics of the LHC-ATLAS experiment through the development and the operation of the muon detectors as well as the analyses of the data.

N-3 Muon g-2/EDM Experiment

The g-2 is the anomalous magnetic dipole moment, a fundamental parameter of particle physics. The current measurement of muon g-2 is deviated from the SM prediction, which would be a hint of the physics beyond the SM. Aiming for more precise measurement with different sources of the systematic uncertainties, the N laboratory is preparing for a new experiment using the muon beam of the J-PARC accelerator at the High Energy Accelerator Organization in Japan. The students are expected to contribute to the development of a new system of the transportation and the diagnostics of the muon beam, a key element of the experiment.

N-4 Advanced Experimental Techniques

Frontiers of particle physics have been explored by advanced experimental techniques. In the N laboratory, a new particle detector called “TOP counter” was developed and installed for the super B-factory experiment. The TOP counter identifies the particle types by precise measurements (10 pico-second order) of Cherenkov photons generated in the quartz radiator. New photon detector for the TOP counter upgrade is under study. For the LHC-ATLAS experiment, a new attempt is ongoing for detecting the signatures of the physics beyond the SM by combinations of FPGA and machine learning. We also work on the techniques of muon acceleration, big data analysis, and applications of machine learning to data analyses and particle identifications. The students can contribute to these researches, which will possibly play essential roles in future discoveries.

●Φ laboratory (Laboratory for Particle Properties)

Experimental approaches to elementary particle physics can be categorized into two criteria: (1) direct observation of high energy particle reactions using high-energy accelerators (2) indirect observation of high energy phenomena in precision measurement of the contribution of higher-order quantum-loops of high-energy phenomena in low-energy processes. In the Phi-lab., slow neutrons from the most luminous pulsed neutron source at J-PARC (Japan Proton Accelerator Research Complex) will be mainly used to probe the properties of elementary particles. We also use muon beam. The following is out list of on-going research items. We encourage students to consider to invent new approaches and welcome motivated students.

Φ-1 Study of the Breaking of the Symmetry under Spatial-inversion and Time-reversal in Neutron-induced Compound Nuclei

Large violation of the symmetry between matter and antimatter is required in order to explain our universe. We are now studying the enhancement of the symmetry breaking in neutron-nuclei reactions. The search for the symmetry breaking in some reactions is independent of and competitively sensitive to that of neutron EDM. We are also developing experimental techniques for neutron spin control, polarization of target nuclei, and high-speed neutron detection to improve the sensitivity beyond standard model of particle physics.

Φ-2 Precise Measurement of Interactions and Search for New Interactions Using Neutron Interferometry

Slow neutrons remarkably exhibit quantum-mechanical wave properties. An interferometer, that splits neutron waves into two paths and recombine them, can be used to sensitively measure the difference in the interaction between the two paths. We are developing neutron interferometers for pulsed long-wavelength neutrons to study neutron-related interactions. They are well-suited for studying extremely weak interactions such as gravitational interaction. By utilizing the wave interference effects in neutron interferometry and neutron scattering, we explore new interactions related to dark energy and anomalous gravity due to extra dimensions.

Φ-3 Neutron Electric Dipole Moment

Neutron does not have the electric dipole moment (EDM) as long as the time-reversal symmetry is a valid symmetry. In reality, any non-zero value of neutron EDM has been measured so far. However, the asymmetry between matter and antimatter in the universe implies a finite value of EDM. The determination of neutron EDM is one of the most important observables to find a clue to the origin of the asymmetry. Extremely slow neutrons, that are sufficiently slow to be confined in bottles, are commonly applied for improving experimental sensitivity to the neutron EDM. We will study to apply precision neutron optics for measurements of neutron EDM. We are also trying to search the neutron EDM by measuring the effects of neutron wave through the non-centrosymmetric crystal.

Φ-4 Neutron Decay Rate (Neutron Lifetime)

Neutron decay rate is a key parameter to define the weak interaction for quarks and also the primordial nucleosynthesis. Its experimental accuracy is still insufficient for precise verification of theoretical models. We are going to improve our understanding by improving accuracy and to search for non-standard interactions.

Φ-5 Precision Measurement of Muonium Hyperfine Structure

Muonium is an atom that consists of a positive muon and an electron. Its hyperfine structure can be analyzed theoretically due to the simple system only with two leptons. Ultra-precise spectroscopy of the hyperfine structure can be used to verify the standard theory of particles physics. Muonic helium, which is a helium atom with one negative muon instead of a electron, can be also used to study the fundamental symmetry of physics through its hyperfine structure.

In addition to above research items, we study "search for the violation of baryon number conservation law (also B-L violation) in neutron anti-neutron oscillation".

●μ laboratory (Laboratory of Cosmic-Ray Imaging)

Our laboratory develops cosmic-ray imaging (muography) technology that uses muons—elementary particles contained in cosmic rays—to visualize the internal structures of large artificial and natural objects such as pyramids and volcanoes, in a non-destructive way. We work on the fundamental development of nuclear emulsion detectors, applied research optimized for various targets, and the social implementation of these technologies. We welcome students with broad curiosity and the motivation to go beyond conventional physics.

μ-1 Fundamental technology for cosmic-ray imaging

We develop new nuclear emulsions with improved stability, sensitivity, and signal-to-noise ratio, as well as machine-learning-based methods for automatic recognition of muon tracks. We also advance simulation and 3D reconstruction techniques for analyzing cosmic-ray data.

μ-2 Archaeological Applications

Since 2015, we have led the ScanPyramids Project, exploring hidden structures in Egyptian pyramids and discovering two unknown cavities inside the Great Pyramid of Khufu. We continue studies on the three Great Pyramids of Giza and are developing non-destructive survey methods for other sites, including Maya temple pyramids in Honduras and Guatemala, underground ruins in Naples and the Kofun (ancient burial mounds) in Japan.

μ-3 Infrastructure and Underground Imaging

We apply cosmic-ray imaging to visualize underground structures and civil engineering facilities, aiming to prevent sinkholes, embankment failures, and other accidents. This research is conducted in collaboration with research institutes, municipalities, and companies, with a focus on practical use in society.

μ-4 New Imaging Targets

We are expanding applications to new fields, including tree diagnostics, Mount Fuji's internal imaging, industrial plant inspection, and underground resource exploration.

Astrophysics

●A laboratory (Radio Astronomy Laboratory)

Understanding how stars and galaxies formed and have been evolved across the Hubble time is one of the biggest challenges in modern astrophysics. We are trying to address those big questions by millimeter / submillimeter observations of interstellar gas and dust in the Milky Way and external galaxies far away.

A-1 Submillimeter-wave observations of distant galaxies in the early universe

Distant star-forming galaxies which are rich in interstellar medium, such as gas and dust, give off a vast amount of energy in the far-infrared, which is cosmologically-redshifted and can be observed in the submillimeter wave in the present-day Universe. Students will exploit a series of multi-wavelength data, especially those taken with the ALMA submillimeter telescope, to investigate how star-formation and supermassive black hole growths are going in galaxies from the epoch of reionization (~100 million years after the Big Bang) to the present day. The students will learn data analysis techniques and radiative processes of interstellar media and study the physical properties of gas and stars in galaxies.

A-2 Development of instruments for the next-generation radio telescopes

Our research includes development of technologies for the next-generation submillimeter telescopes; (1) development of millimetric adaptive optics for instantaneously correcting radio wavefront disturbed by atmosphere and deformation of telescope optics, (2) development of data-scientific method to design the structure of a telescope, and (3) development of ultra-wideband spectrometers for high-redshift galaxy surveys, especially in terms of signal processing and data analysis software. We also plan to install those instruments on existing radio telescopes, such as the Nobeyama 45 m telescope, the ASTE 10 m telescope in Chile, and the 50 m Large Millimeter Telescope in Mexico. The students will join one of the projects and learn instrumentation basics.

A-3 Submillimeter-wave and microwave observations and data analyses of molecular and atomic clouds in the Galaxy and nearby galaxies.

Revealing the distribution and nature of the molecular and atomic gas clouds in the Galaxy and nearby galaxies is important for understanding formation of stars, planets and their birth clouds. For this sake, students join observations of spectral lines of molecules (e.g., CO, OH) and atoms (e.g., hydrogen and carbon), by using the NANTEN2 4 m submillimeter telescope we are operating in Atacama, Chile (remotely) and/or JAXA's Usuda 64 m microwave antenna in Nagano (on site) to learn how the telescope system works. The students will also learn how to analyze the data taken for the Galactic Center, high-latitude diffuse gas clouds, low/high mass star forming regions, supernova remnants, a Galactic micro-quasar, and nearby galaxies, etc.

A-4 Developments of the multi-beam heterodyne receiver system and software

In order to enhance NANTEN2's capability exploiting the good sky transparency in Atacama, we develop a new multi-beam receiver system and related software for telescope control and data analysis. We also develop cryogenic microwave receivers and data analysis software for the Usuda 64m antenna. Students will join development of those instruments, such as receivers, spectrometers, and software for instrument control and data analysis.

●U laboratory (Space Astronomy Laboratory)

U-1, 2, 3, 4 Infrared Astrophysics (Uir)

The main purpose of our research is to understand the properties of dust grains and gas under various environments in galaxies through near- to far-infrared observations using space-borne and ground-based telescopes. We have developed a far-infrared imaging spectrometer for AKARI, a Japan-led infrared astronomical satellite. (U-1) We are analyzing AKARI data, in addition to other space (e.g., Spitzer, Herschel, JWST) and ground-based (e.g., South Africa IRSF, Subaru) infrared observational data extensively, to pursue the above scientific researches. We are responsible for producing AKARI all-sky diffuse maps in the mid-infrared, which are uniquely designed to trace the distribution of organic matter in the interstellar space. (U-2) We are developing space cryogenic optics for future infrared astronomy satellite projects, such as US-led PRIMA and Japan-led GREX-PLUS. (U-3) We are evaluating the performance of a near-infrared spectrometer as a new focal-plane instrument for the IRSF 1.4 m telescope in South Africa. We are also testing a far-infrared spectrometer to be carried aboard the balloon-borne 1 m telescope in India. (U-4) We are developing special optics to be utilized for the future space interferometer project called SEIRIOS, a formation-flying interferometer using 3 micro-satellites in collaboration with the Univ. of Tokyo.

U-5 Development of new instruments for X-ray and MeV gamma-ray astronomy (Uxg)

Universe is filled with hot and energetic phenomena, emitting strong X-rays. As these photons cannot penetrate earth's atmosphere, X-ray observation requires observatories in orbit. We are developing new devices to improve cosmic X-ray and MeV gamma-ray observations, such as; new X-ray telescope technology, innovative thermal control membrane technology, new hard X-ray imaging spectrometer and future sub-MeV Compton camera. Research on MeV gamma-ray emission from thundercloud is also on-going.

U-6 Observational X-ray astronomy (Uxg)

Using existing X-ray observatories and those to be launched soon, we are analyzing the X-ray observational data of high energy celestial objects, such as: stellar flares, Galaxy X-ray emission, Clusters of galaxies, black holes, neutron stars and others.

U-7 Gravitational-wave astronomy and detector science (Uxg)

Since Advanced LIGO's first detection of gravitational waves in 2015, gravitational wave astronomy has advanced rapidly through tests of general relativity, multi-messenger observations of binary neutron star mergers, and the observation of binary black hole and neutron star mergers. The next-generation gravitational wave detector project, Cosmic Explorer, is expected to enable observations of black hole mergers beyond the nearby universe, reaching the edge of the universe ($z \sim 20$), and uncover the processes of cosmic evolution. In our group, we are closely collaborating with gravitational wave projects worldwide, including Advanced LIGO and Cosmic Explorer, and are working on the development of cutting-edge detector technologies and data analysis methods. Gravitational wave detectors are based on laser interferometry, and their scale is vastly larger than conventional telescopes (e.g., 4 km optical cavities). These extremely complex instruments integrate state-of-the-art technologies and involve many physical phenomena in optics, materials science, mechanics, and control systems. Research topics can be chosen based on the interests and aptitudes of the students. Examples of research topics we are currently pursuing include: (1) In Advanced LIGO, the interferometer mirrors are heated by lasers reaching up to 500 kW, causing operational issues. What physical phenomena are affecting the mirrors and optical cavities? How can these effects be controlled? (2) Can the detector's sensitivity be optimized by utilizing the etalon effect to freely modify the reflectivity of the mirrors through thermal changes? (3) Can the classical feedback control systems currently used in gravitational wave detectors be improved or replaced by AI and machine learning? (4) Can AI and machine learning be used to more accurately determine the state of the instrument, such as its sensitivity, operational stability, and the risk of control failure? Through these themes, students will also have the opportunity to engage with researchers from around the world and develop the skills necessary to conduct independent research.

Condensed Matter Physics

●I laboratory (Solid State Magnetic Resonance Laboratory)

The Solid State Magnetic Resonance Laboratory aims to elucidate the universal physical laws governing the properties of matter using nuclear magnetic resonance (NMR), which is primarily a microscopic measurement.

NMR is a microscopic means of observing physical properties that can be observed from the atomic nucleus, which is closest to the electrons that determine the properties of matter. In particular, it can detect with high sensitivity slight changes in the symmetry of electron orbital and spin states, charge states, and local structures, and from these, we can elucidate the origin of the ground and excited states of matter.

In the fourth year, students will learn how to conduct experimental studies of physical properties and how to understand the physical properties of real materials on the basis of quantum mechanics, statistical physics, and electromagnetism, which they have studied so far, through the following experimental topics.

I-1 Magnetism of strongly correlated electron systems

Quantum many-body effects in electron systems are one of solid-state physics's most important problems. Various and novel physical properties emerge in which the fundamental degrees of freedom of electrons, charge, spin, and orbital, are entangled by strong electron-electron interactions. We will study the synthesis, characterization, macroscopic properties, and NMR measurements of transition metal compounds in which 3d, 4d, and 5d orbital electrons play a major role.

I-2 Physical properties of various superconductors such as iron-based superconductors

Following the High-*Tc* Cuprate, layered cobalt oxides, and iron-based superconductors, a layered nickel oxide with a superconducting transition temperature *Tc* of 80 K, which exceeds the liquid nitrogen temperature under pressure, has been discovered in 2023, and it has attracted attention because of its high *Tc* comparable to that of the High-*Tc* Cuprate. The discovery of layered nickel oxides with a superconducting transition temperature *Tc* of 80 K, which exceeds that of High-*Tc* Cuprate materials, has attracted much attention due to the possibility of having a superconductivity mechanism different from that of High-*Tc* Cuprate due to the difference in electronic states. The novel physical properties brought about by the change of the orbital state and the break of the rotational symmetry of the electronic system are also expected to be of interest. We synthesize various layered nickel oxides and measure their macroscopic and microscopic properties to investigate the relationship between spin/orbital/charge fluctuation and superconductivity, which is considered to be the origin of superconductivity.

<u>I-3</u> Superfluid

Helium 3 and Helium 4, liquids that do not freeze no matter how cold they are, behave as quantum liquids at low temperatures. This is a superfluid state, an ordered state in which many particles are in a single quantum state (Bose-Einstein condensation), and has been the subject of much research. If the helium is confined in nanopores of 10^{-9} m size and the motion of helium is controlled in low dimensions, a new quantum fluid of helium is expected to emerge. We will measure the thermal and magnetic properties in this state and investigate the ground state of this new quantum fluid.

<u>I-4</u> Development of NMR measurement technology

Unique properties of strongly correlated electron systems often appear under extreme conditions of cryogenic temperature, high pressure, and high magnetic field, and NMR measurements must be performed under these conditions. For this reason, we will develop usable NMR probes, increase the sensitivity of NMR instruments, and develop NMR data analysis. In addition, we are developing cutting-edge technologies such as “optical magnetic resonance,” which uses light to control and detect nuclear and electron spin states. These technologies have the potential to be used in the design of new high-temperature superconductors and in core technologies for quantum computers and magnetic resonance imaging (MRI), which will surpass the performance of conventional devices.

●J laboratory (Laboratory of Nanomagnetism and Spintronics)

The group’s research focus is on nanoscale magnetism and spin related effects, aiming at discovering novel concepts in condensed matter physics. Research study in nanostructures allows us to address the challenging questions in the field of spin-related phenomena by artificially designing and fabricating nanostructures. A number of remarkable new physical effects have been already discovered by designing artificial interfaces, where strong electron-phonon-spin coupling emerges at nanoscale. Quite the opposite, revealing the physics underlying provides a fundamental basis and means for manipulating the physical phenomena. In this course, you will be trained in state of the art techniques such as growth of nanoscale materials, fabrication, and magnetic and transport measurements, and will enjoy the superb flavor of condensed matter physics. The group’s current research programs are divided into the following key themes.

<u>J-1</u> Cross-correlations in multiferroic heterostructures

<u>J-2</u> Spin dynamics in heterostructures with topological textures

<u>J-3</u> Magnon propagation in exchange-biased heterostructures

<u>J-4</u> Static and dynamic spin phenomena in artificial antiferromagnets

<u>J-5</u> Electron correlations at magnetic/superconducting interfaces

●O laboratory (Optical physics laboratory)

O laboratory just started from fiscal year 2024. Our research theme is the understanding of the physical properties and functions of condensed matters by developing state-of-the-art experimental apparatus based on the laser technology. New angle-resolved photoemission spectroscopy with focused monochromatic laser will be developed, in order to observe the fine electronic structures. By employing this system, we will obtain the information of the energy, momentum, spin and orbital of the electrons in the strongly-correlated electron systems and high-transition-temperature superconductors. Furthermore, it will be also available to detect the electronic states in a small region less than 1 μm, such as the self-organization of the strongly-correlated electrons and strange metallic behavior at the magnetic domain wall. From 2025, we started the construction of new photoemission spectroscopy system and ultrafast transmission electron microscopy system with undergraduate students at Nagoya University. Please join our laboratory if you are interested in optical physics and apparatus development. During the apparatus development at Nagoya university, you will have experimental themes below by using shared photoemission spectroscopy at University of Tokyo and synchrotron radiation facilities. In this research program, you will obtain the skills of laser, vacuum and low-temperature measurements. We hope you enjoy the optical physics with originality and ingenuity.

O-1 Development of the photoemission spectroscopy with focused monochromatic laser

O-2 Electron pairing in the unconventional superconductors

O-3 Normal-state electronic structure of the high-transition-temperature superconductors

O-4 Development and application of the ultrafast transmission electron microscopy

●V laboratory (Laboratory of Condensed-Matter Physics of Functional Materials)

We are interested in the sample syntheses and precise measurements for useful and interesting materials. Our research field covers a wide variety of functional properties in correlated electron systems; a large thermoelectric power in transition-metal oxides, nonlinear conduction phenomena in organic conductors, and magneto-dielectric behavior in novel low-dimensional materials. Basic understanding of electromagnetism, thermal/statistical physics, and quantum mechanics is prerequisite for graduate research.

V Functional materials studied by numerical analyses

Based on experimental data obtained for newly developed functional materials, we aim to elucidate their electronic states through comparison with numerical calculations. The experimental data include unpublished results measured in our laboratory, which will be analyzed using various numerical methods and data analysis techniques. First-principles calculations will also be employed when necessary.

●Y laboratory (Materials Response Laboratory)

Our group focuses on various response properties of materials, including the dielectric response, the optical response, the magnetic response, the thermal response, and the mechanical response. Based on their fundamental mechanisms clarified from a viewpoint of the structure-property relationship, we address designing of functional materials, which lead innovation in science and technology. Current themes in our lab are listed below:

Y-1 Environmentally-friendly functional dielectric materials

Y-2 Novel ferroelectric materials

Y-3 Novel properties in quasicrystals

Y-4 Search for new quasicrystals and approximants

Biophysics

●D laboratory (Laboratory of Biomolecular Dynamics and Function)

Biomacromolecules such as proteins and nucleic acids exhibit unique physiological functions through dynamic phenomena like structural transformation, self-assembly, and the binding and dissociation with other molecules. At D Lab, we aim to deeply understand the operating principles of these biomolecules by directly visualizing molecular movements in real time and analyzing their structural dynamics and interactions at the single-molecule level. We utilize high-speed atomic force microscopy (AFM) technology to observe molecules in solution at the nanometer scale, pursuing the development of new functions and the integration of advanced single-molecule measurement techniques. This allows us to explore the forefront of dynamic structural life sciences. Furthermore, we are working on the creation of hybrid molecules that combine synthetic and biomolecules, aiming to artificially control molecular movements and intracellular functions. This research represents a crucial step toward the creation and application of new biological functions.

D-1 Analysis of the Dynamics of Biomolecular Functions and Elucidation of Mechanisms of Function Expression

Many proteins exhibit unique functions triggered by changes in their surrounding environment, as well as by chemical reactions such as substrate binding, degradation, and dissociation. These processes lead to localized structural changes and, over time, result in larger-scale structural transformations and cooperative interactions with multiple molecules. By focusing on motor proteins and membrane proteins, we utilize high-speed AFM to visualize the dynamics of structural changes and molecular interactions in real time. This detailed analysis allows us to elucidate the operating principles of biomolecules.

D-2 Development of Novel Single-Molecule Measurement Techniques

In biomolecules, not only the structure but also the local distribution of electric and mechanical properties, as well as their temporal evolution, are considered to play extremely important roles in function. While high-speed AFM typically images the surface structure of samples, we are advancing the development of new functionalities to visualize property distributions. Additionally, we aim to develop devices that enable the dynamic analysis of complex systems involving multiple proteins by integrating advanced single-molecule microscopy techniques, such as fluorescence microscopy.

D-3 Creation and Functional Control of Hybrid Molecules

We aim to create hybrid molecules that combine synthetic and biomolecules, allowing for the artificial control of molecular movements and intracellular functions. This research represents a crucial step toward the creation and application of new biological functions. By designing, synthesizing, and evaluating the functions of hybrid molecules, we hope to bring about new developments in the understanding and control of biological functions.

D-4 Development and Application of Dynamic Mechanical Property Measurement Techniques for Synthetic Polymer Materials

High-speed AFM has recently gained attention as a method capable of measuring the nanostructures and mechanical properties of synthetic supramolecules, polymer gels, and polymer films. We are currently conducting a project aimed at developing mechanically stable polymer materials that can be easily decomposed by multiple stimuli. As part of this research, we are investigating the mechanical stability of polymer microparticles, ranging from tens of nanometers to several micrometers in size, and their aqueous dispersions (synthetic latex). We aim to elucidate the factors controlling the decomposition of these microparticles in response to multiple stimuli through nanoscale measurements using high-speed AFM.

● G laboratory (Photo-Bioenergetics Laboratory)

Proteins are extremely elaborate ‘nano-devices’ that have been formed during evolution for 4 billion years. Photosynthesis performed by plants and cyanobacteria realizes light-energy conversion with an extremely high quantum yield using a number of pigments and metal ions embedded in proteins. To understand this most basic and significant biological process, it is necessary to clarify the mechanisms of light-energy conversion in the photosynthetic ‘nano-devices’. In our laboratory, we investigate the molecular mechanisms of the reactions in photosynthetic proteins using various physical methods such as vibrational spectroscopy, electron spin resonance, and quantum chemical calculations. Students in the 4th grade challenge their own research themes mastering basic experimental and analytical techniques, like preparations of biological samples, spectroscopic measurements, and analyses using computer calculations.

G-1 Mechanism of light-energy conversion in photosynthetic proteins

In photosynthesis, successive processes of light absorption, excitation transfer, charge separation, electron transfer, and proton transfer take place upon light illumination in the time scale from femtoseconds to milliseconds. It is also possible to trap the intermediate states after charge separation at cryogenic temperatures. The molecular mechanism of light-energy conversion in photosynthesis is investigated by detecting reactions and intermediates in photosynthetic proteins using various spectroscopic methods.

G-2 Molecular mechanism of photosynthetic oxygen evolution

The mechanism of photosynthetic oxygen evolution remains to be the biggest mystery in photosynthesis researches. Although oxygen evolution is known to be performed by water oxidation at the Mn_4CaO_5 cluster in photosystem II protein complexes, the detailed reaction mechanism has not been well understood. We challenge the clarification of water oxidation mechanism utilizing spectroscopic methods such as infrared spectroscopy and electron spin resonance.

● K laboratory (Laboratory of Cellular Signaling Biophysics)

Our laboratory aims at understanding the mechanisms of the information conversion and communication occurring in biological systems at the molecular and cellular levels. We focus on the mechanisms of protein folding / complex formation as the research at the molecular level (K-1). We also focus on the mechanisms of communication between nerve cells at the synapse as the research at the cellular level (K-2). The specific aims and the details of the research are described below.

K-1 Protein folding mechanisms

Proteins are biological macromolecules consisting of a series of amino acids, and indispensable in almost all aspects of biological phenomena. Proteins play their roles in biological systems only after they form their own specific three-dimensional structures and often multimeric complex. The conversion from an ensemble of the unstructured conformations without biological functions to the specific native structures is referred to as protein folding. There are many questions to be addressed in their physicochemical mechanisms although the protein folding / assembly is important in that these phenomena are associated with biology as well as molecular science. For the purpose of addressing the questions, our laboratory studies the mechanisms of proteins folding / assembly by means of our own ultrarapid mixing devices and spectroscopy. The details of the course are molecular biology to construct variant proteins, expression and purification of proteins, spectroscopic measurements of proteins and kinetic measurements of protein folding / assembly.

K-2 Research on the mechanism of synaptic transmission

In the nervous system, communications between nerve cells are executed through chemical synapses. In the presynaptic process, inflow of Ca^{2+} through Ca^{2+} channels opened by an action potential triggers the exocytosis of neurotransmitter through the fusion of synaptic vesicles with presynaptic membrane. When nerve is repeatedly stimulated, the amount of transmitter released gradually increases. This phenomenon, synaptic plasticity, is essential for higher function of brain as memory and learning. You study about the presynaptic mechanism and its regulation, especially modulation of transmitter release and dynamics of divalent cations, with the preparation of frog neuromuscular junction synapses using electrophysiological methods and ion-imaging techniques.

Heliospheric and Geospace Physics

●AM laboratory (Atmospheric and Environmental Science Laboratory)

The atmospheric environment on the Earth has been affected by various anthropogenic causes of human activities since the industrial revolution, including the recent increase of greenhouse gases and the depletion of the ozone layer. On the other hand, the atmosphere is also affected by a variety of natural causes, such as changes in UV radiation and solar wind associated with the solar activities, galactic cosmic rays from space, and volcanic activities on the Earth. In order to predict the future atmospheric environment more accurately, it is necessary to clarify the mechanisms and effects of the atmospheric changes by the natural and anthropogenic factors. In AM Laboratory, we use state-of-the-art millimeter-wave (radio) and infrared remote sensing techniques to study the mechanism of atmospheric changes through ground-based observations and laboratory experiments. We welcome motivated students to face the environmental issue and to study the atmospheric science, based on their knowledge and skills of physics.

AM-1 Study the influence of solar activity on the Earth's atmosphere by using the observed data of trace gas in the polar regions

Atmospheric molecules having electric dipole moments emit spectral lines in the millimeter wavelength through the rotational transitions. We have been conducting long-term observations of trace gas molecules at Syowa Station in Antarctica and Tromsø (Norway) in the Arctic region. In the 4th-grade experiment, students will develop data analysis programs for these observations and analyze the data to clarify the actual situation of variability of the trace gases in the polar region. In addition, students will work together with the research group on the magnetosphere and ionosphere to reveal the impact of energetic particles on the composition in the polar middle atmosphere.

AM-2 Study on variations of trace molecules such as greenhouse gases by infrared spectroscopic observation

The atmospheric minor constituents such as greenhouse gases, a primary cause of climate change, have many absorption lines in the infrared region. Our group, in collaboration with the National Institute for Environmental

Studies, has been operating large high-resolution Fourier transform infrared spectrometers (FTIRs) in Nagoya and Hokkaido, and has obtained the altitude distribution of various minor constituents from solar absorption spectral data. In the 4th-grade experiment, students will study changes in the atmospheric environment and their causes by analyzing the altitude distribution and temporal variation of greenhouse gases and air pollutants. In addition, we will develop analysis software and perform actual observations using infrared spectroscopic instruments such as FTIR.

AM-3 Development of the next generation instruments for the millimeter-wave atmospheric observation

The atmospheric emission lines in mm-wave are often very faint, and the use of superconducting receiver with ultra-low noise is essential to obtain the data with a sufficient signal-to-noise ratio. We have developed a multi-frequency observation system in collaboration with a research group at National Astronomical Observatory of Japan (NAOJ) and succeeded in simultaneous ground-based multi-molecular-line observations at 230 GHz and 250 GHz bands for the first time in the world at Syowa Station. Further improvements are underway to realize automated long-term continuous operation at remote sites. We hope that motivated students will participate in these developments and get a part of creating the world's first observing instruments.

AM-4 Study of global composition change of trace gases by using satellite observation dataset and model simulations

By using the ground-based instruments, we can continuously observe the temporal change of the trace gases, but spatially, observable only above a fixed point on the Earth. On the other hand, by using satellite sensors in orbit around the Earth, we can acquire data above various locations on the Earth, but the observing time over a certain point on the Earth is a very short period while the satellite passes over that point. Thus, ground-based and satellite-based observations are complementary, and in order to capture global-scale phenomena more accurately, it is effective to utilize various satellite data and model simulations to combine and/or to compare with the ground-based data. This 4th-grade experiment aims to develop tools to read and visualize the satellite and simulation datasets, and to promote the combined use with ground-based observation data, as well as to develop new analysis methods for atmospheric composition change using so-called AI such as machine learning and deep learning.

●CR laboratory (Cosmic-Ray Physics Laboratory)

Have you ever heard of dark matter, black holes, supernova explosions, or solar flares? The field that studies these phenomena is broadly called astroparticle physics, a discipline that bridges the worlds of particle physics and astrophysics. One of the key approaches to advancing this field is through the study of cosmic rays. At the CR-lab, we address a wide range of questions: unraveling the origin of ultra–high-energy cosmic rays, searching for unknown particles and interactions hidden in the universe, understanding the physics of the early universe, and exploring how cosmic rays affect the Earth and humankind. At the graduate level, our research covers a broad spectrum of topics, including the development of liquid-xenon detectors for the direct dark matter search experiments XENONnT and its future successor XLZD; gamma-ray observations with the Fermi Gamma-ray Space Telescope (Fermi-LAT), the MAGIC telescopes, and the CTA Observatory; neutrino studies with Super-Kamiokande and Hyper-Kamiokande; investigations of hadronic interactions at the highest energies with LHCf, RHICf, and FASER; and reconstruction of ancient cosmic-ray variations through carbon-14 measurements in tree rings. Undergraduate students in their fourth year first gain hands-on experience with basic experiments related to these diverse research areas. Building on this foundation, they select a topic of interest and engage in their own research projects. In addition, they receive essential training in statistics and radiation-detection techniques, which are fundamental for data analysis. The CR Lab welcomes students who are passionate about exploring both the microscopic world of particles and the vast universe, and who possess curiosity, enthusiasm, and a strong spirit of inquiry.

CR-1 Direct dark matter searches by using liquid-xenon detector at XENON and XLZD

Dark matter, which accounts for most of the universe's gravitational potential, remains one of the compelling mysteries in astrophysics and particle physics. Among the many promising candidates for dark matter, WIMP, a yet undiscovered elementary particle stands out as one of the most intriguing. The XENONnT experiment, a liquid-xenon TPC detector, is at the forefront of this quest to discover WIMP. Students will actively participate in activities related to this experiment and explore various developments for the future 60-ton liquid-xenon detector, XLZD. They will have an opportunity to fabricate a homemade liquid-xenon detector, gaining hands-on experience in cryogenic systems, new ultra-violet photo-sensors, and the fundamental principles of direct dark matter experiments.

CR-2 High-energy astrophysics and dark matter searches with gamma rays at CTA and Fermi

Origins of cosmic rays can be studied using neutral messenger particles like gamma rays or neutrons because they aren't deflected by the cosmic magnetic field. Students contribute to the development of new silicon photosensors for the Cherenkov Telescope Array Observatory or a new silicon pixel sensor for future gamma-ray satellites. They also conduct searches for gamma rays from dark matter annihilations or studies of the acceleration mechanism of cosmic rays in cosmic-ray accelerator candidates like supernova remnants or supermassive black holes by analyzing data from the Fermi satellite and/or MAGIC telescope.

CR-3 Neutrino physics/astronomy using a large water Cherenkov detector.

Neutrinos, neutral particles with a tiny mass and exclusively left-handed, hold significant importance in unraveling the enigmatic history of the early universe and the process of baryogenesis. Students will engage in data analysis of Super-Kamiokande, an enormous water Cherenkov detector, to delve into the field of neutrino physics and astrophysics. Additionally, they may contribute to the development of novel photosensors or develop analysis tools utilizing machine learning for the upcoming Hyper-Kamiokande detector.

CR-4 Hadronic interactions of ultra-high-energy cosmic rays.

The very high-energy interactions of the highest-energy cosmic rays with 10^{20} eV can be studied by very-forward-angle detectors, such as LHCf/RHICf at the LHC/RHIC accelerators. Students can participate in data analysis of such interactions, develop detectors for future measurements, or participate in Monte Carlo simulation studies of high-energy cosmic-ray air showers in the atmosphere.

CR-5 Past cosmic-ray activity probed by cosmogenic radiocarbon-14 and belilium-10.

Cosmogenic nuclides, radioisotopes produced by cosmic-ray interactions in the atmosphere, offer a unique tool to unravel past activities of cosmic rays and solar cycles, even those that occurred over a millennium ago. For instance, carbon-14 found in tree rings or beryllium-10 in the ice core of Antarctica can be used to search for past extreme solar events, nearby supernovae, or past solar cycles. Students actively participate in data analysis of radiocarbon-14 to study ancient cosmic-ray burst events or the variability of past solar activities.

●SS$_E$ laboratory (Space Science Experiment Laboratory)

The outer space near the Earth and planets are consists of multi-type regions, as represented by the ionosphere/plasmasphere/magnetosphere, where numerous physical mechanisms are emerging. For instance, the solar wind/intrinsic magnetic field/atmospheric plasma/neutral atmosphere/lower atmosphere are interacting in complex ways, producing the auroras in the polar regions and the substorms/storms widely in the magnetosphere. Since these physical processes are fundamental and universal not only in our solar system but also in the distant universe, it brings us with comprehensive understandings on the space/Earth/planets to demonstratively elucidate the phenomena and their variations occurring in the near-Earth space that we could explore directly and precisely and the other various regions, e.g., the upper atmospheres and their space environment surrounding the planets in the solar system. In our SSE laboratory, we have been conducting experimental studies based both on the intensive/worldwide ground-based observations and the space explorations through innovative developments of state-of-the-art science instruments.

For more details, please visit "https://www.isee.nagoya-u.ac.jp/en/research/study03.html".

SS$_E$-1 Measurement technique development for future space plasma explorations

Our group has been leading several space exploration missions for the research of the fundamental processes and physical mechanisms in the space coupling with the terrestrial/planetary environment by applying in-situ (direct) observation techniques to spacecraft/satellites. In this subject, some experimental studies will be conducted in order to innovatively develop new types of plasma particle analyzers for future space missions in our particle beamline facilities. The construction and renewal of the facilities/equipment in a clean room are also required in our research and development.

SS$_E$-2 Data analyses based on high-resolution space mission observations in the terrestrial auroral regions

The space plasma dynamics in the near-Earth outer space can also be measured in the terrestrial polar regions because the geomagnetic field lines map the electromagnetic processes originating from the space environment such as dynamical auroral phenomena. The physical mechanisms represented by space plasma accelerations in the terrestrial/planetary boundary regions connected to the outer space will be studied by the data analyses based on the high-resolution observations by the innovative space missions to bring new insight to realize future space exploration missions.

SS$_E$-3 Study of upper mesosphere and lower thermosphere

The upper mesosphere and lower thermosphere (70-120 km in altitude) is influenced significantly by atmospheric waves (tides, gravity, and planetary waves), and then the temperature and wind vary with time/altitude. Furthermore, solar wind energy comes into and disturb the atmosphere there. We study such variations using EISCAT, MF, meter radars and a sodium lidar operated in northern Scandinavia. Fourth-grade students will learn the observational tools and basic atmospheric dynamics, and study scientific topics using data obtained with the radars and lidar.

SSE-4 International collaborative observation experiment of the polar upper atmosphere using state-of-the-art equipment

This research project will conduct comprehensive observational experiments under an international collaborative framework, focusing on the newly deployed ionospheric radar (EISCAT_3D) and high-performance optical interferometer (SDI-3D) in Northern Scandinavia, in conjunction with the optical camera and radio receiver network and satellite observations in the region. Through analysis of the acquired observational data, the project aims to elucidate the physical mechanisms that induce significant variations in the polar upper atmosphere (ionosphere and thermosphere), exceeding diurnal fluctuations during auroral displays and geomagnetic storms. This investigation will directly contribute to the understanding of the conversion and dissipation processes of solar wind energy entering Earth's upper atmosphere, the heating and expansion of the upper atmosphere, which is a key issue in space weather research, and the global energy budget through the transport of energy and particles from polar regions to mid- and low latitudes.

●SW laboratory (Heliospheric Plasma Physics Laboratory)

The solar wind is a supersonic (300-800 km/s) plasma flow emanating from the Sun, creating a huge region called the heliosphere. There are many unsettled questions on the solar wind; e.g. the mechanism for solar wind acceleration, global structures of the heliosphere, and responses to the solar activity. We intend to elucidate these questions from observations of interplanetary scintillation (IPS) with large radio-telescopes developed by our laboratory. The IPS observations of SW laboratory is able to derive 3D properties of the solar wind. Taking advantage of IPS observations, the following subjects are studied in our laboratory, and students are able to acquire skills for system development and programing through the graduation research.

SW-1 Origin and acceleration mechanisms of the solar wind

How does the solar wind accelerate to speeds of 300–800 km/s? From which regions of the Sun, and through what physical processes, is the solar wind released? To answer these fundamental questions, the SW Lab combines its unique IPS observations with data from the Japanese solar satellite Hinode and other spacecraft from around the world, as well as numerical simulations of the solar wind. In particular, our laboratory is the only group in the world that continuously obtains global solar wind speed distributions from IPS observations. By making full use of this unique dataset, we can test and evaluate many solar wind acceleration models proposed so far, and identify which mechanisms are most consistent with the actual observations.

SW-2 Propagation dynamics of solar wind disturbances and improvement of space weather

Disturbances of the solar wind impose significant influences on the space environment and the upper atmosphere around the Earth, and sometimes cause serious damages to infrastructure of our society. Therefore, social needs are growing for predictions of the arrival of solar wind disturbances at the Earth. In order to improve the accuracy of space weather predictions, we investigate propagation process of solar wind disturbances from assimilating with IPS data and simulations and comparing with in situ observations. In addition, practical applications of this system to the real-time space weather operations are under development with space weather forecasting centers.

SW-3 Development of the next generation radio telescope

The SW Laboratory is developing a new radio telescope to lead the next generation of heliospheric research. This telescope is planned to be one of the largest radio telescopes in Japan, with a diameter of approximately 100m. This telescope will be equipped with the latest phased array antennas and digital signal processing technology, and aims to achieve 10 times the observation performance of existing devices. Part of the budget was allocated in 2024, and there are currently many attractive development and research topics.

SW-4 Exploring the heliosphere and communication science with advanced AI

Artificial intelligence (AI), which has been developing rapidly in recent years, is transforming the way we study the heliosphere. We actively integrate cutting-edge AI technologies into various research topics related to the Sun, the solar wind, and space weather. We also maintain and continuously update a research environment equipped with high-performance GPU servers specialized for AI research. The skills and experience gained through our projects are highly transferable and applicable to a wide range of scientific and industrial fields.

Themes of
Graduation Research-Theoretical Studies in 2026

●B laboratory seminar (Computational Biophysics Laboratory)

Biophysics is a field that seeks to understand biological phenomena through the principles and tools of physics. While all living organisms obey the laws of physics, the complexity of biological systems limits our current understanding. The B Laboratory studies biological molecules, such as proteins and nucleotides, using computational techniques, often in collaboration with experimental groups. This research involves

Developing new algorithms to decipher the structure and dynamics of biomolecules

For modeling structure and dynamics, we develop new algorithms using computational modeling techniques that utilize simple concepts of mechanics in physics to simulate the dynamics of biological molecules and combine various experimental data (integrative modeling / hybrid approach).

Structure Dynamics and Biological Functions through Simulations

We perform molecular dynamics simulations of biomolecules to examine various functions. We can study their interactions with other molecules, such as proteins or drug molecules, and study conformational transitions following such interactions. Observations from simulations are examined carefully to discover new insights that have not been accessible from experimental studies.

In the first part of the year, students will familiarize themselves with various computational methods (e.g., MD simulations, machine learning), as well as biological systems, through literature reviews and tutorials. In the second half, students will conduct research on a specific project.

We use English in the Tama group and English/Japanese in the Yamato/Kimura group. For more information, please visit https://www.phys.nagoya-u.ac.jp/docs/pamphlet/B.pdf.

●C laboratory seminar (Cosmology Group)

Astrophysics Theory, especially Observational Cosmology

Recent observations reveal that the energy density in the Universe consists of 70% of dark energy, 25% of dark matter. The purpose of observational cosmology is to find effects of dark energy and dark matter on the evolution of the Universe and the formation of structures such as galaxies, clusters of galaxies, and large scale structure, and to understand the nature and beginning of the Universe through observable quantities. In the first term of this seminar, participants read a book written in English and learn the fundamentals of cosmology. In the second term, participants do numerical calculations and data analysis on cosmology and give presentations.

●E laboratory seminar (Theoretical Elementary Particle Physics Laboratory)

Relativistic quantum field theory

Purpose of this course is to study the relativistic quantum field theory, which is a basis of theoretical elementary particle physics. Text in this course will be chosen after the students attending this course discuss with tutors.

They have to learn following topics in quantum mechanics before the course starts: general theory of quantum mechanics, including the Schrodinger, Heisenberg, and interaction pictures, angular momentum, scattering theory, symmetry and conservation law, and perturbation theory.

The students in the course are also required to make a report about one of selected topics and present it at the end of this course.

● H laboratory seminar (Quark-Hadron Theory Group)

Fundamentals of quark-hadron physics

Aiming to learn the fundamentals of quark-hadron physics. In Fall semester, students will attend a seminar once or twice a week. In the seminar, students read a textbook and explain the main points of it in turn. The textbook will be decided based on the discussion among the students and instructors at the guidance. An example of the textbook is “An Introduction to Quantum Field Theory" written by Peskin & Schroeder. In Spring semester, students perform graduation studies. The topic of the study for each student is chosen from the discussion with faculties. Each student submits a report and gives a presentation for the graduation study. The credit is given by evaluating the attendance and the effort to the seminar and the graduation study including the final presentation and report. We expect that the students earned the credit of Quantum Mechanics I and II before the seminar starts. We can accept 4 students at most.

●P laboratory seminar (Theoretical Plasma Physics Laboratory)

Basic plasma physics

High temperature plasmas in space and fusion involve a variety of instabilities, turbulence, shocks, or relaxation processes which extend over a wide range of spatio-temporal scales. In the seminar it is aimed to master basic theories and methods for studying the plasma phenomena. In the first semester, an introductory text is used for learning fundamentals in plasma physics. The second semester is devoted to learning more advanced topics or numerical computations on plasma physics. It is also requested to submit a report on the product and to make a presentation.

●QG laboratory seminar (General Relativity and Quantum Cosmology Laboratory)

In the QG lab, students study general relativity and quantum field theory in curved spacetimes---fundamental tools for understanding physical phenomena where gravity plays a major role, such as those occurring around black holes and in the early universe. In the Fall semester, students delve into general relativity through careful study of a textbook. In the Spring semester, students undertake their own research project on specific topics under the guidance of their supervisor(s). They are required to submit a report detailing the results of their projects and give a presentation based on their findings. Prospective students are expected to have mastered the basics of electromagnetism, quantum mechanics, and statistical mechanics, along with classical mechanics (including analytical mechanics) and special relativity.

●R laboratory seminar (Theoretical Nonequilibrium Physics Group)

In the spring semester, we read representative textbooks on the subject, such as R. Zwanzig "Nonequilibrium Statistical Mechanics" (Oxford) or R. Kubo et al. "Statistical Physics II" (Springer) to master the basics of nonequilibrium/nonlinear physics. Like a journal club, a section or two will be assigned to every student and she/he is to give a "lecture" on the section(s) at the weekly gatherings. In the fall semester, the students learn more advanced subjects and undertake a small project, under the supervision of faculties, (K. Miyazaki and Y. Nishikawa). The final report should be presented at the group colloquium at the end of the course. We accept not more than 4 students per year.

●S laboratory seminar (Theoretical Solid State and Statistical Physics Laboratory)

Condensed Matter Theory Group (Sc)

In metals, interesting quantum phenomena occur thanks to the electron correlations, such as the superconductivity (=Cooper pair formation) and various types of symmetry breaking phenomena. Recent topics of condensed matter physics are the unconventional (high-Tc) superconductivity, the electronic nematic/smectic orders, and the permanent charge/spin current orders due to the topological phase transition. The aim of this seminar is to learn the basis of the strongly correlated electron systems. In the first semester, the students study statistical physics and many-body physics by reading a textbook, such as "Statistical Mechanics" written by Feynman. In the second semester, each student selects his/her theme of graduation work on condensed matter physics, and studies it under the guidance of the staffs, by reading textbooks and scientific papers. At the end of the second semester, we have a presentation of graduation theses. The maximum number of acceptable fourth year students is six. Each student is required to have gotten the credits of Statistical Physics I and II.

Quantum Transport Theory Group (St)

Our research interest is in material physics that focuses on spin current (flow of spins) and topology of electrons' wave functions in solids. The former field is called spintronics and the latter topological quantum physics. Students in St Lab learn basic quantum statistical physics in the first semester, and apply it to some specific problems (graduation project) in the second semester. Each student writes a report on the project and gives a presentation around the end of the semester. We accept up to four students who are familiar with Quantum Mechanics and Statistical Physics.

●Ta laboratory seminar (Laboratory for Theoretical Astronomy & Astrophysics)

Faculty Member:
Shu-ichiro Inutsuka and Hiroshi Kobayashi

The theme of this seminar is to learn spectacular astronomical phenomena in terms of basic physics. It focuses on some of very recent topics in astrophysics. Students choose their own favorite topics and try to start introductory research. In the spring semester students mainly study the textbook subjects in the form of a group seminar, but in the fall semester they learn the basics of numerical analysis and try to investigate some of frontier subjects. Finally each student is required to give a summary presentation of the research. Choices of the research subjects are made in discussion between students and supervisors.

●Ω laboratory seminar (Laboratory of Galaxy Evolution)

A galaxy is a huge agglomeration of stars, interstellar medium, and dark matter, and in a cosmological scale, a unit structure of the large-scale structure in the Universe at the same time. While the spatial distribution of matter in the beginning of the Universe was almost homogeneous, namely there was not astronomical object like a galaxy, we observe tremendous number of galaxies with rich cosmological structures in the present-day Universe. Also, it is known that the heavy elements consisting the earth and life like ourselves were not produced by the Big-Bang nucleosynthesis in the early Universe. These elements have been produced at the center of stars through nuclear fusion, and injected into the interstellar space at the final phase of stellar life. Thus, how galaxies formed and evolved in the cosmic history is one of the most important topics in the astrophysics today.

In our laboratory, we aim at understanding the physics of the formation and evolution of galaxies through the cosmic age, based on the multiwavelength data analysis, theoretical models, and data-scientific methods such as machine learning. We provide the latest observational data for the graduation study, like for master or PhD students. We try to choose a theme which may be published as a research article as much as possible. Then, we want students who are enthusiastic to the theme and responsible for taking part of the international project.

●SS$_T$ laboratory seminar (Solar and Space Physics – Theory Laboratory)

SST laboratory conducts the research to understand the solar and space environment as a single holistic system, which consists of the Sun, the Earth, planets, and the interplanetary space, by using numerical simulation and in-situ data analyses. Research targets of the SST laboratory are wide-ranging, e.g., solar activity such as solar flares and sunspots, solar wind and interplanetary space dynamics, plasma environments of planets such as Mars, space weather phenomena such as auroral breakups and geomagnetic storms, fundamental space plasma phenomena such as magnetic reconnection, and the development of numerical simulation methods.

The solar and space dynamics driven by solar flares and magnetic storms impact not only artificial satellites and astronauts, but also social infrastructures such as aviation, communications, and power networks, and may cause "space weather disasters." It can also influence the global climate. In the SST laboratory, we study not only to elucidate the mechanisms of various solar and space dynamics but also to predict them to mitigate space weather disasters.

In this laboratory, graduation research themes will be set based on each student's interests from the following topics, and we will hold a seminar to learn the basics of solar/stellar physics and space physics by reading a textbook. We will also provide training on computer usage and programming necessary for research..

Radiative magnetohydrodynamic simulations of solar/stellar interior, surface, and wind

We perform numerical simulations for solar/stellar turbulence, large-scale flows, and magnetic field generation in the interior, sunspot formation on stellar surfaces, and chromosphere, corona, and solar wind to solve significant problems in solar and stellar physics, including the 11-year cycle of magnetic activity, chromosphere and corona heating, and solar wind acceleration.

Solar flare research through the analysis of multi-wavelength observational data

We study the physical processes of high-energy phenomena in solar flares, such as particle acceleration and plasma heating, through the analysis of multi-wavelength data observed with spacecraft and ground-based telescopes.

Space weather phenomena such as aurora breakup and space storms

Various disturbances on the Earth caused by solar flares and solar wind will be studied with satellite data analysis and simulations. Such disturbances include the ionization of the atmosphere in 8 min caused by the X-ray and ultraviolet radiation, the increase of radiation flux in a few hours caused by the high-energy particles, and the magnetic storms, aurora substorms, and plasma dynamics.

Study of planetary plasma environments through spacecraft data analysis

We study plasma dynamics in the vicinity of planets, surface-plasma interactions, and planetary space weather by analyzing data obtained by spacecraft around the solar system bodies such as the Moon, Mars, and Mercury.