Report of the review committee for
Department of Physics
Research Center for the Early Universe
Universal Biology Institute
Institute for Physics of Intelligence
School of Science
The University of Tokyo

東京大学理学部・大学院理学系研究科
物理学科・物理学専攻
ビッグバン宇宙国際研究センター
生物普遍性研究機構
知の物理学研究センター
に関する
外部評価委員会報告書

Committee members 委員会メンバー

Mitiko Go	郷　通子
Masahiko Hayashi	林　正彦
Maki Kawai	川合眞紀
Dmitri Kharzeev	
Taichi Kugo	九後太一
Yoshio Kuramoto	倉本義夫 (Chair 委員長)
Kaichiro Sakuma	佐久間　嘉一郎
Zhi-Xun Shen	

東京大学理学部物理学科・大学院理学系研究科物理学専攻

2020年2月

February, 2020

Table of Contents

Report of the review committee for
Department of Physics
Research Center for the Early Universe
Universal Biology Institute
Institute for Physics of Intelligence

THE DEPARTMENT AS A WHOLE

The field of physics is expanding with tremendous new opportunities, as exemplified by such developments as cosmological science featured by the gravitational wave, neutrino physics going beyond the standard model, condensed matter physics with novel quantum materials, quantum information and their potential impacts to science and technology, and the latest frontier at the intersection between physics and biology, just to name a few.

Physics provides exceptional opportunity to train young people for its own fields and far beyond, by cultivating commendable quality for future leaders. In addition to providing rigorous training for investigating fundamental laws of nature, physics encourages critical thinking. Huge projects as exemplified by LHC, LIGO, super/hyper-Kamiokande, KAGRA, X-ray free electron laser require not only leadership skills but courage of physicists who are not afraid of thinking differently. Physicists often have led the world to embark on risky but rewarding new directions. At the same time, physics research led to technologies that benefit the society at large, as exemplified by Internet, Global Positioning System (GPS), and Magnetic Resonating Imaging (MRI).

The physics department of the University of Tokyo, hereafter called “the Department”, is a world class department with outstanding faculty leading in exciting areas of research and providing effective training for students. It covers very broad topical areas, and excels in many of them. The committee, while pleased to see the accomplishments of the Department, will make some suggestions in this report for further development into a major center of excellence in the international standard. In fact, the committee is concerned that certain external environment of the Department remains unsatisfactory for a long time. Especially, its space in Hongo campus is poorer as compared with many other universities in Japan. The committee strongly urges the university administration to invest more resources so that the Department can fully realize its potential.

1 Education

Undergraduate Education

The curriculum for undergraduates is mostly consisting of regular lectures, exercises, and experiments. In addition to this standard form to teach basics of physics, the Department provides compulsory courses with a seminar style which encourages the students to interact with professors more informally in small groups, each consisting of four students. The course is in the winter semester of the junior (third grade), and intends to give the flavor of research to students. The subjects are chosen from specific modern topics.

The committee had the opportunity to talk with a few junior students who volunteered. All students can communicate in English normally, which seems a big change since 2005 when the past report pointed out the opposite. According to the students interviewed, the level of lectures is optimum for understanding. Most of them are living in area close to the campus, and do not need a long time to commute even in Tokyo. It appears that economical situation for students is much above the average in Japan. Another notable feature is that almost all students go up to the same Department for the graduate course.

The diversity of undergraduate students is low; there are at most a few female students per year, and almost no foreign students. The lectures are all delivered in Japanese. The committee recommends that the Department takes some measure to enhance the diversity.

Graduate Education

The master course students with slightly more than 100 annual enrollment come both from inside and outside with almost equal proportion. The Department provides different levels of course work, and graduate students can also take classes delivered mainly for senior undergraduate students. If one or more foreign students take the course, the lecture is given in English. Otherwise the lectures are delivered in Japanese.

About half of the master course students continue to the doctor (PhD) course. Those students who continue to the PhD course come more from inside. In 2012 the number of dissertations is about 50, which increased gradually to almost 70 in 2018. These numbers seem by far the largest among Japanese universities; in other major domestic universities the typical number is 20 or less.

A notable feature is more than half of them go to industry. Those who continue research after graduation decreased to less than 30 in 2016, and are still decreasing. This tendency is understandable in view of the hard situation for Japanese young researchers; most of them cannot assume a permanent position, and continue to work in unstable conditions for years. The tendency also warns the academic sector that many good students may avoid continuing research. In contrast with most other universities which suffer from decreasing number of enrollment to the PhD course in physics, the unique situation enjoyed by the Department deserves more systematic analysis. Apparently, the effort of the Department to financially support the students is a major factor for the statistics. The details of financial issues are described in the next section.

The committee talked with several students who volunteered and can communicate well in English. Some of them try to continue the academic career, and others try something new including entrepreneurship. A student from Europe likes to work in Japan rather than going back. The language seems the major barrier for such students.

Financial Issues

Students in the PhD course of the graduate school are financially supported either by the Japan Society for Promotion of Science (JSPS) or by the University. The Department commits to four graduate course programs and those are the main basis of the support for students:
(1) Advanced Leading Graduate Course for Photon Science (ALPS 2011-2018) went through Program of Excellence in Photon Science (XPS 2018 – 2019) to Forefront Physics and Mathematics Program to Drive Transformation (FoPM 2019 – 2026);
(2) International Graduate Program for Excellence in Earth-Space Science (IGPEES 2018 – 2026);
(3) Materials Education Program for Future Leaders in Research, Industry and Technology (MERIT) to World-leading Innovative Graduate Study Program for Materials Research Industry and Technology (MERIT-WINGS); and
(4) World-leading Innovative Graduate Study for Frontiers of Mathematical Sciences and Physics (WINGS-FMSP).
On average, 60% of the students are supported either as JSPS fellow or from the gradu-

ate courses above with the amount close to ¥200,000/month, and 20% are supported as research assistant from the Department and the School of Science with ca ¥70,000/month.

The Committee is pleased to know the high percentage of students receiving the financial support and will encourage the Department to continue or further improve the condition. One concern we have is the resource of the graduate program described above. Only one out of four programs is the program certificated by MEXT and the others are fully supported by the University as of today. Regarding the freedom for the planning of the program, we may consider the support from the University is suitable considering the present status of the Department. Then the Department should find its original financial resource to maintain the stable support for the students.

2 Research and Hiring Policy

Research Fields

The Department at present covers fundamental areas of research in physics, and is making good efforts to cope with new frontiers and developments in the physical science. For example, a new biological institute was established in 2016 including professors in Komaba campus. Another institute dealing with artificial intelligence was created very recently (2019). In the field of astrophysics, the Research Center for the Early Universe (RESCEU) has a long history since 1999, and is very active in various fields including experimental research on the gravitational wave.

In the entrance examination to the graduate course, research groups are classified into subcourses basically according to the research fields. There is a subcourse named "Experimental General Physics", the meaning of which seems hard to understand for students. Actually the subcourse is a mixture of various fields in condensed matter, and some previous members went out to another subcourse. The committee recognizes the significance of the subcourse if the Department utilizes it to cope flexibly with newly developing fields. Nevertheless we recommend the Department to put an intelligible name for the subcourse in order to make it more attractive to students.

Structure of Research Teams

The Department regards full and associate professors, and lecturers as principal investigators (PI's). On the other hand, assistant professors, though sometimes included as faculty members, have a situation rather different from that meant by the ordinary sense of the word. The previous name "assistant" for the position is closer to the reality. Namely, each assistant professor is selected by the relevant PI alone, and the candidate is to be approved by the faculty meeting. Assistant professors hired without discussion among committee members have no right to vote in the faculty meeting of the Department, nor to decide on grading of students. As a matter of fact, such a system used to be common also in other physics departments in Japan, but is no longer the case in most physics departments. This is especially so after the legal change from "Joshu" (assistant) to "Jokyo" (assistant professor), which took place in 2007.

Each research unit in the Department consists of a PI and at least one assistant professor. It often happens that one or more postdoctorals join the team. Such research units may work most efficiently in certain experimental research in traditional condensed matter, for instance. In particle physics, on the other hand, a larger group consisting of plural PI's and assistant professors is more suitable to cooperate in international experimental projects. In theoretical research units, it can happen that the PI actually does not impose any restriction to activity of the corresponding assistant professor. Then the current system may have a good side to let young assistant professors concentrate mostly on research. It may also encourage them to be promoted earlier in other universities; internal promotion is forbidden for assistant professors in the Department. We have to add that the assistant professorship is permanent in this Department as in other physics departments.

Since the position is far from the ordinary junior professorship, however, their independent role in driving a new field to the international forefront may be discouraged, especially in experimental research. The selection decided by a single person also makes it hard for the Department to strengthen certain directions by strategic employment.

The committee recommends the Department to seriously consider the merit and demerit of the current system, and employ a more flexible system for extracting the best performance of the talented young people in the long run. If the Department selects assistant professors by decision of the relevant committee, it would be natural to treat them as junior professors instead of assistants. This change will not only give them self-confidence but also help make the Department more active and attractive for young students and researchers.

Promotion and Recruitment

Most full professors are promoted internally in this Department. During the period from 2013 to 2019, all promotions (five) were internal. For such a system to work, it is crucial to judge the quality of candidates by careful comparison with other potential candidates from outside. To be internationally active, the Department should pay attention to the right proportion of insiders and outsiders. Traditionally in this Department, however, the proportion of insiders, including those who spent some short time outside, is far dominant. The committee recognizes that the dominance is mostly a result of fair competition, since this Department has produced competent physicists over many generations. Nonetheless, the Department should care about diversity of professors by hiring more foreigners and females in order to enhance the activity, and to gain higher international recognition.

Relation to Industry and Contribution to Society

Advances in science and technology are enriching people's lives, and at the same time, new social problems are emerging. The Japanese government has been advocating the Society 5.0 for sustainable development goals as a growth model for solving these problems and creating the future. Participation from academic fields is also highly expected, and in particular, it is required to contribute to solving social problems by implementing the results of research on knowledge at universities into the real world through industry-academia collaboration.

Traditionally, industry-academia collaboration has been mainly based on technology. It will be more important now to start collaboration from the stage of searching for problems to be solved, and to collaborate at the organizational level by making full use of the knowledge possessed by both industry and academia. In particular, physics is the most important foundation supporting scientific and technological innovation. In addition, the progress of digital transformation, including AI, IoT, and quantum computers, has been remarkable, and it has become possible to solve complex problems that could not be dealt with before.

In this context, it is timely to have created the Institute for Physics of Intelligence in the Department. The results of its activities are expected in the near future. It would also be effective to promote industry-academia collaboration using this institute as a hub. At present, corporate sponsored research programs have been realized only by the one from DAIKIN, and it should be further vitalized in the future. In order to achieve this, it is necessary to make the intellectual foundation of the Department more widely known to the public. It will be useful to consider upgrading of its website, and opening it to the public through various means such as the open campus.

In addition, in an era of uncertain future, it is necessary to have human resources capable of tackling unknown issues in all fields without limitation to research and development. In universities, the diversity of professors and students is important in this respect. It is highly expected to bring up mentally tough students with intellectual skills of physical thinking, who can powerfully lead the next generation.

The Department has an enormous store of intelligence. Utilizing this resource through industry-academia-government collaboration, we expect that some of the social problems facing Japan may be solved ahead of the rest of the world. In this way the Department may contribute to realization of a sustainable future.

3 Management

Budget and Space

The total amount of annual budget from the government has been reduced by 2% constantly in most public universities in Japan. This situation applies also to the Department. It is very difficult to maintain the high level of education and research without additional income from other sources. The professors in the Department are very competitive in getting research funds from both governmental and non-governmental sources. As a result, the external scientific grants amount to about 150% of the operating budget from the university. However, such external funds have strong restrictions to be used for education and administration. Furthermore, there is always a fluctuation in the amount of external funds, which makes it difficult to build the long-range plan.

The floor space at present is only 67% of the allocated space according to the regulation with the current number of faculty members and students. Obviously, the reasonable space is a necessary condition for researchers. The students also benefit from the space to interact more spontaneously, have group discussions and brainstorming outside the ordinary lectures. If not carefully attended, the leadership position of the Department may erode, which will be huge loss for science in general, and for Japanese science in particular. The committee supports the continuous effort of the Department to improve the situation.

Gender Equality and Diversity

The fields covered by physics are diverging. Correspondingly, more diversity in professors and students should be necessary for harmonious development. A major indicator of the diversity is the number of female professors and students. The current status for female professors at the Department is as follows: one full professor, one associate professor, and three assistant professors. The presence of only one female professor in the Department is far from enough, even in the current standard in Japan. The number of female students is five in the senior (undergraduate) in 2019, which is the maximum in the past seven years. In the newest enrollment to the graduate course, the number amounts to 11 including three from abroad who entered in autumn. The Committee urges the Department to consider seriously how to improve the situation. At the same time, the Committee hopes that female students recognize the Department as a wonderful place to continue study and research of physics further.

Another indicator of diversity is the number of international professors and students. The current status for the number of foreign professors is far from all right; only one full professor at RESCEU and one assistant professor at Institute for Physics of Intelligence. We encourage the Department to improve the situation. A good sign is that the number of foreign students in the graduate course increased during the past five years, and reached to a maximum number (19) in 2019. We expect that the number will keep increasing.

INDIVIDUAL RESEARCH FIELDS

1 Elementary Particle Physics

The particle theory group consists of three units at present, two specializing in phenomenology and cosmology led by Prof. Takeo Moroi and Associate Prof. Koichi Hamaguchi, and the other one specializing in formal aspects of string theory and quantum field theory led by Prof. Yutaka Matsuo. They are the same members as those at the previous external review in 2012, aside from moving out of Associate Prof. Yuji Tachikawa (2016) and promotion of Matsuo from associate professor.

The phenomenology group is investigating physics beyond the standard model (BSM) like supersymmetry and grand unified theory, together with particle cosmology as its application or the clue for it. Their active work is still well recognized in the world. While the supersymmetry (SUSY) is excluded in the expected 100 GeV regions in LHC experiment and only little direct experimental data are available, they are working on fundamental problems in particle physics using particle cosmology/astrophysics data. The constraints on long-lived new particle masses and reheating temperature from the big-bang nucleosynthesis have been being updated since 1995. Other constraints on possible axion decay constant and on dark matter signal are obtained from the neutron star cooling. Those limits are cited in Particle Data Book. Two phenomenology groups, each adopting a young assistant professor, have mutually a close interaction including direct collaborations and keep active level of researches.

The formal theory group has been studying the universal symmetry structure in supersymmetric string and gauge theories hidden behind the celebrated Alday-Gaiotto-

Tachikawa (AGT) relation, found by Tachikawa, which directly connects the partition functions of four-dimensional (4D) SUSY gauge theory and 2D conformal field theory. Matsuo made a remarkable finding that the quantum toroidal algebra exists as a more universal structure containing both Virasoro algebra and duality, which led not only the proof of AGT relation for some set-up but also the quantum version of Seiberg-Witten curve.

The present form of only one group in the formal theory is too thin-layered to play such a leading role in the field in Japan as this group did so-far. The Committee recommends to fill one more group up as quickly as possible.

The communication between phenomenology group and formal theory group is still poor as the previous (2012) review pointed out. If the fulfillment of the theory group helps to improve the situation, this particle theory group will become a firmer central base to lead the research and education of graduate students in Japan.

The experimental particle physics group consists of Profs. Hiroaki Aihara, Shoji Asai and Associate Prof. Masashi Yokoyama; they are the same members as at the previous external review aside from the retirement of Prof. Sachio Komamiya and promotion of Asai from associate professor.

Asai is a world's visible physicist and one of the important leaders of the Japanese participation in ATLAS/LHC experiment at CERN. Also after the historical discovery of the Higgs boson, they measured precisely the Yukawa- and gauge-coupling constants and searched the SUSY particles excluding already wide low-energy regions which provide important clues for the BSM physics.

Aihara continues the experiments in Belle and Belle II collaborations. Aside from updating B-$\bar{B}$ asymmetry data further confirming Kobayashi-Maskawa mechanism for CP-violation, he searched new BSM physics performing precision experiments of rare/new tau decay processes. He recently extends the horizon into astro-particle physics and plays a co-PI of HSC dark energy survey at Subaru Observatory, beginning to obtain new data there.

Yokoyama made important contributions to epoch-making observations in T2K experiments, the electron neutrino appearance and non-vanishing leptonic CP-violating phase on 2σ confidence level. He is now leading the project in hyper-Kamiokande experiment as a steering committee member and technical coordinator.

While they all show their existence in each big international experiment, all these three groups are also doing small-scale experiments simultaneously; it is very good and essential for educating graduate students as it is one of the most important missions of the Department. It is, however, a miracle for the present staffs, two professors and one associate professor, to manage this situation. Performing three or four big international experiments plus even more small-size ones is clearly an overload for them. The Committee thinks it better to refill the professor position and simultaneously to reorganize the experiment group to focus on fewer big-scale projects.

2 Nuclear Physics

The nuclear physics program at the Department is world class, both in theoretical and experimental physics. Nuclear theory group is led by Prof. Kenji Fukushima, one of the most prominent nuclear theorists of his generation in the world. The hire of Fukushima assures not only the Department's leadership in QCD and hadron physics, which was desired in the previous review in 2012, but also in the emerging cross-disciplinary field of chiral matter where the nuclear theory group successfully collaborates with condensed matter and AMO colleagues within the Department and elsewhere.

The retirement of Prof. Takaharu Otsuka however left the Department with a gap in the important area of low energy nuclear physics and nuclear structure, where the University of Tokyo has traditionally been a leader, and where it has a thriving experimental program. The recent approval by the Department to hire associate professor in the nuclear theory group is commendable, and can solve the problem created by retirement of Otsuka, if the hire is made in the area of low energy nuclear physics.

Nuclear experiment group is led by Prof. Hiroyoshi Sakurai who is a pioneer in experimental studies of nuclear structure and neutron-rich nuclei. The group's ground-breaking research resulted in the discovery of anomalies in magic numbers of the neutron-rich nuclei, marked by 2015 Nishina Memorial Prize awarded to Sakurai.

However the group does not currently have an experimentalist working in high or intermediate energy nuclear physics. This creates a disconnect to current large-scale experimental efforts at high or intermediate energy nuclear facilities both within Japan (J-PARC) and elsewhere, including Electron-Ion Collider at BNL, FAIR at GSI, NICA at JINR. Therefore a new hire is desirable at the associate professor level in nuclear experiment with a program at one of the high or intermediate energy nuclear facilities. This experimental hire will match the theoretical work of Fukushima, and position the Department as a leader in all important areas of modern nuclear physics.

3 Condensed Matter Physics

Theory

Since the topics covered by condensed matter are wide-ranged, there are two contrasting strategies for the structure of a theory group. For a small university, it is impossible to cover all relevant fields. Hence trying to form a single peak or two in the specific area will be a natural choice. On the contrary, in a large organization such as the University of Tokyo, presence of many people in similar topics is unreasonable. In this sense, the present structure of professors in condensed matter theory is well balanced. Namely, the important topics in condensed matter are basically covered; strongly correlated electrons (Prof. Masao Ogata, Associate Prof. H. Katsura), energy band theory (Prof. Shinji Tsuneyuki), statistical physics (Prof. Masahito Ueda, Prof. Synge Todo), and a newly developed field of quantum information (Prof. Miho Murao). In statistical physics, the flavors of Ueda and Todo are rather different; Ueda is particularly interested in fundamental aspect and optical properties, while the main expertise of Todo is numerical calculation for model systems. At the time of previous review in 2012, Ueda and Murao belonged to the group of General Physics, and Katsura was not in the Department.

The wide research activity of Ogata in electronic properties in solids ranges from a numerical study for the Mott transition to topological aspect of Dirac electrons in bismuth. His high level of research has led him to a leading figure in the academic community, and also education of students. On the other hand, Katsura, who is by far the youngest newcomer, has already made highly visible research in disordered topological systems and many-body systems.

The modern version of band theory has been actively explored by Tsuneyuki, who has developed a new method complementary to the standard density functional formalism. He has also long been involved in the community of utilizing large computers such as one at ISSP and the K computer.

For the study of quantum spins and highly-correlated electrons, numerical simulation is a major tool, which bridges analytic theory and experiment in real materials. Todo has developed not only simulation algorithms but provided open-source softwares, which have been widely used in the community.

In statistical physics, the most fundamental problem is the condition for the increase of entropy. Ueda has challenged the long-standing problem of Maxwell's demon from a new point of view emphasizing the energy cost of information. He has thus developed a new field known as information thermodynamics.

Recent experimental progress has removed doubt on quantum mechanics at least on consequences of its paradoxical prediction, which has plagued many physicists including Einstein. Murao has been investigating the fundamental problems in quantum information with a scope to connect to quantum computing and quantum cryptography. She has proposed a protocol to estimate parameters of a quantum state in a precision-guaranteed manner, which is beyond the scope of classical computations.

As described above, the professors of the theory group are all very active and play leading roles in the world-wide research. It seems, however, that the theory group has not fully made use of the merit of size and diversity of fields. In order to bring about a kind of fusion and integration, the Committee recommends to consider some device such as informal report meetings to encourage interaction among members.

Experiment

The experimental condensed matter physics program consists of eight faculty groups, with a healthy seniority distribution as exemplified by the recent addition of three new groups (Profs. Masamitsu Hayashi 2016, Kensuke Kobayashi 2019 and Satoru Nakatsuji 2019). The field of condensed matter physics is vast – ranging from physics at extremely low temperature, quantum Hall/topological phases of matter, correlated electron systems/high temperature superconductivity, novel magnetism, 2D/surface physics, device physics and quantum technology. All major topics over the last five decades, as indicated by the nine related Nobel prizes are touched by the groups. Advanced tools that are important hallmarks of successful condensed matter physics program, are also represented, with terahertz (THz) spectroscopy and low temperature STM being examples.

The Department manages to cover impressive range of topics with a philosophy of diversity and presence. This ensures that the students get wide exposures to the fundamentals in their basic education and ample selections in their research topics. The need to cover a wide range makes it a necessity to collaborate, both internally through shared facilities (e-beam lithography, PPMS, LT-STM) and joint projects, and externally through Collaborative Institute of Trans-scale Quantum Science, joint appointments with other institutions and exchange programs like MPI-UBC-Tokyo exchange.

Fukuyama group covers the fundamental physics at extremely low temperature, such as quantum liquid and quantum solid. Specific-heat experiment for 2D He on graphite surface by the group succeeded to provide solid evidence for the quantum liquid crystal representing anomalies at 1.4 and 0.9 K for ^{4}He and ^{3}He, respectively. This finding has provided an existence of new phase on the state of ^{3}He as a two-dimensional matter. In more recent years, the activity expands to synthesis and STM study of zigzag nano-ribbons of graphene, with focus on spin-polarized edge states.

Hasegawa group has an active program in surface physics focusing on an exotic electronic and structural properties originating from the symmetry breaking at surfaces. The group has enormous experience on the study of electronic properties of metallic atomic layer at Si(111) surfaces. In recent years the group has found Pb and Tl on Si(111) exhibiting the property of the 2D Rashba superconductor where spin-orbit interaction plays an important role, while the normal BCS type is expected for the case of In on Si(111). Superconductivity for single graphene bilayer with Ca/Li intercalation is confirmed as well. The group has unique technique of micro-four-point probes, combining with STM/STS and ARPES to confirm the local property of transport, and the heterogeneous physical property at surfaces.

Okamoto group focuses on the physics of two dimensional systems, such as 2D electron gases in semiconductor heterostructures and cleaved surfaces. The group explores both transport and STM/STS experiments. In addition to the traditional topic of quantum Hall Effect, the group's activity expands to 2D Rashba superconductor, and demonstrated a new type of superconductivity induced by magnetic field.

Hayashi group studies spin-conversion effects in spin-orbit materials, including spin Hall Effect, spin Nernst effect, and anomalous Seebeck effect, chiral magnetism, Dirac materials and current induced domain wall motion. They have found certain heterostructures that enable fast motion of domain walls via the Dzyaloshinskii-Moriya interaction. This finding is being applied to the domain-wall (or racetrack) memory.

Kobayashi group covers device physics, with focus on the non-trivial behavior of charge/spin in non-equilibrium when the states are subjected to flow and/or change. In addition to unique opportunities to study "on-chip" condensed-matter physics, this activity is at the heart of electronics, chemical reactions and life. Taking advantage of recent progresses in materials science and nano-technology, the group actively studies spintronics, strongly correlated electron system, and molecular electronics.

Takagi-Kitagawa group has an active program in material physics with focus on searching and studying material platforms to realize novel physics. This includes exotic phases of correlated d-electrons in novel transition metal compounds with strong Coulomb repulsion and strong spin-orbit interaction. An example is their discovery of the spin-orbital Mott state in Sr_2IrO_4 where the $5d^5$ of Ir configuration has the effective spin $J_{\text{eff}} = 1/2$. The group has a string of important discoveries: spin-orbital entangled quantum liquid with $J_{\text{eff}} = 1/2$ on 2D honeycomb lattice $H_3LiIr_2O_6$; correlated Dirac semimetals made of $4d$ and $5d$ electrons; and excitonic insulator Ta_2NiSe_5.

Nakatsuji group has an active program at the rich interface of superconductivity, topological materials, quantum spin liquid, spintronics and energy harvesting. Its activity expands from fundamental condensed matter physics to application of these novel phenomena and devices. A notable success is the pioneering contribution on the magnetic Weyl fermion in antiferromagnet Mn_3Sn, and other important progresses by measurements of anomalous Nernst effect, magneto-optical Kerr, and magnetic spin Hall effect in this compound.

Shimano group has an active search program using laser and THz spectroscopy to understand and light-control/create macroscopic quantum states in matter. This is an excellent combination of important conceptual issues and novel experimental techniques.

Notable achievements include discovering Higgs modes in superconductors, realization of electron-hole BCS-like states in a semiconductor, optical quantum Hall effect in 2D electron gas and graphene.

Over all, this is a highly successful program, with the groups very productive and globally recognized. Some issues encountered by this group are common among different fields – gender, internationalization, but others may require specific attention – such as shared facility and theory/experiment balance among the student body.

4 Astrophysics

There are five professors and four associate professors at the Department and Research Center for the Early Universe (RESCEU). Each of them, as a principal investigator (PI), is responsible for a research unit with assistant professors, graduate and undergraduate students, and other staff members. Their research covers the entire area of astrophysics, both theoretical and observational, from the solar neighborhood of the present Universe to the farthest reaches and to the first moment of the Universe. The overall activity of the astrophysics group is of the highest quality competing with the world.

All the professors have demonstrated their expertise for many years, contributing to the advancement of their respective research fields, thus achieving renown and receiving high reputation. They play principal roles in their research communities, also enlightening the public. Associate professors are relatively young, but are all established front-line researchers with brilliant expectations.

It deserves high praise that the astrophysics group has expanded its research areas to new fields such as exoplanets (including their formation sites and astrobiology) and CMB (cosmic microwave background) experiments. Also noted is the increase of researchers in the gravitational-wave experiments, of which the Department has a long history. The Committee admires the efforts made by the Department and RESCEU to take such new research areas in by closely observing the forefront of astrophysics.

The details of each research group (or team) are given below.

Department of Physics

The theoretical astrophysics group consists of Profs. Yasushi Suto and Naoki Yoshida as core members. Their research areas include observational and computational cosmology, first stars and blackholes, and exoplanets.

Suto's research is primarily on exoplanets, leading one of the RESCEU projects (see below). One of his recent works is the discovery of an exoplanetary system where a planet has a significantly different direction of orbital angular momentum with respect to the spin of the central star. He supervised eight PhD students in 2013 - 2019. He has been influencing the public by writing articles for major Japanese newspapers.

Yoshida received Japan Academy Award and JSPS Prize in 2017 for his numerical simulations of structure formation in the early universe. One of his recent interests is the application of machine learning to cosmology. His team applied the technique to classify transient objects in Subaru HSC images, automatically identifying many supernova explosions with different types. He supervised eight PhD students in 2015 - 2020.

The experimental astrophysics group is comprised of Prof. Satoshi Yamamoto and Associate Profs. Aya Bamba, Masaki Ando, and Akito Kusaka as core members. Their research areas cover a wide range of observational astrophysics: the interstellar matter and formation of stars and planets, X-ray emission from supernova remnants and clusters of galaxies, gravitational-wave, and the cosmic microwave background radiation.

Yamamoto's interest is in astrochemistry. His recent work includes the discovery of chemical diversity in star and planet forming regions, showing a new picture of chemical evolution in the star and planet forming process. He is a leading figure of radio astronomy communities in Japan and in the world, essentially contributing to the success of world frontier large projects like ALMA.

Bamba is an X-ray astrophysicist. She contributed to the Hitomi mission and obtained high spectral resolution X-ray data of the Perseus cluster, measuring for the first time its Ni/Fe ratio, an important parameter to characterize the nature of the cluster of galaxies to infer the chemical enrichment history of the Universe. Her team is instrumental in the XRISM mission to be launched in 2022.

Ando's research field is gravitational-wave. He is an executive member of the KAGRA collaboration playing a key role for its planning, construction, and commissioning, with his team contributing to the main interferometer system. The research activity of his team is diverse, including smaller scale experiments on gravitational-wave detection technique. He supervised nine PhD students in the last eight years.

Kusaka's research target is CMB polarization. His latest publications include the first evidence of correlated gravitational lensing between the Polarbear CMB measurement and Subaru HSC data. His team is a member of the Simons Observatory collaboration, contributing to the hardware development crucial to its operation and success.

Research Center for the Early Universe (RESCEU)

The RESCEU, also called the Big Bang Center, consists of Profs. Jun'ichi Yokoyama and Kipp Cannon, and Associate Prof. Toshikazu Shigeyama as core members, with Suto in the Department as director. In addition, the RESCEU has nine affiliated professors and associate professors belonging to the Department of Astronomy, Institute of Astronomy, and Department of Earth and Planetary Science.

In 2016, the RESCEU reorganized its research projects into the following three:
(1) Evolution of the Universe and cosmic structure;
(2) Gravitational-wave astrophysics and experimental gravity; and
(3) Formation and characterization of planetary systems.
It hosts frequent international symposia and annual summer schools, facilitating its visibility from foreign and younger generation researchers.

Yokoyama leads the first project (1). His main research interest is theoretical studies of the early Universe (inflation) and gravitational wave. He supervised nine PhD students in 2012-2019, publishing 59 research papers. For many years, he has been contributing to the Association of the Asia Pacific Physical Societies (AAPPS) as editor and currently serves as president.

Cannon leads the second project (2), focusing on detection and interpretation of gravitational wave. His team played a major role in the discovery of GW170817, the first observation of a neutron star collision, and contributed to developing the infrastructure required to incorporate KAGRA into the international network of gravitational-wave detectors.

Shigeyama, member of the first project (1), leads theoretical studies of supernova explosions, nucleosynthesis, and chemical evolution of galaxies. He suggested that rare neutron star mergers are the main site of the rapid neutron-capture process (r-process) to create elements in the Universe. He predicted the detection of gravitational wave from neutron star mergers with current detectors before the neutron star merger event GW170817 was detected.

The third project (3) was led by Suto (see above).

5 Biophysics

Biophysics group used to be a part in the program of General Physics before 2016. The Committee congratulates the Department on the successful action to establish biophysics as an independent and important group.

The biophysics group was consolidated through establishment of Universal Biology Institute (UBI) in the Graduate School of Science. By the end of 2016, the UBI was further extended to Collaborative Research Organization for Universal Biology Institute (Collaborative UBI) by including research groups in Komaba campus. The name "Universal Biology" comes from intention to regard the life system as a kind of universality class in nature. The UBI performs theoretical and experimental researches to resolve the fundamental question of life from the viewpoint of physics. To promote the research further, the UBI has contracted with Quantitative Biology Center in Riken. As a whole, scientific activities in biophysics group are excellent. The cooperation between theoretical physics and experimental biology is quite successful.

The following is the report of the research by the members of the UBI at the Department. The UBI consists of Profs. Chikara Furusawa and Sosuke Ito as full time members, and Profs. Hideo Higuchi, Yasuyoshi Okada and Akinao Nose as concurrent members. Okada belongs, besides the School of Science, to the School of Medicine in the University of Tokyo, and also to RIKEN.

Furusawa made an important contribution to evolutionary biology on the basis of theoretical and experimental studies of *Escherichia (E.) coli*. He has contributed to show evolutionary robustness causes reduction which restricts possible phenotypic changes in response to variety of environmental conditions. A reduction in high-dimensional phenotypic states to a few degrees of freedom is essential to understand biological systems. He found that the evolutionary changes are constrained to the changes along a one-dimensional major axis, within a huge-dimensional state space.

Ito has been discussing connections between thermodynamics and information theory which are applicable to biochemical systems. He and his group applied the generalized second law to the biochemical signal transduction of *E. coli* bacterium chemotaxis. In this application, they focused on the information flow from the kinase activity (CheA) and the methylation level of the receptor in *E. coli* cell. As a result, they could quantitatively show that the generalized second law gives the informational bound of the robustness of the sensory adaptation.

Higuchi, who is the director of UBI, and his group observed the walking of single motor molecule for the first time, and formulated its mathematical model of the movement of protein. Cytoplasmic dynein is a molecular motor moving toward the minus end of microtubules. The swing of the dynein linker is supposed to be crucial for walking of dynein. There was no measurement of the displacement generated by the swing. Higuchi investigated the displacement of microtubule driven by the swing of single molecules of single-headed dynein by optical tweezers. The displacement of swing by dynein is close to tubulin spacing in microtubule, indicating that dynein is able to walk only by the swing of dynein lever.

Okada and his group are trying to understand the dynamics of the protein molecules working in the living cells, especially motor protein undergoing the intracellular transport. They observed dynamic processes of fine structures in the living cells, using their original device which is called the Spinning-Disk Super Resolution Microscope (SDSRM). They have identified that the microtubles, the rail polymer for the transport, can take two different conformations. It was disclosed that the binding of kinesin-1, the motor protein for the axonal transport, triggers the cooperative conformational changes in the microtubule, which serves as the road sign for the following kinesins. Axonal transport is essential logistics in neurons and is related with Alzheimer's disease.

Nose is interested in mechanisms of how the neural circuits develop and function to generate specific behavior, by using the nervous system of the fruitfly called Drosophila as a model. In this organism, the relative simplicity and highly sophisticated genetic techniques allow one to identify and manipulate specific neurons. To dissect the circuit logic, Nose and his group use calcium imaging to record the activity of specific population of neurons. By using optgenetics, they manipulate the activity of specific neurons with light at high resolution. Connectomics, which makes reconstruction from 3D images of electron microscopy, allows determination of neuronal wiring diagrams at the cellular and synaptic level.

6 General Physics

General Physics

Important changes have occurred in "General Physics" since the last review in 2012. Reflecting the report of the 2012 review, also following the 2005 review, the Department has strengthened biophysics as one of their major branches. Simultaneously, topics such as "ultracold gases and information thermodynamics" and "quantum information" are now transferred to the program of "Condensed Matter Physics". Another point to note is the weakening of the activity in atomic, molecular and optical (AMO) physics, which was carried out by Profs. Makoto Gonokami, Masahito Ueda, and Hirofumi Sakai. Since Gonokami is now the president of the University, his commitment to experimental research cannot be the same as before. If the presence of "General Physics" is regarded as effective in coping with new tidal changes in physics, the Department should consider next candidates to succeed the tradition and pursue further development.

Atomic, Molecular and Optical (AMO) physics

Sakai has developed novel technique to align and to control the orientation of molecules at dilute condition. His unique technique to realize molecular orientation under the laser-field-free condition is to combine electrostatic and intense nonresonant shaped laser fields with a slow turnon and a rapid turnoff and wherewith succeeded to maintain molecular orientation in nano-second time scale. As suggested in the 2012 review, the technique has been applied, for example, to the study of stereodynamics of dissociative ionization of OCS molecules where the orientation dependence was observed. Considering the future development of free-electron laser systems, his physics and technology are expected to develop toward complex molecular systems.

Plasma Physics

Prof. Yuichi Takase is one of the international leaders in fusion plasma physics. The research is carried out using the spherical Tokamak device, TST-2, at Kashiwa campus. It is important for research and human resource development that his group has its own experimental equipment and can freely conduct experiments by driving it by itself. Utilizing this advantage, the group is investigating on issues that complement large-scale experimental devices such as ITER (the International Thermonuclear Experimental Reactor). At present, plasma current ramp-up using the lower-hybrid wave (LHW) without the central solenoid (CS) is being investigated, with the aim of realizing a compact Tokamak device by removal of CS. It is also expected that the group will provide scientific leadership in the international collaboration between Japan and Europe at the JT-60SA. The leadership will promote Japan's fusion strategy in ITER and the subsequent demonstration reactor (DEMO), and contribute to the realization of fusion.

Experimental Statistical Physics

Prof. Kazumasa Takeuchi leads an active research program on statistical physics of none-equilibrium systems by using soft matter (liquid crystal, colloids, granular systems, etc.) and living matter (mostly bacteria), in search of large-scale and universal phenomena. This includes topological defect turbulence of liquid crystal, order formation in bacteria turbulence, statistical physics of dense bacteria suspensions. The program boosts synergetic activities of simulations and experiments. For example, they have a string of beautiful experiments that uncovered the Kardar-Parisi-Zhang (KPZ) class of physics, providing a bridge to KPZ exact solution. For this work, Takeuchi received the MEXT Young Scientist Prize in 2018.

Laser Physics

Prof. Junji Yumoto serves as a director of the Research Institute for Photon Science and Laser Technology since 2017, providing an important technical platform for the physics research in the field within the University of Tokyo. The research in the lab is under continuing advice of President Gonokami and in collaboration with the Institute.