The Department of Physics at UNIST (Ulsan National Institute of Science and Technology)

DONGSU RYU DEPARTMENT OF PHYSICS, UNIST, KOREA

UNIVERSITY

Located in Ulsan, which is the most representative industrial city of Korea, UNIST (Ulsan National Institute of Science and Technology) was founded in 2009 as the first government-supported national university in the Ulsan metropolitan area. UNIST started its journey with the aim of becoming a world-leading institution specializing in science and engineering fields. This university vision was set forth with the three keywords of creativity, convergence, and globalization. Here, convergence is the declaration for pursuing interdisciplinary research covering multiple fundamental scientific and engineering disciplines and leading eventually to innovative technologies beneficial for mankind. The key strategy for globalization is to offer all the classes taught on campus in English, which is quite effective for attracting many talented students and internationally renowned scientists from all over the world

Even with its short history, UNIST has grown rapidly and already has been positioned as one of the top universities in Korea, based on its many high-impact research outcomes, educational programs that develop creativity and innovation, and for hosting several major research centers established for leading cutting-edge research in the nation in fundamental sciences and their applications. One highlight is the three campus research centers of IBS (the Institute of Basic Science), which is the central research institute for fundamental sciences established and managed by the Korean government.

In 2015, UNIST took another big step forward by becoming the 4th national research institute for science and technology, which was secured with a special law



Fig. 1: The UNIST buildings.

approved by the National Assembly Legislation and Judiciary Committee of Korea. This transition implies that the achievements of UNIST have been quite rewarding and that the national expectations for it as a leading research institution in Korea has become ever greater.

DEPARTMENT OF PHYSICS

From its inception to 2013, the physics program at UN-IST had been open only at the graduate level as a part of the Graduate School of Natural Science. In 2014, the pre-existing physics program expanded to include the undergraduate physics major. Since then, the Department of Physics has been aiming at exploring fundamental scientific aspects of modern physics and establishing their links to various real-world applications.

As stated previously, an interdisciplinary approach is the main strategy for education and research at UNIST. Consequently, the thorough understanding of basic sciences is essential to make the strategy successful. The study of physics helps one to assemble diverse scientific methodologies to create an interdisciplinary research platform. Furthermore, the collaboration of physicists with various research backgrounds can be a particularly fruitful channel for interdisciplinary research.

In 2016, a brand-new building dedicated for the School of Natural Science was constructed, and it is where the Department of Physics also is now located. The new building is spacious and equipped with modernized infrastructures making it an ideal place for conducting state-of-the-art theoretical and experimental research as well as being an excellent space for providing highquality education to students.

As of August 2017, we have 18 faculty members (including 1 chaired professor) in addition to 1 research professor, and 9 research associates in the Department of Physics. We anticipate some more faculty members to be added in next few years. Although our department is not numerous at this moment, all the faculty members are conducting pacesetting research in their specialized areas and some of them are participating in the IBS centers. In particular, we are currently concentrating on the areas of plasma & astrophysics, soft matter physics, and condensed matter physics with an emphasis on quantum materials and devices. The Department of Physics is currently hosting three government-funded research centers: the Fusion Plasma Stability and Confinement Research Center, the Center for High Energy Astrophysics, and the Basic Research Laboratory for Non-Equilibrium Quantum Dynamics in Condensed Matter.

Our department offers a BS degree course for undergraduate majors and MS and PhD degree courses separately as well as a MS/PhD combined course at the graduate level. There are currently 104 undergraduate students and 61 graduate students enrolled in those courses.

RESEARCH AREAS

Plasma & Astrophysics

There are six faculty members in the plasma and astrophysics group (Hyeon K. Park, Dongsu Ryu, Min Sup Hur, Kyujin Kwak, EunMi Choi, and Moses Chung). Plasma is considered to be the fourth state of matter, and it comprises more than 99.9% of the observable matter in our universe. Hence, the plasma state is of significant importance in many astrophysical phenomena. At the same time, understanding high-temperature plasma is a key to the realization of nuclear fusion energy, which is the power of the sun. The research topics of this group are not limited to the astrophysical and fusion plasmas, but also include a wide variety of plasma physics problems, such laser-plasma interactions, computational plasma physics, beam-wave interactions, THz generation by electron beams, beam-plasma interactions, and accelerator physics.

Hyeon K. Park is an experimental plasma physicist working on fusion plasma physics and plasma diagnostics. His research interests include the physics of stability of fusion plasma, the physics of turbulence on fusion plasma confinement, advanced imaging diagnostics, and comparative studies with the modeling of MHD and turbulence physics. In particular, his research team has developed advanced 2D/3D imaging systems with high temporal and spatial resolutions for KSTAR (Korea Superconducting Tokamak Advanced Research). He leads a government-funded fusion research center, the Fusion Plasma Stability and Confinement Research Center, and also serves as the director of the KSTAR research center of the National Fusion Research Institute (NFRI).

Dongsu Ryu is a theoretical astrophysicist working on high-energy astrophysics. His research interests include shock waves and turbulence in clusters of galaxies, the origin and evolution of magnetic fields and cosmic rays in the Universe, and plasma astrophysical phenomena in the large-scale structure of the Universe. He also directs the Center for High-Energy Astrophysics, which is a government-funded science research center.

Min Sup Hur is a theoretical plasma physicist working on computational plasma physics and laser-plasma interactions. His recent research interest is focused on strong, coherent light sources in X-ray and THz based on laserplasma interactions, plasma-based compact particle accelerators, and shock formation in a high-density plasma driven by ultra-intense lasers.

Kyujin Kwak studies astrophysics by means of computer simulations, including nuclear astrophysics models and astro-chemical models. His recent research topics include non-equilibrium ionization simulations of astrophysical plasma in interstellar and intergalactic media, numerical relativity, nuclear astrophysics, relativistic radiative transfer for astrophysical applications, and numerical astrochemistry. EunMi Choi leads THz vacuum electronics and electrodynamics laboratory. Her research interests include highpower THz source development, novel/compact THz amplifiers, and generation of higher order modes and propagation. Her group recently demonstrated the possibility of remote radioactive material detection using a THz source.

Moses Chung is an accelerator physicist working on intense beam physics, advanced beam diagnostics, beamplasma interactions, and ion traps. His group is interested in developing next-generation high-intensity accelerators.

Soft Matter Physics

The soft matter physics group consists of five faculty members (Hyuk Kyu Pak, Tsvi Tlusty, Jaeup Kim, Chae Un Kim, and Joonwoo Jeong). Considering the relatively small size of the Korean soft matter physics community, this is one of the largest soft matter research groups in Korea. The research interests of the group include 1) non-equilibrium statistical physics, 2) the physics of living matter, 3) field theory for soft matter, and 4) the biophysical study of protein function and dynamics.

Hyuk Kyu Pak is an experimental physicist working on the research areas of soft matter and statistical physics. His research interests cover a wide range of problems from microfluidics to liquid thin films, and phase transition and critical phenomena at the interfaces of liquids. Recently, to study non-equilibrium statistical physics, his group has focused on building novel soft matter systems utilizing state-of-the-art optical techniques. In addition to that, his group explores unexpected phenomena at the electrical layers of liquid-solid interfaces.

Tsvi Tlusty tries to answer what distinguishes living matter from the inanimate. He believes that hallmarks of living things may originate from basic physical principles of their non-equilibrium state of matter. His group approaches this problem using a variety of theoretical methods including non-equilibrium statistical mechanics, information theory, graph theory, topology, and soft active matter theory. Ultimately, his group wants to construct a unified framework or language to describe how living matter evolves and self-assembles into systems which are able to self-replicate, develop, process information, and learn.

Jaeup Kim applies his multidisciplinary background (physics and chemical engineering) and expertise in self-

consistent field theory (SCFT) to diverse problems in the field of nanostructured polymer materials. The current and future research of his group includes brush theory, the interaction between polymer and nanoparticles, block copolymer self-assembly, amphiphilic bilayers, and transmembrane protein embedded in the bilayers. Moreover, in order to overcome the limitations of SCFT, his group focuses on developing novel field-theoretical simulation methods.

Chae Un Kim studies biological and soft matter systems using high pressure and X-ray techniques. His group utilizes a novel high-pressure technique, high-pressure cryocooling, to stabilize ligand–protein interactions, to study the pressure effect on the structure, and to entrap an intermediate enzymatic state. Additionally, highpressure cryocooling is an excellent tool to study interesting phase behaviors of glassy water at low temperatures. Using this high pressure method, the group will study the phase behaviors of glassy water, water-protein interactions, and protein functions and dynamics at cryogenic temperatures.

Joonwoo Jeong studies the structure and dynamics of a variety of mesophases in soft matter using experimental methods. A mesophase is a partially ordered state of matter where the order lies between that of a liquid and a solid. Some common examples of mesophases, such as liquid crystals and gels, are indispensable to our daily lives; they are seen in displays, organic electronics, and consumer products. In particular, his group pursues the deep understanding of symmetry breaking, pattern formation, and topological defects in mesophases using diverse imaging techniques.

Condensed Matter Physics

In the condensed matter/quantum material research area, we have five faculty members (Kibog Park, Noejung Park, Kwanpyo Kim, Yoon Seok Oh, and Hosub Jin). The group's main research interests are focused on 1) the discovery of new quantum materials, 2) the design of new quantum materials using theoretical models and various computational methods, and 3) novel device applications using new materials and concepts.

Kibog Park explores emergent (new) materials and device structures for electronic/optoelectronic applications. In particular, the group focuses on investigating the fundamental material properties of wide band-gap semiconductors and functional metal oxide thin films, and on developing novel devices based on these materials such as non-volatile memory, high-power and high-frequency semiconductor devices, and scalable quantum devices.

Noejung Park leads a computational physics and electronic structure laboratory. His main research interests include 1) the computational and theoretical physics of condensed matters and many-electron systems, 2) computational chemistry for energy-storage materials (hydrogen storage, solid electrolyte), and 3) multiferrocity in low-dimensional organic systems. He leads the Basic Research Laboratory for Non-equilibrium Quantum Dynamics in Condensed Matter, which is a government-funded research center.

Kwanpyo Kim's research focuses on the synthesis and various property characterizations of nano-materials. His group seeks new and exciting physical phenomena originating from reduced dimensions of various materials. Graphene, carbon nanotubes, small organic molecules, and newly emerging other two-dimensional materials are currently under investigation, especially their novel electronic, mechanical, and optical properties. Areas of research interest also include nanoelectromechanical systems and atomic-scale characterization of materials using electron microscopy.

Yoon Seok Oh's research is focused on finding and understanding exotic phases and novel phase transitions in the emergent materials. In particular, the group studies strongly correlated electron systems, where the entanglement of charge, spin and orbital degrees of freedom gives rise to a variety of emergent phenomena (e.g., Mott insulators, various charge, spin and orbital orderings, metalinsulator transitions, multiferroics and superconductivity, etc.). The research mainly lies in studying those exotic phases and novel phase transitions in bulk single crystals.

Hosub Jin leads the Quantum Materials Design Laboratory. His research interests include 1) non-trivial topology in oxides, 2) ferroelectric-coupled Rashba effect, and 3) correlated relativistic electrons systems, utilizing computer simulation methods.

RESEARCH CENTERS

Fusion Plasma Stability and Confinement Research Center

The Fusion Plasma Stability and Confinement Research Center was launched at the Department of Physics at UNIST in 2014. The center is being led by Hyeon K. Park with an annual funding of ~ 1 million USD funded by the National Research Foundation (NRF) of Korea. The first phase of the program (2014-2017) has ended successfully, and the second phase (2017-2019) has just started to pursue internationally groundbreaking fusion plasma research.

The center focuses on following subjects: 1) understanding fundamental mechanisms of MHD instability and its turbulent structure using advanced 2D/3D microwave imaging diagnostics, 2) developing an MHD simulation code to predict instability conditions 3) optimizing electromagnetic wave sources for instability control experiments. The final goal is resolving challenging issues degrading fusion plasma performance to realize the fusion energy.

Five faculty members from four universities in Korea participate in the program with strong collaborations with seven international institutions from the United States (PPPL, LLNL, UC Davis), France (CEA), and Japan (Kyoto Univ., QST, NIFS). The center also strongly collaborates with the National Fusion Research Institute (NFRI) in Daejeon through the state of the art 2D/3D Electron Cyclotron Emission Imaging (ECEI) and Microwave Imaging Reflectometer (MIR) diagnostics on the Korea Superconducting Tokamak Advanced Research (KSTAR) as shown in Fig. 2.



Fig. 2: Two state of the art ECEI imaging systems separated in the toroidal plain are shown and the MIR system is combined with the ECEI-II system.

The center truly plays a central role as a leading fusion research program domestically and internationally. Here, research unveiled many new aspects of unresolved physics that were not solved with conventional diagnostics. In addition, the center has contributed in educating future fusion plasma scientists for ITER and the Korean fusion energy development plan.

Center for High Energy Astrophysics

The Center for High Energy Astrophysics (CHEA) was established in 2016 as one of the privileged science research centers that are funded by the National Research Foundation (NRF) of Korea. The annual funding for the center is about 1.1 million USD until 2022. CHEA focuses on two research topics of high energy astrophysics; clusters of galaxies and compact objects. CHEA is a multiple-institute center, whose headquarters is located at the physics department of UNIST. Eleven faculty members from five Korean institutes participate in CHEA, among which five members are faculty members of UNIST's physics department, including the director, Dongsu Ryu.



Fig. 3: Designed site view of RAON, which is expected to operate from 2021. CHEA will perform laboratory astrophysics experiments at RAON to measure masses and reaction rates of rare isotopes that could commonly exist in the universe.

The unique feature of the center is that CHEA pursues the combined efforts of observation, theory, and experimentation in order to obtain better understanding of high energy astrophysical phenomena. CHEA is proposing to perform laboratory astrophysics experiments at two large facilities in Korea, the X-ray Free Electron Laser of Pohang Accelerator Laboratory (PAL-XFEL) and RAON (the Rare Isotope Accelerator Complex for Online Experiments) of the Institute of Basic Science (IBS). High resolution X-ray spectroscopies of highly ionized ions such as Fe²⁶⁺ are possible at PAL-XFEL, which will put more accurate constraints on the X-ray emitting astrophysical environments. Measuring masses and reaction rates of unstable nuclei, i.e., rare isotopes at RAON, will allow us to better understand the explosive phenomena such as supernovae and X-ray bursts. For the more information, visit the CHEA homepage http://sirius.unist.ac.kr/SRC-CHEA.

Basic Research Laboratory for Non-equilibrium Quantum Dynamics in Condensed Matter

As one of the exclusive basic research laboratories, five experts - including the director, Noejung Park - in solid state physics are involved in this project, funded by the NRF of Korea. Non-equilibrium quantum dynamics of condensed matter has not been well understood in physics. With the goal of producing groundbreaking results in non-equilibrium quantum matters, the Basic Research Laboratory studies fast non-equilibrium phenomena of strongly correlated motions of charge, spin, orbital, and phonons. In order to understand various dynamical nonequilibrium phenomena in quantum matter, the experimental techniques of femtosecond laser strong electric field THz pumping & probe measurement as well as the theoretical method of time-dependent density functional theory will be developed.

For further information, please visit the department homepage: http://physics.unist.ac.kr/



Dongsu Ryu is a professor and the head of the Department of Physics and the dean of the School of Natural Science. He is also the director of the Center for High-Energy Astrophysics, a government-funded science research center. He received his PhD in astronomy from the University of Texas at Austin in 1988. He was a professor of the Department of Astronomy and Space Science, Chungnam National University from 1992 to 2014, and joined the Department of Physics of UNIST from 2014. He is currently the vice president of the Korean Astronomical Society, and the vice chair of the Division of Plasma Physics of the Association of Asia Pacific Physical Societies.