World Premier International Research Center Initiative (WPI)
Executive Summary (For Final Evaluation)

Host Institution	The University of Tokyo	Host Institution Head	Makoto Gonokami
Research Center	Kavli Institute for the Physics and Mathematics of the Universe		
Center Director	Hirosi Ooguri	Administrative Director	Tomiyoshi Haruyama

Instruction: Based on the Center's Progress Report and Progress Plan, prepare this summary within 6 pages.

A. Progress Report of the WPI Center

I. Summary

The mission of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) has been to study five interrelated, basic, yet ambitious questions about the Universe: how it began, what it is made of, what its fate is, what its fundamental laws are, and why we exist in it. Advances over the past couple of decades have made it possible to address them by scientific methods.

The Kavli IPMU was launched from scratch with the WPI funding on October 1, 2007, as a unique interdisciplinary institute in the world that combines mathematics, theoretical and experimental physics, and astronomy. Since then, it has grown to an international research center of 330 members (about half of them are from abroad). We also had about 800 visitors on average every year, until the COVID-19 pandemic. We have produced high impact signature papers with the "made in the Kavli IPMU" brand, with citation counts and the number of highly cited papers comparable to, or better than world-leading institutes. About 90% of our former postdocs have landed research positions at prestigious institutions all over the world, and 60% of them are on faculty positions.

In addition to the five major questions, we work intensively on the 9 challenges proposed for the WPI funding extension period addressing new objectives:

(1) We are creating new areas and tools in statistics, integrating mathematics with observation and experiments. N. Yoshida has led the JST CREST project "Statistical Computational Cosmology" to develop fast imaging data analysis applications for the Subaru Hyper Suprime-Cam survey.
(2) T. Takahashi and others are conducting a new interdisciplinary project by applying their hard X-ray and gamma ray detectors to biomedical research. This is a new synergy among the fields not imagined at the launch.
(3) Our mathematicians, including M. Kapranov and Y. Toda, are advancing a new framework for geometric thinking provided by noncommutative and derived geometry.
(4) We have launched major experimental initiatives such as SuMIRe (HSC and PFS), T2K, LiteBIRD, EGADS, and Belle II to produce world-competitive results on fundamental physics, including dark energy, dark matter, and cosmic inflation.
(5) We are attracting and retaining the best scientists with broad interests from around the world. All of our 28 PIs are world-renowned scientists and ensure an international environment for research activities here. Other faculty members also play leading roles in each field.
(6) Our successes in system reforms have not only inspired changes within the University of Tokyo (UTokyo) but have also spread throughout Japan. They include split appointments, merit-based salary scales, and the establishment of the Kavli IPMU endowment by donation from the Kavli Foundation (the first time such an endowment has been established in a Japanese national university by a foundation abroad). Our administrative staff members have been awarded the UTokyo's Special Prizes for Business Transformation from the President six times.
(7) We have created a new international graduate program with robust student exchanges. The student exchange program with the University of Oxford has been successful. We are also involved in the international graduate program in physics (GSGC), and we are leading the new graduate program supported by WISE program of MEXT.
(8) Our outreach program has been highly successful and mobilized several thousands of people every year. We organize schools for high-school students, some of which are to support female students. The Kavli IPMU is collaborating with Consortium for Renovating Education of the Future (CoREF) to experience the latest advances in scientific research for high-school students.
(9) UTokyo has established the University of Tokyo Institutes for Advanced Study (UTIAS) to house the Kavli IPMU as a permanent entity within the University. The 'university functionality boost' budget from MEXT for 13 positions and for operation has been approved to be a permanent

budget. The University is committed to sustain the Kavli IPMU at its current high level of activities, even after WPI support ends in 2022.

II. Items

1. Overall Image of Your Center

Overall, the Institute met and exceeded our promises to the WPI program. Our unique building allows mathematicians, physicists, and astronomers to be located under the same roof, sharing seminars and the daily teatime. Interdisciplinary discussions have become commonplace. We are international. Thanks to several high-profile papers and international visibility, our members are invited to major conferences as keynote or summary speakers.

Our mathematicians and physicists inspire each other and their collaborations have led to many interdisciplinary publications. We have also strengthened the connection between astronomy and statistics in order to analyze large-scale data anticipated from HSC and PFS. In addition, there are unanticipated types of interdisciplinary activities between astronomers and mathematicians, between science and society, and between high energy astrophysics and medical imaging. Our research building specifically designed to mix up people from different disciplines and the mandatory daily teatime for informal interactions have proved extremely successful. During the COVID-19 pandemic, we are continuing this effort by holding Kavli IPMU social hour in a virtual space. Precious lessons we have learned on how to utilize virtual spaces will help us work more efficiently and build stronger international connections, even after the pandemic ends.

We have also carried out experimental and observational programs from accelerators, underground laboratories, and telescopes, and have launched major experimental initiatives such as HSC, PFS, T2K, LiteBIRD, EGADS, and Belle II.

2. Advancing Research of the Highest Global Level

Our research activities span a wide spectrum from pure mathematics and theoretical physics to experimental physics and astronomy as summarized in the Progress Report. Here we do not try to cover more than 4900 papers exhaustively, but rather focus on a few significant results.

How did the Universe start?

Our Universe is believed to have started with an explosive expansion called inflation. We are leading a CMB satellite mission LiteBIRD, which has been selected as the second ISAS/JAXA strategic large-class (L-class) mission, to hunt for primordial gravitational waves emitted during the inflation era.

Primordial black holes (PBH) formed in the early universe are attracting attention as a promising candidate of dark matter as well as LIGO black holes. M. Sasaki has been leading an international collaboration on PBHs and their observational signatures. M. Takada and others searched for microlensing events using HSC data have placed a new constraint on the mass of PBHs.

The discovery of the Higgs boson in 2012, in particular the value of its mass, raised new questions on the state of the Universe a billionth of a second after the Big Bang. In order to extrapolate it to even earlier moments, we need a consistent theory that explains the observed mass of the Higgs boson. T. Yanagida and others came up with a supersymmetric theory called pure gravity mediation and predict a new type of candidate for dark matter.

What is the Universe made of?

It has been known since 2003 that more than 80% of the matter in the Universe is mysterious dark matter not made of atoms. It is responsible for building up the stars and galaxies we see in the Universe today, yet its nature is completely unknown. Without it, we would not be here today.

Kavli IPMU theorists including S. Matsumoto, T. Melia, H. Murayama, and S. Shirai are exploring various phenomenological scenarios for dark matters. In particular, they developed thermal dark matter candidates having weak charges of the standard model and light dark matter candidates whose masses are much less than the electroweak scale.

Y. Suzuki has led the XMASS experiment to detect dark matter particles directly with a highly sensitive device in the Kamioka underground laboratory. It has demonstrated a versatile capability in looking for many different reactions, producing world's best limit on certain candidates of dark matter. Kavli IPMU members in XMASS collaboration have joined XENONnT. Its Japanese team led by K. Martens and S. Moriyama is applying the expertise they have acquired at their experiments at Kamioka to this new liquid xenon dark matter search.

What is the fate of the Universe?

We are leading the SuMIRe (HSC and PFS) projects to study the nature of dark matter and dark energy which determines the fate of the Universe. The HSC Subaru Strategic Program (HSC-SSP) team has been carrying out a large-scale imaging survey of the Universe with the Subaru HSC since 2014. We have successfully created 2D and 3D maps of dark matter, which we cannot see directly, by measuring tiny gravitational lensing distortions of distant galaxy shapes. We have explored how

cosmic large-scale structures evolve as a function of cosmic time and determined the clumpiness of the Universe at a world-competitive level. The HSC papers published in PASJ received a lot of attention from the community and contributed to the highest impact factor that PASJ has ever achieved. The Kavli IPMU also made progress in a major astronomical instrument called Prime Focus Spectrograph (PFS), a next-generation instrument of wide-field spectrograph mounted on the Subaru telescope. The instrumentation is in the phase to actively integrate and test the hardware and software of the subsystems so that we can start engineering observations soon.

What are its fundamental laws?

H. Ooguri studies aspects of quantum field theory and quantum gravity. H. Ooguri and D. Harlow completed a mathematical proof of one of the fundamental theorems in quantum gravity that there is no global symmetry in a consistent quantum theory of gravity. This theorem had been conjectured for over half a century, but no definite proof was given until their paper. The proof makes use of ideas from quantum information theory. The short announcement of their result was published in Physical Review Letters as Editors' Suggestion. H. Ooguri and others also proposed a new type of constraints on the potential energy in any consistent quantum theory of gravity, called the swampland conjecture. This paper turned out to be the most cited one in elementary particle theory in the year 2018.

Y. Toda developed Gopakumar-Vafa (GV) invariants for Calabi-Yau (CY) 3-folds and 4-folds. The GV invariants were suggested by the physicists R. Gopakumar and C. Vafa around 1998, but their precise mathematical definition had been missing for almost 20 years. Y. Toda and D. Maulik proposed a mathematical definition of GV invariants on CY 3-folds, and formulated several conjectures relating them with Gromov-Witten invariants and PT invariants.

M. Kapranov developed several applications of the formalism of factorization algebras to algebraic geometry based on the concept of factorization homology originated from quantum field theory. For example, he proved a longstanding conjecture of B. Feigin on Lie algebra cohomology of the algebra of vector field on an affine algebraic variety, thus providing an algebro-geometric generalization of the classical Gelfand–Fuchs theory.

Why do we exist?

To understand why we exist, we need to understand how stars are born. N. Yoshida managed to simulate how the very first stars in the Universe formed from first principles without assumptions. He also performed state-of-the-art supercomputer simulations to study how supermassive black holes are formed in the center of galaxies. These works were published in Science.

For life to emerge, we need chemical elements beyond helium. They are formed inside stars and spread by explosions called supernovae. How? K. Maeda and K. Nomoto observed a number of supernovae a year later and could see "inside" after the ejected materials became transparent. They discovered for the first time that most of the supernova explosions were not spherical and the gas is spreading out in a bipolar jet-like form. It was published in Nature.

We also uncovered clues on how supermassive black holes grow, and determined the distribution of cosmic dust accompanied by dark matter. M. Vagins showed we can detect supernova neutrinos from cosmological distances by doping gadolinium into Super-Kamiokande with the R&D program called EGADS (Evaluating Gadolinium's Action on Detector Systems). The Gd-loaded EGADS serves as a fully-automated, real-time early-warning system in case of a core-collapse supernova (SN) explosion occurring anywhere in the Milky Way galaxy.

3. Generating Fused Disciplines

We promote interdisciplinary interactions with daily teatime (after the COVID-19 pandemic, it has moved to a virtual social hour), joint seminars, and interdisciplinary workshops. These have led to many publications that otherwise would not have been possible. In addition, there are various unanticipated types of interdisciplinary activities.

An unexpected synergy between astronomy and mathematics. Based on the teatime discussion of R. Quimby (astronomer), M. Werner (mathematician) and M. Oguri (physicist), they found that a class of the brightest supernovae called superluminous supernovae comes from the magnification by gravitational lensing, though a Harvard group claimed that it was a yet brighter, new type. This result was published in Science and was covered by more than 80 media outlets internationally as: "Tokyo theory correct; Harvard theory wrong."

There are a variety of interdisciplinary works among physics in different fields and mathematics. H. Ooguri worked with M. Oshikara, a condensed matter physicist, and showed that an analog of a dark matter candidate creates instability in a magnetic system that can be studied in the laboratory. H. Murayama worked with the Kavli IPMU mathematicians and string theorists to apply techniques from conformal field theory to make the classification completely systematic. A joint work between arithmetic geometry and string theory was done by S. Kondo and T. Watari, triggered by Kondo's colloquium at the Kavli IPMU. T. Melia collaborated with experimental condensed matter

physicists and chemists and developed his idea for chemical dark matter detectors

We are strengthening the connection between astronomy and statistics needed for analyzing large-scale data anticipated from HSC and PFS. N. Yoshida has led the JST CREST project "Statistical Computational Cosmology" to develop novel tools of fast imaging data analysis using machine learning-based methods and to apply them for the Subaru HSC and PFS data.

A team led by T. Takahashi is working on an interdisciplinary research to develop advanced detectors for medical imaging, in collaboration with National Cancer Center and other institutes.

H. Yokoyama is an expert of science and technology studies, in particular their relations to society. She led a JST-RISTEX policy research project to study why there were so few women in mathematics and physics in Japan.

4. Realizing an International Research Environment

We have world-renowned international PIs who are heavily involved in our daily research activity. We have attracted excellent scientists from abroad. In return, other world-leading institutes have recruited many of our former members. The traffic of visitors is so high that we can meet world leaders in the fields while at the Kavli IPMU. We have hosted 179 international workshops, where half of the attendees came from abroad.

The quality of our members is extremely high. Our annual postdoc search attracts about 700 applications for about 12 positions. Among 193 postdocs who have left the Kavli IPMU since its inception, 115 (60% of our postdocs) have landed faculty positions at prestigious universities and research laboratories all over the world.

The Kavli IPMU has signed 27 cooperative research agreements with overseas institutes and international collaborations by 2020. Under the MOU with Oxford U, Kavli IPMU faculty members supervise doctoral students from the University of Oxford. So far, we have accepted nine students, and five have defended their Ph.D. theses. The Kavli IPMU is involved in the international graduate program in physics (GSGC) and is leading the new graduate program supported by Doctoral Program for World-leading Innovative & Smart Education (WISE) program.

The Kavli IPMU has appointed K. Martens the first Director of the Kamioka-branch. The fact that a foreign researcher can take such a leadership role demonstrates that the Kavli IPMU has established a truly international environment and support system.

An example of establishing the institute as an international research center of high reputation was manifested at the Kavli IPMU 10th anniversary symposium. It had about 200 participants and about 40% of them were from abroad. The speakers included two Nobel laureates in physics, T. Kajita and D. Gross, and two Fields medalists in mathematics, A. Okounkov and S.-T. Yau.

5. Making Organizational Reforms

The Kavli IPMU inspired the system reform not only within the UTokyo but also at other universities in Japan. We made split appointments possible with institutions inside and outside Japan. We offer merit-based salaries. The Kavli IPMU employed so-called "nenpo system" which improves the mobility of the members. Kavli IPMU administrative staff members have been awarded the UTokyo's Special Prizes for Business Transformation from the President six times and their development products have been requested by other organizations in the UTokyo.

In January 2011, UTokyo established the TODIAS (afterwards renamed as the UTIAS), and the Kavli IPMU became its first member institute within this new and permanent organization. This was the first major organizational reform at UTokyo since 1949 and was motivated by the WPI program. Being a member of this organization allowed up to operate as an incubator of system reforms within UTokyo.

These reforms have inspired other universities in Japan. For example, the Administrative Director T. Haruyama was invited to Tokushima University to advise its program established by the Cabinet Office project "Promotion of Regional Industries and Universities". He gave a lecture to the President and board members of Tokushima University on detailed successful experience of the WPI program at the Kavli IPMU. He has been a member of the External Evaluation Committee of the newly established laboratory at the university.

6. Outreach Activities

The Kavli IPMU has spent significant effort on science outreach activities as we believe our sciences excite the general public, improve scientific literacy, and attract young minds crucial for the future of this country to science, technology, engineering, and mathematics.

Since 2015, the Kavli IPMU has hosted the Artist in Residence Program (AIR), creating a new opportunity to showcase the social and creative value of fundamental research. We hosted a two-week exhibition featuring work by three past AIR residents.

Monoshiri Newspaper became a new feature of the Kavli IPMU following the institute's 10th

anniversary in 2017. The two-sided wall newspaper is filled with pictures and stories surrounding specific research fields. The Kavli IPMU hosted an event, "Kavli IPMU Monoshiri Newspaper Online Talk Series". Four researchers featured in the newspapers gave lectures on their research and their lives as scientists. About 1895 people tuned into the event, and roughly half of them were students, including undergraduate and graduate students. The event also attracted people from all over Japan, providing the opportunity to introduce the institute to a wider audience.

7. Others

The Kavli IPMU is the first institute in Japan to establish an endowment donated by a foreign foundation (the Kavli Foundation) and named after the donor, demonstrating our high international visibility. Another measure of our international visibility is citation counts. Web of Science by Clarivate Analytics (previously Thomson Reuters) showed that the Kavli IPMU has produced 4939 (4859) papers from 2007 to 2020 including (excluding) review papers. Among them, 820 (787) papers have more than 50 citations, and 40.1 (34.4) citations per paper on average. These numbers are comparable to or better than those of world-leading institutes in similar research areas.

H. Ooguri has introduced several measures to improve our diversity, including bias training for search committee, revision of harassment training, best practices for selections and recruitments, and diversity requirements on workshops. We have a weekly women's lunch and provide leadership opportunities for female and international scientists. We also established our code of conduct. This has inspired UTokyo to establish its own code of conduct.

During COVID-19 pandemic, we recruited six short-term postdocs, "Postdocs en passant", who could not move to their new appointments due to visa/travel restrictions but could come to Japan.

B. Progress Plan

1. Mid- to Long-term Research Objectives and Strategies Based on the Center's Research Results to Date

The mission of the Kavli IPMU is to discover fundamental laws of nature and address the questions about the Universe; how it was born, how it evolved, and what the future will be. Our long-term objectives are to solve these problems by integrated efforts of mathematicians, physicists and astronomers. Immediately after H. Ooguri became the Director in the fall of 2018, he initiated the Long Term Strategic Planning Exercise of the Kavli IPMU. It identified the three areas; CMB, Kamioka experiments, and survey astronomy projects, as the institutional priorities in experimental physics and observational astronomy. Each of these projects involves multiple faculty members of the Kavli IPMU, and a large fraction of our resources will be invested in them. Cosmology and neutrino physics are making significant progress and there are also opportunities for synergies among these projects. We expect that these investments will bear fruits over the next five to ten years, and it is important to ensure their successes. In addition to these priority areas, we will also support projects conducted by single PI's as well as theoretical research.

For CMB projects, with expertise gained from POLARBEAR/Simons Array and the Simons Observatory, the Kavli IPMU is expected to contribute to the LiteBIRD project with development of polarization modulators and hosing of the data analysis center. For Kamioka projects, Kavli IPMU PI M. Vagins with J. Beacom proposed the idea to add the gadolinium to Super-Kamiokande. It is now being added and is substantially increasing in its sensitivity. For survey astronomy, Hyper Suprime-Cam (HSC) and Prime Focus Spectrograph (PFS) are flagship projects of the Kavli IPMU. HSC has already had great success with its early science results, in particular with the weak lensing survey. PFS will play a complementary role with highly multiplexed, deep, wide redshift survey. The instruments are being assembled in Hawaii. To make the most of HSC and PFS, close collaborations with other survey projects worldwide are essential. The Rubin Observatory (formerly known as LSST) will be the main survey project for the coming decade. In coordination with NAOJ, we are negotiating with the Rubin Observatory to join the project.

There are several projects conducted by single PI's, which we will continue to encourage. They include a high energy project Belle II, a dark matter search project XENON-nT, and medical applications of gamma-ray imaging in collaboration with the National Cancer Center, which provides unique opportunities for us to make societal impacts.

As for theoretical studies, although project-style research is not suitable for them, there are a few important topics about which we expect to make significant contributions. Collaborations between mathematics and theoretical physics have been very successful and have produced many noteworthy results. One of our challenges in the coming decade is to expand the frontiers in algebraic geometry toward other areas in mathematics and theoretical physics. In astrophysics, cosmology and particle physics, there are important unsolved issues, such as the nature of dark matter and dark energy. With the planned world-leading projects mentioned above at hand, our challenges are to develop an efficient analysis method that can deal with the big data delivered by

those projects, to reveal the physics of dark matter and dark energy. This will be possible only with concerted efforts by astronomers, physicists, mathematicians, and computer scientists. Theorists at the Kavli IPMU are exploring for various candidates for dark matter, ranging from ultralight to macroscopic ones. Through these studies we proposed concrete models, found new mechanisms on dark matter processes, suggested experimental methods to test the candidates, and contributed to dark matter search projects by showing the nature of each candidate. We continue exploring theoretical models in close collaborations with experimenters and observers.

We are also taking a new opportunity in quantum information theory. The Kavli IPMU is a member of the Trans-Scale Quantum Science Institute, a crosscutting research platform for quantum science including cosmology, particle physics, condensed matter physics, quantum information and mathematics at UTokyo. Kavli IPMU theorists are involved in applications of ideas and techniques of quantum information theory to advance our understanding of quantum gravity. We also expect that insight gained in quantum gravity will be useful in quantum computers and quantum cryptography.

2. Management System of the Research Organization

To secure success in the above research objectives, human resources are essential. We will maintain our high standard in searching and recruiting new faculty members and postdocs from all over the world. In 2021, the Kavli IPMU has launched the diversity initiative to promote the diversity and inclusion in our institute and spread successful practices within UTokyo and throughout Japan. We are currently reviewing both the PI system and the faculty system and will come up with a coherent personnel system and document them.

Currently, the Kavli IPMU is managed under the strong leadership of the Director. The steering committee chaired by the Director is its decision-making body on important matters such as faculty hiring and promotion. This top-down management structure allows timely decisions on recruitments, retentions, and resource allocations. The organization remains flat with no "departments" within the institute, and the directorate is always open to new initiatives from the individual faculty members. We intend to maintain this administrative structure in coming years.

As an important aspect of fostering and securing the next generation of researchers, recently we have established a new tenure track system. A tenure track assistant professor is hired for the initial seven years, and through the process of mid-term review and the following final review, the candidate can be promoted to a tenured associate professor. We are planning to form a standing committee to search for talented young researchers, especially female and under-represented minority researchers. We established the Kavli IPMU code of conduct to promote diversity and inclusion. This has inspired UTokyo to establish its own code of conduct.

We will continue our effort to recruit and retain top-level researchers by providing the excellent research environment.

3. Plan for Promoting the International Circulation of World's Best Brains

We will continue to require our postdocs to spend at least one month a year abroad, and we will also maintain our robust visitors program. Our annual postdoc search attracts about 700 applicants for about 12 postdoc positions. After they leave, they often keep connections with us via our affiliate members program.

4. Center's Position within the Host Institution and Measures to Provide IT with Resources

In March 2021, UTokyo approved our proposal to place the university funding for the Kavli IPMU in the core expenses category, at about 1 billion yen per year. Being part of the core expenses category means that the funding is permanent.

In the same month, UTIAS approved that the Kavli IPMU continue its state as a research organization within UTIAS. This ensures that the Kavli IPMU will be able to function as an incubator of system reforms within the University.

These actions reflect University's commitment to sustain the Kavli IPMU as a permanent institute, both in terms of finances and administrative arrangements. The Kavli IPMU has already secured 26 permanent positions for the core of faculty to guarantee excellent activities of the Kavli IPMU as it is. Most positions are assigned to core faculty. The University secured also 9 UTokyo permanent administrative staff. In addition, the university has decided that termed administrative staff should be hired as permanent positions, including bilingual staff so they can continue to support foreign researchers at the Kavli IPMU. In 2020, the Kavli Foundation decided to increase the Kavli IPMU endowment by $10 million, guaranteeing a stable source of discretionary research funding. The Kavli Foundation has also committed to provide matching fund up to $2 million to help fund raising of UTokyo for more support for the Kavli IPMU.

World Premier International Research Center Initiative (WPI)
Progress Report of the WPI Center
(For Final Evaluation)

Host Institution	The University of Tokyo	Host Institution Head	Makoto Gonokami
Research Center	Kavli Institute for the Physics and Mathematics of the Universe		
Center Director	Hirosi Ooguri	Administrative Director	Tomiyoshi Haruyama

Common Instructions:
* Unless otherwise specified, prepare this report based on the current (31 March 2021) situation of your WPI center.
* As a rule, keep the length of your report within the specified number of pages. (The attached forms are not included to this page count.)
* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.

1. Overall Image of Your Center (write within 2 pages including this page)

Describe the Center's current identity and overall image.
・ List the Principal Investigators in Appendix 2, and enter the number of center personnel in Appendix 3-1, 3-2, diagram the center's management system in Appendix 3-3, draw a campus map in Appendix 3-4, and enter project funding in Appendix 3-5, 3-6.

The Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) was proposed to address five fundamental questions about the Universe: how it began, what it is made of, what its fate is, what its fundamental laws are, and why we exist in it. We proposed to address these questions by combining mathematics, physics, and astronomy, employing accelerator-based experiments, underground experiments, and observations at telescopes, exactly as the name of the Institute suggests. This Institute did not exist before the WPI funding; it literally started from scratch. In 14 years, the Institute grew to approximately 330 people including graduate students and support staffs.

Overall, the Institute came out to be exactly as proposed. Our unique building allows mathematicians, physicists and astronomers to be located together, sharing seminars and the daily teatime. Interdisciplinary discussions have become a commonplace. The Institute is highly international; approximately half of the scientific members are not Japanese nationals. We were the first Japanese university department to name our institute after an overseas donor, Mr. Fred Kavli, which has helped raise our international visibility. Every member was hired under the leadership of the Director. The quality of the hires is evidenced by the fact that about 90% of our hiring postdocs have been offered positions at other excellent institutions after their term at the Kavli IPMU and 60% of them are on faculty positions. Our faculty members have been constantly wooed by other institutions in and outside Japan.

Many high impact papers with clear "made in the Kavli IPMU" brand have been produced. Our citation counts are comparable to other world-leading research institutions. Thanks to high profile papers and high international visibility, our members are invited to major conferences as keynote or summary speakers, including Strings, Lepton Photon, International Congress of Mathematicians, Neutrino, and Nobel Symposium. We advertise positions internationally and attract about 700 applications on average each year.

In addition to the five major questions, we proposed the following 9 challenges for the WPI funding extension period addressing new objectives.

(1) Creating new areas and tools of statistics, integrating mathematics with observation and experiments:

The JST CREST project "Statistical Computational Cosmology" led by N. Yoshida aims at developing fast imaging data analysis applications for the Subaru Hyper Suprime-Cam (HSC) survey. The team has developed an image analysis program that automatically detects supernovae out of numerous transient candidates in HSC survey data by using various machine-learning methods. To date they found 58 distant Type Ia supernovae invaluable to our cosmological analysis. The team has also performed an ensemble of cosmic structure formation simulations and developed an emulator enabling fast and accurate computations of statistics of spatial clustering to infer key cosmological parameters.

(2) Creating new synergies among fields not imagined at the launch:

The Kavli IPMU team led by T. Takahashi is performing interdisciplinary activities centered around the development of an advanced hard X-ray and gamma-ray detector in cooperation with National Cancer Center, Keio University School of Medicine, the Department of Medicine at Osaka University, RIKEN, and the Centre for Advanced Imaging at The University of Queensland. In vivo and three-dimensional gamma-ray imaging, which enables us to visualize and measure cell activity and biological processes, provides improved and novel methods for the diagnosis and treatment of cancer in the pre-clinical phase. The collaboration completed a successful clinical trial using a newly-developed imaging diagnosis device.

(3) Discovering new major frameworks for geometric thinking in mathematics and physics with the derived and noncommutative geometry, e.g., to unify various types of dualities:

Our mathematicians have advanced a new framework for geometric thinking with noncommutative and derived geometry. Y. Toda used non-commutative deformation spaces of coherent sheaves on Calabi-Yau varieties to give a natural construction of Gopakumar-Vafa invariants in string theory. He introduced a new

concept of derived critical loci to extend several fundamental results of birational geometry (such as wall-crossing equivalences) to a broad class of derived moduli spaces important in physics. M. Kapranov and E. Vasserot provided a definition and a study of the cohomological Hall algebra (COHA) for algebraic surfaces based on ideas of derived geometry. A. Bondal, M. Kapranov, and V. Schechtman interpreted the flop behavior of derived categories in terms of perverse schobers.

(4) Executing projects successfully to produce world-competitive results on dark energy, dark matter, and inflation:

The HSC team carries out a wide range of studies in various areas of astronomy and physics, including the search for new objects, studies about galaxy properties, and the reconstruction of 3D maps of dark matter revealed from the measurements of tiny gravitational lensing distortions of galaxy shapes. The HSC papers published in PASJ have received attention from the community and contributed to the highest impact factor that PASJ has ever achieved. The Prime Focus Spectrograph (PFS) team finished a successful engineering trial of the metrology camera, re-assembling the first spectrograph modules, and a successful installation of all the 2394 "Cobra" robotic fiber positioners over the Prime Focus Instrument's focal plane. Engineering observations are planned to start from fall 2021. M. Hartz serves as co-Analysis Coordinator of T2K experiments. The team measured the phase governing CP violation with high significance, and the result was published in Nature Journal. In May 2019, LiteBIRD, a CMB satellite mission led by M. Hazumi, was selected as the second ISAS/JAXA strategic large class mission. The Kavli IPMU team accelerated the design study. We also lead the major ground-based CMB experiments including POLARBEAR/Simons Array, and Simons Observatory and published many scientific papers. Belle II has launched a 10-year operation collecting e^+-e^- collision data using the silicon vertex detector partially produced at the Kavli IPMU. The Belle II team have started CP-asymmetry measurements. After 10 years of large scale R&D studies, EGADS team led by M. Vagins starts to dissolve gadolinium in the water inside Super-Kamiokande (SK), which will make previously-invisible neutrons visible and enables the world's first detection of the diffuse supernovae neutrino flux.

(5) Attracting and retaining the best and broadly-minded scientists from around the world.

We retained the best and open-minded scientists from around the world. All our 28 PIs, including 7 non-Japanese, are world-leading scientists and ensure an international environment for research activities at the Kavli IPMU. H. Ooguri was conferred the 2019 Medal of Honor with Purple Ribbon by the Emperor of Japan for his contribution to theory of elementary physics. H. Murayama has been appointed as a University Professor of UTokyo and also Hamamatsu Professor. T. Takahashi is performing a new interdisciplinary activity, applying hard X-ray and gamma ray detectors he developed to biomedical research. K. Martens was appointed the first non-Japanese Director of the Kamioka-branch, demonstrating the Kavli IPMU has established a truly international environment and support system. Other faculty members also play leading roles in each field including PIs of big international projects such as Belle II, T2K, EGADS, HSC, PFS, and LiteBIRD.

(6) Bringing successful system reforms to the rest of the University and other research institutions to help boost the overall competitiveness of Japan on a global scale:

The Kavli IPMU has led system reform in not only the University of Tokyo (UTokyo) but also National Universities at large. We made split appointments possible with institutions inside and outside Japan. We offer merit-based salaries. The Kavli IPMU has employed so-called "nenpo system", improving the mobility of the members. Kavli IPMU administrative staff members have been awarded the UTokyo's Special Prize for Business Transformation from the President six times and their development products have been requested by other organizations in the UTokyo.

(7) Attempting seriously to create a new international graduate program with vigorous student exchanges:

Faculty members of the Kavli IPMU supervised doctoral students in astrophysics or particle physics at the University of Oxford to conduct joint research. To date, we have accepted nine students and five have defended their Ph.D. theses. The Kavli IPMU also works with another international graduate program in physics (GSGC) and a new graduate program supported by WISE program of MEXT.

(8) Enlarging the force for outreach to young students by organizing workshops for scientists and high-school teachers:

Since inception, the Kavli IPMU has been very active in public outreach. We mobilize many thousands of people to our public lectures and events every year. We organize schools for high-school students, some of them dedicated to female students. Our members published popular science books with high impact approaching a million copies altogether. We believe we are helping the nation by attracting young minds to science, building a work force for the next generation. The Kavli IPMU continued collaboration with Consortium for Renovating Education of the Future (CoREF) to experience the latest advances in scientific research for high-school students.

(9) Attaining sufficient stability of the organization so that we can bring our research objectives beyond the WPI funding:

UTokyo created a new organization called University of Tokyo Institutes for Advanced Study (UTIAS) to house the Kavli IPMU as a permanent entity within the University. President's Action Plan "Vision 2020" emphasized the importance of "Expansion and Establishment of Internationally-renowned Bases for Research." The President recognized the Kavli IPMU perfectly matches his vision as a role model for the rest of the University. Based on this stance, UTokyo has put together a plan for the extension period and beyond the WPI funding. UTokyo has already provided 10 tenured positions, and permanent assignment of nine administrative staff members. Thanks to MEXT, from FY 2018, the 'university functionality boost' budget from MEXT for 13 positions and for operation has been approved to be a permanent budget. The University will maintain and hopefully expand the Kavli IPMU even after WPI support finishes.

2. Advancing Research of the Highest Global Level (within 15 pages)

2-1. Research results to date

Describe issues of a global level that the Center has challenged, and give the results. Select 20 representative results achieved during the period from 2007 through March 2021. Number them [1] to [20] and provide a description of each. Place an asterisk (*) in front of those results that could only have been achieved by a WPI center and explain the reason in the description.

- In Appendix 1-1, list the papers underscoring each research achievement (up to 40 papers) and provide a description of each of their significance. And in Appendix 1-4 list the center's research papers published in 2020.

2-1.0 The Big Picture

We proposed to address five basic and interrelated questions about the Universe:
(1) How did the Universe start?
(2) What is the Universe made of?
(3) What is the fate of the Universe?
(4) What are its fundamental laws?
(5) Why do we exist?

These questions clearly need a millennia time scale to be fully solved. The initial phase of the Institute focused on how to turn these big questions into well-defined specific scientific questions that can be addressed based on the combination of mathematics, theoretical physics, experimental physics, and astronomy in a relatively short time scale of a few decades. Therefore, the initial phase emphasized theoretical investigations and smaller projects to try out various directions, that gradually came to a well-defined strategy for major experimental and observational programs. Those projects conceived at the beginning are now producing data with much more coming in the next few years. We describe the accomplishments in this context. When we refer to papers in Appendix 1-1 (1-2), we use square brackets (curly braces) such as [2] ({3}) etc.

In addition to the five major questions that we proposed to address in our original plan in 2007, we have proposed the following 9 challenges for the extension period addressing new objectives. The progress is denoted as [(X) of 9 challenges].
(1) Create new areas and tools of statistics, integrating mathematics with observation and experiments;
(2) Create new synergies among the fields not imagined at the launch; and
(3) Discover new major frameworks for geometric thinking in mathematics and physics with the derived and noncommutative geometry, e.g., to unify various types of dualities.
We will achieve these goals building on the initial success by
(4) Executing projects successfully to produce world-competitive results on dark energy, dark matter, and inflation; and
(5) Attracting and retaining the best and broadly-minded scientists from around the world.
Concerning the system reform, we take up the challenge to
(6) Bring successful system reforms to the rest of the University and other research institutions to help boost the overall competitiveness of Japan on a global scale;
(7) Make a serious attempt to create a new international graduate program with vigorous student exchanges;
(8) Enlarge the force for outreach to young students, by organizing workshops for scientists and high-school teachers; and
(9) Attain sufficient stability of the organization so that we can bring our research objectives beyond the WPI funding.

We structure this report according to the five major questions as before, but we will make it clear how our progress addresses these nine challenges.

2-1.1 How did the Universe start?

This question is one of the most difficult problems, but we made some important progress. Based on the initial investigations, it became clear that this question has three parts.

(a) Primordial black holes (PBH), which might have formed in the early universe, are a promising candidate of dark matter. PBHs might be a lead to the formation of binary BH systems that are gravitational wave (GW) sources detected by the LIGO-Virgo observations. The connection of dark matter, GW sources, and also possibly supermassive BHs at galactic nuclei via PBHs is a very interesting idea, becoming one of the hottest topics in astrophysics and physics these past years. It overlaps significantly with the Question (2) 'What is the Universe made of?'
(b) The inflation that is believed to have expanded the initial microscopic Universe to a macroscopic one, while creating seeds of structure we see in galaxies today due to quantum fluctuations. We are leading major CMB experiments to test cosmic inflation and quantum gravity theories with unprecedented precision. At the same time, we consider possible alternatives to inflation.
(c) The subsequent evolution of the early Universe is governed by elementary particles, and many extensions of the currently accepted standard model of particle physics predict different behaviors,

especially with extra dimensions of spacetime or supersymmetry.

*[1] Primordial Black Holes

Since the discovery of gravitational waves from merging binary black holes by LIGO in 2015, primordial black holes (PBHs) have attracted renewed interest, not only as a possible candidate for those LIGO black holes but also as a candidate for dark matter of the universe. M. Sasaki has been leading an international study of PBHs and their observational signatures. With R.g. Cai and S. Pi, he showed that the gravitational waves induced by the curvature perturbation that lead to primordial black hole formation will be detected by the planned gravitational wave observatory in space, LISA, independently of primordial non-Gaussianities in the curvature perturbation, if primordial black holes are the cold dark matter of the universe [1].

An international team, led by M. Takada, H. Niikura (a former Ph.D. student) and N. Yasuda, carried out an observation of the Andromeda Galaxy (M31) to search for microlensing events of stars in M31 caused by PBHs. If dark matter consists of PBHs of masses lighter than the Moon, the team expected to find about 1000 microlensing events. However, the team identified only one possible candidate after a careful analysis. The team's results showed PBHs can contribute no more than 0.1 percent of all dark matter. The results correspond to the most stringent constraints on the abundance of PBHs [2] (see Fig. 1).

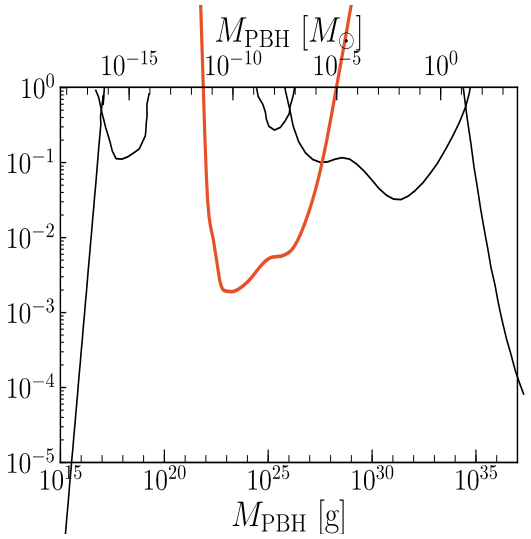

Fig. 1 Constraints on the mass fraction of PBHs to dark matter in the Milky Way and Andromeda Galaxy as a function of PBH mass. Shaded regions show excluded regions where existence of PBHs are not consistent with various observations. The red-color region shows the HSC microlensing constraints on the abundance of PBHs. The one-night HSC result gives the most stringent constraints for PBHs with masses lighter than the moon, e.g. compared to the NASA Kepler 2-year data.

The team also used the public 2622 microlensing events of the Optical Gravitational Lensing Experiment (OGLE). They showed that 6 ultrashort-timescale microlensing events can be explained by PBHs of Earth-mass scales. Interestingly, these OGLE ultrashort timescale events and the possible HSC microlensing event of M31 star can be explained by PBHs of the Earth-mass scale (H. Niikura, M. Takada, et al. 2019). These microlensing studies, carried out by the Kavli IPMU team, have received attention from the community and triggered a lot of discussion on PBH research.

*[2] B-Mode Polarization of Cosmic Microwave Background

Kavli IPMU members, M. Hazumi (joint appointment with KEK), N. Katayama, E. Komatsu, H. Sugai, T. Matsumura play active roles in the LiteBIRD Satellite mission. The objective of LiteBIRD is to test cosmic inflation and quantum gravity theories with unprecedented precision. With the mission's full success, it can discover direct evidence of cosmic inflation in any models within a broad class called "large field" model, and prove that the primordial gravitational wave originates in quantum fluctuations in the gravitational field. The Science Council of Japan selected the LiteBIRD project as one of the twenty-seven projects in the "Master Plan of Important Large Projects 2014", and it has received an "A" rating from MEXT. To realize this mission, the Kavli IPMU, Japan Aerospace Exploration Agency (JAXA), and High Energy Accelerator Research Organization (KEK) agreed that the Kavli IPMU would lead the scientific team and coordinate efforts to build the mission instrument while the project manager resided at JAXA and coordinated the LiteBIRD satellite project. In 2019, LiteBIRD was selected as the second ISAS/JAXA strategic large-class (L-class) mission with its expected launch in the late 2020s using JAXA's H3 rocket.

LiteBIRD is in the concept design phase. Despite facing various challenges due to COVID19 in 2020, we successfully pushed the projects forward under the new standard. The international partners, including CNES from France and ASI from Italy, have started their Phase-A. The US team is supported by the NASA Technology development funding. Progress on various science and technological fronts has been shared over online meetings. Even with limited access to the lab, the LiteBIRD team presented 13 instrumental development-related presentations and proceedings (4 are from Kavli IPMU lead projects) at the online SPIE conference 2020 [3]. The development of the analysis technique has been also pushed forward. In relation to the demanding calibration requirement to the polarization angle, Y. Minami and E. Komatsu have developed the technique to extract both the cosmological birefringent rotational angle and the instrumental angle offset simultaneously.

The Kavli IPMU CMB team also leads the major CMB ground-based experiments including POLARBEAR/Simons Array, and Simons Observatory. POLARBEAR has released 5 scientific papers. POLARBEAR2 receiver has been deployed and is now observing from Atacama, Chile. The team is actively participating in the Simons Observatory (SO) Small Aperture Telescope development and they successfully delivered the optics tube to the US SO team, which is to be integrated into the rest of the receiver system

and eventually be shipped to Chile for observations. In relations to these activities, they published 37 refereed papers during the WPI extension period [(4) of 9 challenges].

*[3] Pure Gravity Mediation and Theories of the Higgs Boson

The discovery of the Higgs boson in 2012 made researchers jump into action. The Kavli IPMU became known as one of the major centers of so-called "model building" activity in the world, aiming to propose a more natural and fundamental theory of elementary particles that govern the behavior of the early Universe. One major progress is the development of the pure gravity mediation (PGM) model that T. Yanagida found [4], which is now accepted as one of the prime candidates. The PGM model was built on the supersymmetric (SUSY) extension of the standard model (SM), based on studies done by the members of the Kavli IPMU, which would not have been possible without the WPI program.

2-1.2 What is the Universe made of?

We learned only in 2003 the composition of the Universe quantitatively, thanks to the results from the WMAP satellite based on the study of the anisotropy in cosmic microwave background. More than 80% of matter in the Universe is unknown kind dubbed dark matter, which was responsible for forming stars and galaxies from the seeds planted by inflation, and also touches on the question "Why do we exist?". Understanding the nature of dark matter has become the focus of this question. In particular, we aim at

(a) Understanding the dark matter properties from phenomenological studies
(b) Unraveling the nature of dark matter using the combination of astronomical data, underground direct detection experiment, indirect detection via cosmic rays, and particle accelerators.

In both questions, the combination of theoretical, observational, and experimental activities is crucial. Yet we made a conscious decision not to be involved in cosmic ray experiments, as we believed we could make a bigger impact on other areas.

*[4] Particle phenomenological studies of dark matters

A number of particle phenomenological studies at the Kavli IPMU are devoted to those of dark matters in various scenarios. Among those, the study of thermal dark matter candidates having weak-charges of the standard model (called EWIMPs), and that of light dark matters whose masses are much less than the electroweak scale (called LDMs) have been particularly developed, as summarized below in some detail.

・ Electroweakly Interacting Massive Particle (EWIMP) Dark Matter

Thermal dark matter candidates (WIMPs) are now being intensively searched for by collider experiments (e.g., LHC, Belle II), underground laboratories (e.g., XENON), and astrophysical observations (e.g., Fermi-LAT). Nevertheless, there are still many candidates that are not experimentally and observationally charted. Thermal dark matters having weak charges of the standard model (called EWIMPs) are such candidates. Because EWIMPs are predicted to be as heavy as O(1)TeV and highly degenerate in mass with their electroweak SU(2) partners, those are difficult to be detected. Several novel ideas have been proposed at the Kavli IPMU to overcome the difficulty. The first one is the indirect detection of EWIMPs by precisely measuring Drell-Yan processes for a lepton pair production at future collider experiments (e.g. HL-LHC, ILC, and 100TeV collider experiments) [5]. Second is a proposal of a novel algorithm to search for a disappearing charged track caused by EWIMPs at high-energy collider detectors [H. Fukuda et al. 2020]. Another is a proposal of the refinement of the dark matter density profile estimation of dwarf spheroidal galaxies to increase the sensitivity of the indirect dark matter detection utilizing gamma-rays from EWIMP annihilations at the dSphs {15}. Further studies on EWIMPs such as the freeze-out phenomenon (T. Binder et al., 2020) and the equation of state (S. Shirai et al., 2018, 2020) have also been developed and had a great impact on the particle physics community.

・ Light dark matters (LDMs): Light, Very light and Ultralight

Non-observation of robust WIMP dark matter signals renders us to consider different dark matter candidates; light dark matters whose masses are (much) smaller than those of traditional WIMPs. Many candidates of light dark matter as well as many methods to detect them were proposed at the Kavli IPMU, including light WIMP-like dark matters (S. Matsumoto et al., 2019; T. Yanagida et al, 2019), SIMP dark matters (H. Murayama et al., 2017, 2018, 2019), and resonant dark matters [6]. Those candidates attracted attention because these may have a large self-scattering cross-section that solves the so-called core-cusp problem. A novel idea of detecting a very light dark matter with mass eV to MeV was proposed in the study with chemists {16}, and theoretical frameworks to describe such detections were developed (T. Melia et al. 2017, 2019, 2020). For ultralight dark matter with mass much less than eV, various novel ideas to search for them were proposed and severe constraints were obtained using a Penning trap for axion spin-precession effects {17}, co-magnetometers (Y. Stadnik 2019) and torsion-pendulum experiments/atomic clocks/observation of atomic and molecular transition frequencies (Y. Stadnik 2020). These are from interdisciplinary studies with various fields such as atomic physics and astrophysics.

An international group including H. Murayama proposed a new class of dark matter theory that dark matter behaves very similar to pions, and interacts with itself [7]. This theory predicts the modification of mass distribution inside galaxies or clusters and resolves the discrepancy between observation and N-body

simulations. The theory can be tested by the Large Hadron Collider and SuperKEKB.

*[5] Dark Matter Detection

Y. Suzuki and his collaborators designed and built the XMASS experiment for direct detection of dark matter. After 4.4 calendar years, the single-phase liquid xenon XMASS-I experiment at the Kamioka Observatory successfully concluded its data taking campaign on Feb 20, 2019. The success of the XMASS collaboration is readily reflected, including three "Top 10% by citations" XMASS-I papers for citations in the period of April 2016 to Dec 2020 (Web of Science, Incites). On a different front, the XMASS collaboration showed the way with its lifetime limit on second two-neutrino double electron capture on ^{124}Xe and ^{126}Xe paper [8], which in 2019 was superseded by XENON-1T's Nature publication of the decay's observation, and a measurement of the associated lifetime - the longest lifetime measured directly so far. The XMASS collaboration published a total of 13 papers in scientific, peer-reviewed journals during the financial years from 2017 to 2020. Out of these, their results on dark photons and inelastic scattering on ^{129}Xe have also been the world's best until superseded by XENON-1T results.

With the final analyses of the XENON-1T data still ongoing, the XENON collaboration has commissioned new components to upgrade XENON-1T to the XENON-nT detector even in this time of a global pandemic. Under the leadership of K. Martens and S. Moriyama, the Japanese team is leading the world in liquid xenon dark matter searches. In upgrading XENON-1T to XENON-nT there were two items where their specific Japanese expertise was crucial: In achieving > 7 millisecond lifetime for drifting electrons through xenon purification in the liquid phase, and in providing an effective neutron veto encapsulating the target mass' cryostat. For the latter, the XENON collaboration adopted the proposal to use the gadolinium sulfate loaded water Cherenkov technology proposed and developed for Super-Kamiokande at the Kamioka Observatory by M. Vagins. One of the first things to address with new data from XENON-nT is the XENON-1T low energy electron recoil excess shown in Fig. 2 [9] [(4) of 9 challenges].

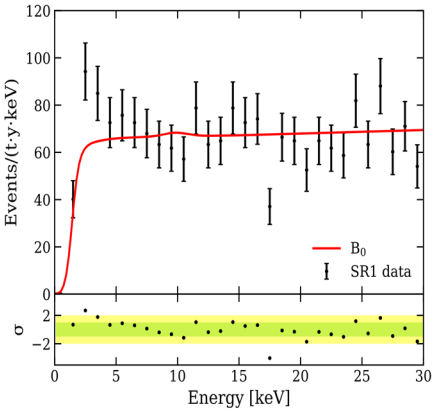

Fig. 2 The Science Run 1 (SR1) data of XENON-1T display an excess between 2 and 3keV over the background model B_0 at the level of 3 σ .

2-1.3 What is the fate of the Universe?

It was discovered in 1998 that the expansion of the Universe is accelerating. It is attributed to yet another mysterious component of the Universe called dark energy. The fate of the Universe hinges on the nature of dark energy, and therefore to understand its nature has become the focus for this question. We need to

(a) Consider theoretical possibilities for the origin of current accelerated expansion
(b) Discriminate among them using astronomical observations including SuMIRe projects.

*[6] Cosmic Acceleration

The discovery of accelerated expansion of the recent universe poses one of the most fundamental questions in physics and cosmology. The popular way to incorporate dark energy into theory of gravity is via Einstein's cosmological constant. However, its value must be 120 orders of magnitude smaller than what is naturally expected. An alternative description of dark energy may be necessary by modifying Einstein's theory of gravity. On the theoretical side, whether there exists such a consistent extension of general relativity by a mass term is an important question in classical field theory. Massive gravity is one of the most interesting attempts in this direction. S. Mukohyama initiated a new search for consistent theories and cosmological solutions in massive gravity, including an extension of quasi-dilatonic massive gravity by A. De Felice and S. Mukohyama, stable de Sitter solutions in rotation-invariant massive gravity by D. Langlois, S. Mukohyama, R. Namba and A. Naruko, and the minimal theory of massive gravity by A. De Felice and S. Mukohyama.

Galaxy redshift survey provides a unique observational tool to measure the growth of large-scale structure, which is sensitive to the nature of gravity. FastSound is a galaxy redshift survey using Subaru Fiber Multi-Object Spectrograph (FMOS) instrument (N. Tamura is one of the builders) aiming to make a 3D map of the universe in the redshift range from 1.2 to 1.5. T. Okumura, C. Hikage and T. Totani analyzed the clustering and motion of FastSound galaxies and tested general relativity on cosmological scales for the first time [10]. The result indicates that general relativity is valid even far into the universe. This work is a pilot study toward a precision test of gravity theory in SuMIRe project.

One major focus of the PFS survey is to see whether dark energy evolves with time. The survey will allow for model-independent measurement of its time evolution up to redshift beyond z=2. Thanks to the de Sitter swampland conjecture by H. Ooguri, this has become a very hot subject. H. Murayama proposed a refinement of the de Sitter swampland conjecture in a way consistent with experimental constraints, yet leaving room for future observational evidence {8}.

The HSC team led by N. Yasuda and N. Suzuki executed two seasons of the Subaru Hyper-Suprime Cam (HSC) Transient survey in 2016-2020 for a precise measurement of dark energy with Type Ia supernova (SNeIa) [11]. Despite a series of incidents such as volcano eruption, they completed the supernova survey in Feb 2020, observing more than 100 supernovae beyond redshift one as they had promised. A photometric follow-up in infrared was done with the Hubble Space Telescope (PI: N. Suzuki), and more than 3 dozens of the best SNeIa were found (Fig. 3). Spectroscopic follow-up observations are underway with Keck, Gemini, VLT, Subaru/FOCAS, GTC and AAT. The observations were halted due to COVID-19 but were recently resumed. They are collecting redshifts from host galaxies. Thanks to the large number of SNeIa and the high data quality, the result will be the most precise measurement of dark energy. If dark energy changes in time, they would be the first to see it [(4) of 9 challenges].

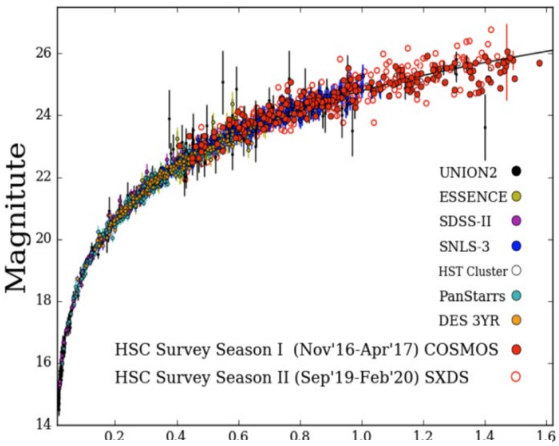

Fig. 3 It shows the HSC SNeIa (red) dominates the high-redshift regions where cosmological parameters become very sensitive.

* [7] SuMIRe: HSC and PFS

The Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) team has been carrying out a large-scale imaging survey of the Universe with the Subaru HSC since 2014. The HSC-SSP survey takes advantage of the unique HSC's capability to carry out multi-color imaging observations of the sky over a wide solid angle of the sky. The HSC team used the first-year data of the HSC-SSP survey to carry out a wide range of studies in various areas of astronomy and physics, including the search for new objects in the solar system and the dark matter distribution revealed by measuring tiny gravitational lensing distortions of galaxy shapes. They reported 40 papers in the special issue of the Publications of the Astronomical Society of Japan (PASJ) in 2018. Kavli IPMU PI M. Takada, who is the Science Working Group co-chair of the HSC Project, together with M. Strauss (Princeton University), led the writing of the overview paper of the HSC-SSP survey [12]. The HSC-SSP team published the reduced data and the catalog of objects (Fig. 4, so far, the team made the public data release twice, PDR1 in 2018 and PDR2). The HSC data has been widely used in astronomical communities.

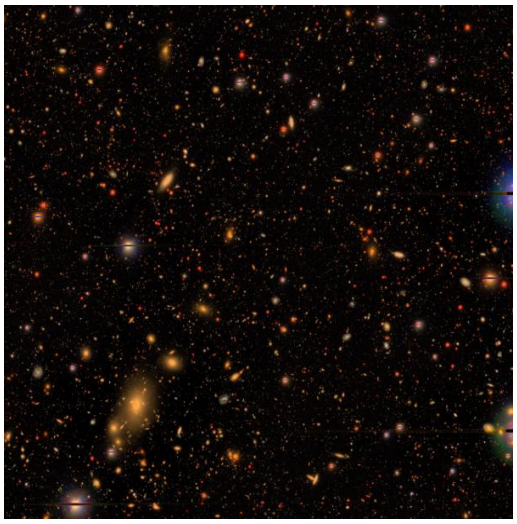
Fig. 4 A color composite image in the g, r and i bands of a small piece of the COSMOS field, as imaged by the HSC. This image contains thousands of galaxies as faint as 27th magnitude. These HSC data and galaxy catalogs are made public to the world.

A team led by M. Oguri used the weak lensing measurement to reconstruct 2- and 3-dimensional maps of dark matter over an unprecedented area with an unprecedented spatial resolution. As one of the 3 dimensions is time, the result reveals the time evolution of dark matter distribution over 8 billion years of cosmic history [Fig. 5, M. Oguri et al. 2018]. An international team led by C. Hikage and M. Oguri used the multi-color data from the first two years over 137 sq. deg. of the HSC survey to carry out a high-precision measurement of cosmic weak lensing power spectra. The team used the measurements to explore how cosmic large-scale structures evolve as a function of cosmic time and then determined the parameter $S_8=0.800^{+0.029}_{-0.028}$ to about 3.6% fractional precision that characterizes the clumpiness of the Universe today. The value is similar to those indicated by other weak lensing experiments such as Dark Energy Survey and Kilo-Degree Survey, but slightly lower than that obtained

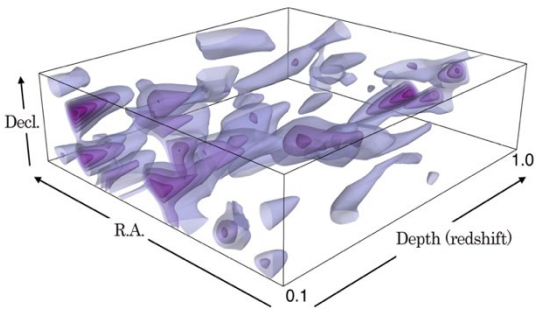

Fig. 5 3D dark matter distribution obtained from weak lensing measurements of the HSC-SSP data. Darker colors indicate higher density.

by the Planck CMB experiments. This small inconsistency might be a sign of new physics beyond the standard ΛCDM model [13]. The team was awarded the 2020 PASJ excellent paper award. The HSC papers published in PASJ received a lot of attention from the community, and contributed to the highest impact factor PASJ has ever achieved [(4) of 9 challenges].

The Kavli IPMU also made progress in a major astronomical instrument called Prime Focus Spectrograph (PFS), a next-generation instrument on the Subaru Telescope. It is a very wide-field, massively multiplexed, and optical & near-infrared spectrograph. A 360-night observation campaign with PFS is being planned as part of SSP. Kavli IPMU is the leading institute of the international collaboration consisting of researchers from tens of research institutes in 7 countries, in both aspects of the instrumentation and survey planning, with H. Murayama as PI, M. Takada as Project Scientist, N. Tamura as Project Manager/Systems Engineer, and Y. Moritani and K. Yabe as the core members in the project office.

The instrumentation is in the phase to actively integrate and test the hardware and software of the subsystems, but some of them have already been delivered to the Subaru Telescope observatory in Hawaii, allowing system integration to be carried out simultaneously. In 2018, Metrology Camera System was delivered from ASIAA in Taiwan and successfully tested on the telescope through the nighttime engineering runs. In 2019-2020, the first spectrograph module with visible cameras was delivered from LAM in France and the performance was fully confirmed. In Sep 2020, all 2394 "Cobra" robotic fiber positioners were fully installed over the focal plane of Prime Focus Instrument (PFI) (Fig. 6). The first fiber cable connecting PFI and Spectrograph System was delivered to Subaru and was successfully installed in Feb. 2021. We managed to install a dedicated little telescope system on the Subaru Telescope that feeds light from the sky to the PFS fiber cable and the spectrograph module. We plan to start on-sky engineering observations from fall 2021. In parallel to these instrumentation activities, the PFS science working group, led by the co-chairs M. Takada and R. Ellis (UCL), have been working on the PFS SSP survey design and feasibility studies in three scientific themes: cosmology, Galactic archaeology and galaxy evolution.

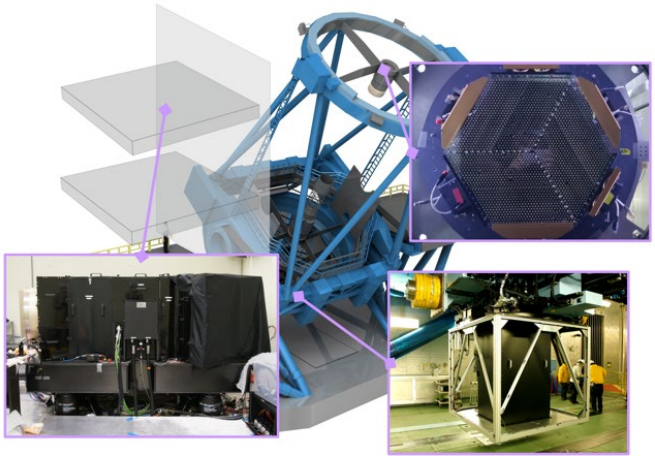

Fig. 6 Components of PFS on the Subaru Telescope: the hexagonal focal plane of PFI with 2394 Cobra fiber positioners (upper-right), the first spectrograph module fully reassembled in a Subaru building (lower-left), and the metrology camera (lower right). (Credit: PFS Project)

As we are approaching the period of on-sky engineering observations, the start of science operation, and thus the start of the PFS SSP survey, interplays between the science and technical teams are vital for basic performances, and other detailed characteristics of the instrument, as well as mutually optimizing the software components, data flow, and survey management. Kavli IPMU members will play key roles both in the integration and commissioning of the PFS instrument and in the coagulation of the entire collaboration during the coming key phases of the project [(4) of 9 challenges].

2-1.4 What are its fundamental laws?

This question touches on all the other questions. Our focus here is the tight connection between mathematics and physical theories such as string theory. Given the unusual structure of the Institute where physicists and mathematicians share the same building and daily research activities, we have mutual stimulation to make progress in developing new mathematics and new physical theories. At the same time, the lessons gained in this activity have applications in other areas of science, such as condensed matter physics.

*[8] Derived Category of Coherent Sheaves and Counting Invariants

Algebraic Geometry is a field in which we study geometric objects (called algebraic varieties) defined as the solution spaces of polynomial equations. In particular, the 3-dimensional Calabi-Yau (CY) manifold appears as extra dimensions in string theory. The derived category of coherent sheaves on an algebraic variety is the category consisting of bounded complexes of holomorphic vector bundles on it. It gives a mathematical formulation of D-branes in Type II-B string theory. Among others, Kontsevich's Homological mirror symmetry conjecture was found based on the ideas from string theory. This is an amazing conjecture relating different kinds of geometry, algebraic geometry and symplectic geometry.

In 2002, Bridgeland introduced the notion of stability conditions on derived categories, which gives the notion of semistable objects in the derived category. It is known that the set of stability conditions on the derived category forms a complex manifold, which is expected to be related to the moduli space of complex structures on its mirror manifold. However, this space is quite difficult to study. In particular, the existence

of a stability condition on a CY 3-fold is not known. In 1998, Thomas introduced the invariants counting stable coherent sheaves on CY 3-folds, as a higher dimensional analog of Donaldson invariants on algebraic surfaces (called DT invariants). The DT invariants correspond to counting BPS states in string theory. In 2003, Maulik-Nekrasov-Okounkov-Pandharipande (MNOP) conjectured that the rank one DT invariants are equivalent to GW invariants, the invariants counting world sheet in string theory. For conjecture to make sense, MNOP also conjectured (called rationality conjecture) that the generating series of rank one DT invariants is a rational function with a certain automorphic property. Moreover, in 2007, Pandharipande-Thomas (PT) introduced the notion of stable pairs on CY 3-folds and conjectured that invariants counting stable pairs are equivalent to rank one DT invariants.

Y. Toda applied the idea of Bridgeland stability conditions to the study of DT invariants, especially the MNOP conjecture. He has developed moduli theories of semistable objects in the derived category and constructed DT type invariants counting semistable objects in the derived category. By studying the dependence of these invariants under a change of stability conditions, he proved a version of conjectures on DT invariants, MNOP rationality conjecture, etc. [Y. Toda, (2010)]. Also, his study of stability conditions led to a conjectural Bogomolov-Gieseker type inequality for Chern characters of certain two-term complexes, which tuned out to connect classical and modern problems in algebraic geometry [14]. Further, Y. Toda developed Gopakumar-Vafa (GV) invariants for CY 3-folds and 4-folds. The GV invariants were suggested by the physicists R. Gopakumar and C. Vafa around 1998, but their precise mathematical definition had been missing for almost 20 years. In the joint work with D. Maulik, Y. Toda proposed a mathematical definition of GV invariants on CY 3-folds and formulated several conjectures relating them to Gromov-Witten invariants and PT invariants [15] [(3) of 9 challenges].

*[9] Langlands Correspondence and p-adic Cohomology Theory

The history of arithmetic geometry began with A. Weil. His conjecture implied that the world of varieties over finite fields, which is a priori far from the one we live, has similar topological structure. Motivated by it, A. Grothendieck constructed cohomology theories for such varieties: ℓ-adic étale cohomology for any prime number ℓ different from the characteristic p of the finite field we fixed, and crystalline cohomology (p-adic theory). The ℓ-adic cohomology theory can be seen as an analog of singular cohomology theory, with which we may extract the topological structure. In the complex geometry, singular cohomology can also be computed by using differential forms: de Rham cohomology. An analogy of this somewhat differential geometric approach is the p-adic cohomology theory.

Given that there are infinitely many cohomology theories, what are the relations among them? Influenced by the Langlands correspondence (LC), P. Deligne proposed a conjecture on the existence of ℓ-adic and crystalline "companion" in his "Weil II", one of the most influential papers in mathematics. This conjecture roughly states that no matter which cohomology theory we use, the cohomological information is essentially the same. The existence of ℓ-adic companion in the curve case was shown partly by Drinfeld and fully by Lafforgue by establishing LC for function fields. Both of them were awarded the Fields Medal. Using this result, later on, P. Deligne and Drinfeld constructed the ℓ-adic companion for more general varieties, even though there are still some cases yet to be treated. T. Abe's main achievement was to establish an analog of LC for the p-adic theory, and showed the existence of crystalline companion in the curve case [16]. On one hand, his results complete the foundation of p-adic cohomology theory. On the other, it opens a door to investigate "motivic property" of varieties over finite fields by means of p-adic differential equations, category of which is much wider than that of ℓ-adic objects.

One of the current issues is to establish a theory of characteristic cycles (of ℓ-adic sheaves) from a homotopical point of view. As an application of this approach, T. Abe expects that the pushforward formula of characteristic cycles, conjectured by T. Saito and one of the most fundamental conjectures in the field, follows. To advance in this direction, as a first step, T. Abe established an infinity-enriched bivariant homology theory in 2020 [17].

*[10] Primitive Forms and Mirror Symmetry

The study of period integrals over elliptic and higher genus Riemann surfaces, started by Euler and developed by Abel, Jacobi, Gauss and Riemann, is a classic in mathematics. Primitive form was introduced as a higher dimensional theory of period integrals for vanishing cycles at an isolated critical point of a function F (K. Saito 1983). It turns out that the theory of primitive forms for a function F is relevant in the complex geometric (B-model) aspects of N=(2,2) supersymmetric Landau-Ginzburg (LG) theory in physics, having F as its superpotential. Thus, it became of common interest for physicists and mathematicians.

The dualities between different string models in physics give strong non-perturbative means to calculate the partition functions. For instance, Witten showed that the LG model and the sigma-model on a Calabi-Yau (CY) manifold give different phases of the same physics. The mirror symmetry (worked out by physicists K. Hori, C. Vafa, et al.) is one of the dualities, which has a strong impact on mathematics, since it predicts an unexpected duality between complex geometry and symplectic geometry. Progress on this subject took place at the Kavli IPMU, and the LG-LG mirror symmetry was confirmed using primitive forms.

At a Math-String seminar, K. Hori and K. Saito made it clear that the primitive form theory is mirror dual

to the symplectic geometric (A-model) theories such as GW theory of a compact Kähler manifold or Fan-Jarvis-Ruan-Witten (FJRW) theory of a LG orbifold (2013).

T. Milanov and B. Bakalov proposed a W-algebra to compute the invariants defined by Givental's higher genus reconstruction in terms of a certain explicit (monodromy) discrete data. Inspired by the work of two physicists B. Eynard and N. Orantin, T. Milanov worked on developing a new method to construct states in the W-algebra [18]. So far, he has only had partial success, but the idea to use the topological recursion of Eynard and Orantin is completely new. The subject is very rich with many interesting problems to investigate. One of the problems is if the correlators defined by the topological recursion of Eynard–Orantin define a Frobenius manifold structure. The answer is that if we allow a spectral curve which is a compact Riemann surface, then the only Frobenius manifolds that can be obtained from the topological recursion are Dubrovin's Hurwitz Frobenius manifolds. T. Milanov proved that the quantum cohomology of P^2 can be identified with a quotient of an open domain in the cohomology of P^2 by the monodromy group of the quantum cohomology, that is, $PSL_2(Z)$, and obtained a natural candidate for a spectral curve, that is, the preimage under the quotient map of the so-called primitive direction in quantum cohomology. I.e., the one-dimensional linear subspace spanned by the unit in quantum cohomology [19].

*[11] Secondary Polytopes and the Algebra of the Infrared

M. Kapranov studies categorical and sheaf-theoretical structures motivated by quantum field theory. Gaiotto, Moore and Witten exhibited algebraic structures governing the behavior of 2-dimensional physical theories in the "infrared" regime. Working with M. Kontsevich and Y. Soibelman, M. Kapranov was able to relate these structures with more traditional mathematical concepts of secondary polytopes, such as convexity, triangulations, discriminants. Related is the theory of perverse sheaves which are topological counterparts of holonomic systems of linear Partial Differential Equations. The data provided by a Landau–Ginzburg model (the set of vacua, the set of instantons connecting the vacua) can be seen as defining a categorical analog of a perverse sheaf, which is called a perverse Schober by M. Kapranov and V. Schechtman. They classified perverse sheaves on hyperplane arrangements in terms of certain diagrams of vector spaces which were a motivation for developing this categorical analog [20].

M. Kapranov developed several applications of the formalism of factorization algebras to algebraic geometry, based on the concept of factorization homology originated from quantum field theory. With B. Hennion, he proved a longstanding conjecture of B. Feigin on Lie algebra cohomology of the algebra of vector field on an affine algebraic variety, thus providing an algebro-geometric generalization of the classical Gelfand–Fuchs theory [B. Hennion, M. Kapranov, arXiv: 1811.05032]. With E. Vasserot, M. Kapranov determined the structure of the cohomological Hall algebra of 0-dimensional coherent sheaves on the affine plane, establishing a Poincare–Birkhoff–Witt result [M. Kapranov, E. Vasserot, arXiv:1901.07641]. Working with V. Schechtman, M. Kapranov related Hopf algebras with perverse sheaves on configuration spaces, first relating graded Hopf algebras with factorizable perverse sheaves and then extracting the abstract universal "skeleton" whose graded components can be related to individual configuration spaces [21] [(3) of 9 challenges].

H. Nakajima, Professor at the Kavli IPMU since 2018, studied partial resolutions of singularities of Coulomb branches arising from flavor symmetry with A. Braverman and M. Finkelberg. In particular, he determined them for Coulomb branches of quiver gauge theories in the following cases: For type ADE, they are convolution diagrams for slices in the affine Grassmannian. For affine type A, they are resolutions given by GIT quotients of bow varieties. He proposed a conjecture realizing geometric Satake correspondence for general Kac-Moody Lie algebras via Coulomb branches. This conjecture was proved for affine type A [22].

*[12] Discovery of New Connections between Geometry, Finite Group and Information Theory

Our notion of geometry is undergoing dramatic changes in string theory and quantum gravity. In string theory, fundamental building blocks are one-dimensional objects rather than point particles. In quantum gravity, geometry is part of quantum degrees of freedom and quantum mechanically uncertain. Researchers at the Kavli IPMU are developing mathematical tools to study new concepts in geometry.

In [23], H. Ooguri and M. Yamazaki (then Ooguri's student, now faculty at the Kavli IPMU) introduced a new perspective on geometry by showing how Calabi-Yau manifolds emerge from the thermodynamic limit of the statistical mechanical model of crystal melting. H. Ooguri has been exploring a new connection between the holography of quantum gravity and information theory. In information theory, entropy inequalities play important roles to quantify the efficiency of information processing tasks. H. Ooguri and his collaborators showed that some of these inequalities can be interpreted as positive energy conditions in gravitational systems which are often postulated in general relativity to prove various theorems (J. Lin et al. 2015). Here, H. Ooguri et al. showed that some of these conditions are consequences of the consistency of quantum gravity theory. The work has also shed light on how local geometry emerges in the holography.

*[13] Supersymmetric Gauge Theories

L. F. Alday, D. Gaiotto, and Y. Tachikawa proposed the so-called Alday-Gaiotto-Tachikawa conjecture in 2009. This conjecture was first phrased in the theoretical physics language, but it was soon reformulated as a precise mathematical conjecture. Large parts of it have been rigorously proven since then. It was originally considered for a restricted class of groups, and the work contains a big step toward the understanding of the general case. As another example of the interplay between physics and mathematics, O. Aharony, N. Seiberg, and Y. Tachikawa found hitherto neglected discrete parameters in general gauge theories [24]. These new parameters are best described in terms of the cohomology of the classifying spaces, a subject intensely studied in algebraic topology, but was rarely used in physics thus far. So it was greatly helpful that Y. Tachikawa could directly ask mathematicians, and could consult books at the Kavli IPMU library, which has a comprehensive coverage of all areas of mathematics.

Then Y. Tachikawa started to shift his focus on the topological properties of more general quantum field theories, the study of which has been influenced greatly by the recent developments in the condensed matter physics of the theory of topological phases of matter. The techniques introduced there, when appropriately developed further, can be used to uncover various subtle features of quantum field theories which could not be seen in the past. For example, the so-called duality symmetry of electromagnetism, exchanging electric and magnetic charges, was shown to have a subtle anomaly [C.-T. Hsieh, Y. Tachikawa, K. Yonekura 2019]. As another example, he studied what happens when a finite subgroup of a larger symmetry group is gauged [Y. Tachikawa 2020]. The gauging of a finite group has been one of the fundamental techniques in low-dimensional quantum field theories, but somehow its effect when the group being gauged is a subgroup of a larger one has not been systematically explored, and whose importance was demonstrated in a couple of recent papers on topological phases of matter [Y. Tachikawa 2020].

*[14] Methods in Quantum Field Theory and String Theory

H. Ooguri investigated various aspects of quantum field theory and quantum gravity. He wrote a 175-page paper to be published in Communications in Mathematical Physics, in which he and D. Harlow presented a mathematical proof of one of the fundamental theorems in quantum gravity that there is no global symmetry in a consistent quantum theory of gravity [D. Harlow, H. Ooguri, arXiv:1810.05338]. This theorem had been conjectured for over half a century, but no definite proof had been given until their paper. The proof makes use of ideas from quantum information theory, in particular theory of quantum error correcting codes. The short announcement of their result was published in Physical Review Letters as Editors' Suggestion [25]. H. Ooguri also proposed a new type of constraints on the potential energy in any consistent quantum theory of gravity, called the swampland conjecture, with G. Obied and C. Vafa at Harvard, and H. Ooguri's Caltech student, L. Spodyneiko [26]. This paper turned out to be the most cited one in elementary particle theory in 2018, according to the INSPIRE database at SLAC-Stanford. H. Ooguri also published papers about mathematical properties of quantum field theories with conformal symmetry, and has developed theoretical tools to study these theories. One is about the singularity of the Green function in a black hole geometry, caused by light-like geodesics near the photon sphere of the black hole, and how the singularity is resolved in string theory. This work was inspired by the recent image of the black hole at the center of Galaxy Messier 87 by the Event Horizon Telescope.

S. Hellerman works on the systematic analysis of strongly coupled quantum field theories in states of large quantum number, under some global symmetry. Following up on work done in 2015 (with S. Reffert, D. Orlando, and M. Watanabe), they found quite generally that the inverse quantum number can be used as a parameter for a controlled perturbation theory even when the underlying theory has no weak-coupling expansion of its own.

T. Melia has discovered new insights into the structure of effective field theory (EFT), centered around the introduction of a partition function to understand a fundamental feature of any EFT: the set of independent physical measurements within the theory. Understanding the possible measurements one can make has practical phenomenological importance. For example, establishing this for the standard model (SM) EFT—an important framework in which to search for signs of new physics at the Large Hadron Collider—was, with techniques at the time, a notoriously difficult problem with a history stretching back to the 1980s. T. Melia's work has systematized such calculations once and for all [27]. Furthermore, it has developed a multifaceted picture by drawing from different areas of mathematics (conformal representation theory, commutative algebra, cohomology) and has reimagined our way of thinking about EFT. His work that focused on systematically constructing operators in EFT revealed a geometric nature to the problem, and identified a natural set of operators for relativistic EFTs to be the harmonics of a surface known as a Stiefel manifold. His work studying the asymptotic behavior of Hilbert series led to fundamental formulae that capture the growth of the 'number of partitions of the SM', similar to the Hardy-Ramanujan formulae for the growth of the number of integer partitions.

*[15] F-Theory: Its Phenomenology Applications and Duality

T. Watari has been addressing the fundamental laws by using one of the formulations of string theory called F-theory, since his earlier paper in 2006 (*Nucl. Phys*. B747, 212). It was difficult, however, to deal with such mathematics as singular geometry and sheaf cohomology which are an essential part of the F-

theory. A few physics-math collaborations had been formed around the world to address these questions by the beginning of 2008. Physicists and mathematicians at the Kavli IPMU set up one of such teams. They employed string duality between F-theory and Heterotic string, and based on mathematical computations using Heterotic string and also by refining string duality, it was shown that quarks and leptons are described by smooth sections of line bundles in F-theory, despite the presence of singularities in the geometry [28].

T. Watari and his Ph.D. students worked on the classification of Heterotic–Type IIA string dual vacua with SO(3,1) Lorentz symmetry and N=2 supersymmetry. They pointed out that the absence of Witten's SU(2) anomaly does not follow automatically, when we only require modular invariance of the new supersymmetric index and the new classification invariant [29]. They also revisited a nearly forgotten (and the only ever known) idea for how to get the cosmological constant and gravitino mass small in flux compactification. They have found a way to construct flux vacua with zero cosmological constant and gravitino mass along with that idea in Type IIB string [29] and in F-theory.

*[16] Application to Condensed Matter Physics

One of the most remarkable and surprising achievements in string theory is the AdS/CFT (anti de-Sitter/conformal field theory) correspondence. The AdS/CFT correspondence and its generalization argue that quantum gravity (or string theory) in a certain spacetime is equivalent to a quantum field theory that lives on its boundary. This reveals a remarkable fact that gravity can be rewritten as a theory without gravity, the so-called holographic principle. This radically changes our idea of gravity and spacetime. This will be crucial to understand Planck scale physics, which is responsible for the origin of our Universe.

The AdS/CFT correspondence offers us a very convenient method to study strongly interacting quantum systems. This is because when quantum gravity effects are suppressed, the string theory becomes equivalent to strongly coupled gauge theories according to the AdS/CFT. This allows us various applications of AdS/CFT to various problems in condensed matter systems. One of the most interesting problems in condensed matter physics is the high T_c superconductors. There exists a special metallic phase when one heats up a high T_c superconductor, called the strange metal phase which differs from the standard metal (Landau Fermi liquids). N. Ogawa, T. Ugajin and T. Takayanagi succeeded in their systematic study of strange metal phases by using AdS/CFT [30]. They proved that a metallic phase always becomes a strange metal in strongly coupled large N gauge theories by introducing a novel quantity called entanglement entropy. Since this paper initiated an application of holographic entanglement entropy to condensed matter physics, it has been appreciated internationally and has earned more than 230 citations based on INSPIRE database.

2-1.5 Why do we exist?

This is a complex and rich question. We see the following concrete approaches to address it:

(a) Origin of asymmetry between matter and anti-matter. It may come either from neutrinos or the quark sector.
(b) Formation of stars and galaxies and their subsequent evolution.
(c) Assembly of galaxies from smaller objects.
(d) Planet formation.

Even though all of these are exciting subjects, we made a conscious decision to leave out (d) because we cannot cover everything. The area (c) was initially not anticipated, but as a result of initial investigations, large-scale survey instruments such as SuMIRe discussed earlier can address (b) and (c) at the same time, and hence (c) is now included in our strategy.

The origin of matter, namely the asymmetry between matter and anti-matter, is central to one of the five questions of Kavli IPMU "Why do we exist?" Arguably the leading theory proposed by T. Yanagida and M. Fukugita associates its origin with the origin of neutrino mass. Yet this theory eluded experimental and observational tests so far due to the very high energy scale relevant for the theory. H. Murayama pointed out that gravitational waves would provide a promising signal, where algebraic topology pointed to new patterns of topological defects that lead to discernible signatures in the gravitational wave spectrum {9}.

*[17] Studying neutrino physics with T2K and Hyper-K experiments, and CP violation with Belle II

The Tokai-to-Kamioka (T2K) experiment studies neutrino oscillation using beams of neutrinos and antineutrinos produced at the J-PARC accelerator and detected 295 km away in the Super-

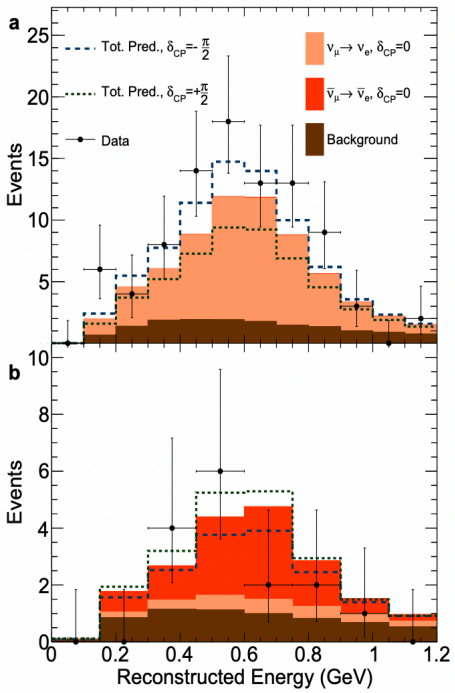

Fig. 7 Observed spectra for electron neutrinos (top) and electron antineutrinos (bottom) from T2K data.

Kamiokande (SK) detector. T2K compares the rate of muon neutrino to electron neutrino oscillations with the rate of muon antineutrino to electron antineutrino oscillations. A difference in the oscillation rates for these neutrinos and antineutrinos would be evidence of CP violation in the lepton sector [31]. T2K has continued to produce the most precise measurements of neutrino oscillations, with significant new antineutrino data collected in 2017-2018, and new neutrino data collected in 2019-2020. With this data, T2K has world-leading sensitivity to neutrino oscillation parameter measurements. The measurement of the CP violation parameter using this new data was published in Nature [32] with the corresponding author being our faculty M. Hartz. As shown in Fig. 7, the data observed by T2K is most consistent with a value for the CP violation governing parameter, δ_{cp}, of $-\pi/2$, which gives the maximum CP violation.

The T2K measurement shows a preference for significant CP violation. The Kavli IPMU has focused its efforts to enhance the T2K data analysis and prepare the experiment for operation at higher beam powers. Oxford-Kavli IPMU graduate student T. Vladisavljevic completed his thesis in 2019 in which he reduced the uncertainty on the calculation of the neutrino production for T2K by a factor of ~2 from 10% to 5%, and this result was included in the neutrino oscillation measurements presented by T2K at Neutrino 2020 [(4) of 9 challenges].

The Hyper-Kamiokande (Hyper-K) project has moved from the proposal phase to approval. The Kavli IPMU, through faculty M. Hartz and M. Vagins, has been involved in the development of the project. M. Vagins has served as one of the leaders of the water system working group for Hyper-K, while considering the application of gadolinium loading in Hyper-K. M. Hartz took part in investigating a second Hyper-K detector located in South Korea [K. Abe et al. 2018]. The intermediate water Cherenkov Detector (IWCD) will have the unique capability to be moved vertically in the neutrino beam at J-PARC, allowing a range of neutrino energy spectra to be studied. The design of the IWCD is now being refined, including the preparation of a technical design report in 2020. The IWCD uses a multi PMT photosensor, where each module contains 19 8-cm diameter photomultiplier tubes (PMTs). The Kavli IPMU has housed the PMT testing lab that has been used by a number of Hyper-K collaborators, including those from Tokyo University of Science and Tokyo Institute of Technology. Oxford-Kavli IPMU student L. Cook carried out the pressure testing for the multi-PMT vessel at Kamioka mine, using custom-made Arduino-based readout of dial gauges to measure displacement and strain on the vessel [K. Abe et al. 2018] [(4) of 9 challenges].

The Kavli IPMU is a collaborating institute of the Belle II experiment at KEK, Japan, which is a high-energy electron-positron collider experiment searching for new physics beyond the Standard Model. The CP asymmetries, which are good probes for new physics, manifest themselves in the distributions of B-meson decay positions (decay vertices). In order to fully understand the Silicon Vertex Detector (SVD) behavior and to utilize the understanding in precise measurement of the CP asymmetries, the team led by T. Higuchi contributed to the production of Belle II SVD modules and commissioning of constructed SVD from the modules (Fig. 8). The module-production project started in the Kavli IPMU in Nov 2012 [33]. The R&D of the module-production procedure finished in March 2016, followed by the start of the real module production in May 2016. The module production ended in May 2018. The produced SVD modules demonstrated much better performance than that required; the electrical sensor-channel efficiency was > 99% and the sensor distortion from the design position was < $\mathcal{O}$(50μm). This was the first successful in-house production of semiconductor detectors at Japanese universities and institutes working for a high-energy experiment. The SVD was installed in the Belle II detector in Nov 2018. The SuperKEKB accelerator, which would provide us with a huge number of B mesons from the e^+-e^- collisions, had started its full operation in March 2019. The position resolution of the SVD was estimated with the collision data, which was adequate with respect to the required performance.

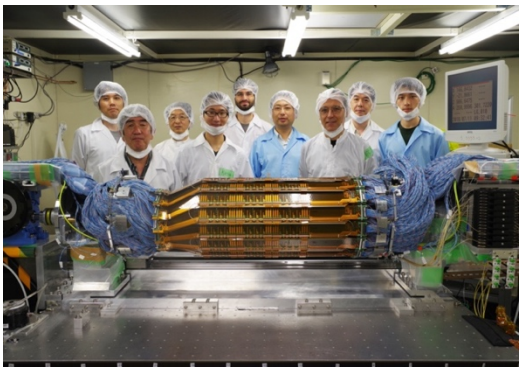

Fig. 8 The photo of the constructed SVD from the delivered SVD modules.

Upon the start of the Belle II data taking, the Kavli IPMU team converted its role to Belle II data analysis. They used 2019 and 2020 for analysis-tool development and detector-signal calibration for their use for all the future CP-asymmetry measurements and publications with the Belle II dataset. The results of the calibration were published. They will publish physics results with the tools and calibrated results from 2021, starting with the measurements of the B-meson lifetime, B^0-$\bar{B}^0$ mixing parameter followed by the CP-asymmetry measurement in the $B^0 \rightarrow J/\psi K^0$ decay [K. H. Kang, H. Park, T. Higuchi, et al. (Belle Collaboration) 2021]. In parallel to the Belle II data analysis, they searched for new physics with the full Belle dataset, which is seven times larger in size than the current Belle II. The CP asymmetry was consistent with the Standard Model prediction, and they concluded no evidence for new physics there. They are finalizing the measurement of the CP-violating phase ϕ_2 and the search for an invisible gauge boson Z' [(4) of 9 challenges].

*[18]: Evolution of Galaxies

J. D. Silverman and his collaborators extended the study of baryons within dark matter halos to even much smaller scales. They used the COSMOS data to identify close pairs of galaxies in both projected separation and redshift space (therefore the cleanest sample of physically close pairs), and showed that close pairs display an enhancement of active galactic nucleus (AGN) in such galaxies, as identified by the Chandra X-ray satellite, as compared to isolated galaxies of similar stellar mass [34]. Their results imply that close encounters between galaxies, at scales of 20 - 100 kpc, trigger gas accretion onto supermassive black holes in galaxy centers, at AU scales (~10^{13}cm). This suggests a connection between physical processes occurring over almost 10 orders of magnitudes in their length scales.

J. D. Silverman and his collaborators have completed an effort to establish a link between the mass of supermassive black holes (SMBHs) and the stellar mass of their host galaxies in the distant universe [35]. To determine how SMBHs and their host galaxies migrate onto the local mass relation, observations at earlier cosmic times are needed to view the progenitors of such local systems. To do so, the team has completed a Hubble Space Telescope (HST) program based on near-infrared imaging of the host galaxies of 32 actively growing SMBHs at z ~ 1.5. Using sophisticated 2D image analysis routines, they found a ratio between the mass of SMBHs and its host galaxy consistent with the local relation, thus indicating a co-evolutionary scenario (X. Ding, J. D. Silverman, T. Treu, et al. 2020a).

K.G. Lee, Assistant Professor at the Kavli IPMU since 2018, developed a useful scientific tool to perform density reconstructions via constrained initial conditions. In collaboration with the Kavli IPMU Project Researcher M. Ata, they have successfully performed a density reconstruction of the 1.7<z<3.5 COSMOS field based on existing spectroscopic survey data [36]. Based on the initial conditions estimated for the observed volume, they are now studying the full cosmic evolution of z~2-3 galaxy protoclusters in COSMOS by simulating their gravitational evolution down to z=0 with N-body simulations. On another front, K.G. Lee has worked with visiting UC Berkeley student B. Horowitz to develop analogous techniques applicable to Lyman-alpha forest absorption data. This technique allows us to recover the cosmic velocity fields from z~2 and in principle infer the final z=0 environments of galaxies observed at high redshifts (B. Horowitz, K.G. Lee, M. White, et al. ApJ 887 (2019) 61). The idea of density reconstructions is now an embedded component of the Subaru PFS Galaxy Evolution Survey in both the Low-Redshift and IGM Tomography components [(4) of 9 challenges].

*[19] Formation of First Stars and Black Holes

Virtually all galaxies host a supermassive black hole at their center. The origin of the massive black holes is largely unknown, and the existence of them even at very early epochs in the Universe poses a serious challenge to the theory of cosmic structure formation. N. Yoshida and his collaborators performed state-of-the-art supercomputer simulations to study early structure formation in a realistic cosmological model. The simulations include all the relevant physical processes on a first-principle basis, and reproduce baryonic streaming motions left over from the Big Bang [37]. The result shows that massive black holes can be formed via the gravitational collapse of massive stars as early as a few hundred million years after the Big Bang.

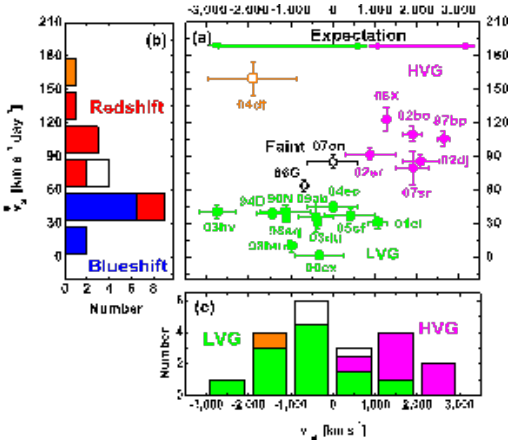

Fig.9 Relations between the features in the early- and late-phases of type Ia SN remnants. (a) Early-phase velocity gradient (vertical axis) as compared to late-phase emission-line shift velocity (horizontal axis). SN Ia sample displays a diversity of the observed features: low- and high-velocity gradients (LVG and HVG, respectively), and red- and blue-redshift (K. Maeda et al. 2010)

*[20] Supernovae and Evolution of Chemical Elements

Supernova explosions, phenomena at the end of a certain class of stars, display rich observational signatures. However, the physics involved in supernovae remains unresolved. The team led by K. Nomoto has been for many years the world leader in the research of supernovae. K. Maeda, K. Nomoto and their collaborators have conducted the Subaru observations of a carefully selected sample of supernovae remnants to study the nature of supernova explosions in combination with numerical simulations (see Fig. 9) [38]. Type Ia supernovae (SNe Ia) form an observationally, almost uniform class of stellar explosions, in that more luminous objects have slower decline-rate. This one-parameter behavior allows SNe Ia to be calibrated as cosmological "standard candles", leading to the discovery of an accelerating Universe. The Kavli IPMU team, however, revealed that the true nature of SNe Ia is more complicated. The observational data for some of SNe Ia imply a signature of an asymmetric explosion, which is also indicated by numerical simulations suggesting that the initial thermonuclear sparks are ignited at an offset from the center of the white-dwarf progenitor.

The Nobel and Breakthrough prize-winning Super-Kamiokande (SK) is of course one of Kavli IPMU's most important and well-known experiments, and the addition of gadolinium (Gd) to its water is one of the Kavli IPMU's flagship experimental initiatives. Originally proposed by - and with the ensuing R&D

program called EGADS (Evaluating Gadolinium's Action on Detector Systems) led by – M. Vagins, Gd loading will allow the reduction of certain physics backgrounds in Super-Kamiokande by a factor of approximately 10,000, with the primary goal of enabling the world's first detection of the diffuse supernova neutrino flux [39]. Adding gadolinium to the water in a water Cherenkov detector suddenly makes previously-invisible neutrons visible; requiring the observation of a neutron in delayed coincidence with its parent physics interaction allows us to identify certain rare processes with great certainty.

In order to prove that gadolinium would not damage SK and would provide the expected physics benefits, EGADS, a 200-ton working water Cherenkov detector and Gd test facility, was built in the Kamioka mine. Years have been spent with EGADS testing and fine-tuning various requisite aspects of gadolinium loading, including: continuous Gd-loaded water filtration, effects of various ion exchange resins, establishment of Gd dissolving techniques, and demonstration of Gd removal methods. Following a major SK in-tank refurbishment campaign during FY2018–2020, the various lessons learned in EGADS were finally applied to SK, culminating in the exciting addition of the first Gd to SK in the summer of 2020. The final week of FY2020 saw Super-Kamiokande host a well-attended virtual workshop on neutron detection software and analysis of the early data coming from the Gd-loaded SK detector. Lessons learned in EGADS are also being applied to the next-generation XENONnT dark matter project at Gran Sasso laboratory in Italy; XENONnT will use an IPMU-proposed Gd-loaded water tank and EGADS-derived water systems as its primary defenses against background neutrons which could otherwise fake dark matter events [40].

Since FY2018, with its primary R&D work winding down, the Gd-loaded EGADS has served as a fully-automated, real-time early-warning system in case of a core-collapse supernova (SN) explosion occurring anywhere in the Milky Way galaxy. The presence of Gd in water allows for the positive identification of supernova neutrinos - most of their interactions in water produce neutrons - with extremely high confidence, making a near instantaneous SN announcement possible for the first time. This technique and its related software are now being applied to the Gd-loaded SK, by far the world's most sensitive SN detector, enabling SK to send a detailed SN alert to the physics and astronomy communities as rapidly as possible. Finally, in mid-FY2020 EGADS was loaded with triple the present SK Gd concentration to simulate the next phase of Gd loading in SK. If all continues to go well in EGADS, the gadolinium concentration in SK is expected to be similarly tripled during 2022 [(4) of 9 challenges].

2-2. Research environment including facilities and equipment

Describe the degree to which the Center has prepared a research environment appropriate for a world premier international research center, including facilities, equipment and support systems, and describe the functionality of that environment.

A new research building for the Kavli IPMU designed by Prof. H. Ohno was built in Kashiwa Campus (5,900 square meters) in Jan 2010. This building has helped us greatly in achieving interdisciplinary research. All the offices are lined up in a spiral from the 3rd to 5th floor, making the three floors effectively a single floor. This arrangement avoids the traditional problem that people on different floors rarely see each other. We intentionally mix people from different disciplines in the office allocation. It also makes everybody equal along the same spiral. The 53rd BCS (Building Contractors Society) prize and the Prize of Architectural Institute of Japan 2011 were awarded to Prof. Ohno and the builders. The laboratory space in the building has been used to assemble the Silicon Vertex Detector of the Belle II experiment, as well as to test Photo Multiplier Tubes to design a future neutrino experiment. The Kavli IPMU Kamioka Satellite Office (500 square meters), which became available in March 2009, has been functioning as a base for the Kavli IPMU researchers working on Super-Kamiokande, KamLAND and XMASS. All of the partner institutions as well as the two Kavli IPMU satellites are connected via a video conference system. They are used daily for seminars and discussions. The Kavli IPMU built a new 3-ton digital camera with 870M pixels called Hyper Suprime-Cam for a major cosmological survey together with NAOJ, Princeton, and ASIAA.

We have built an underground laboratory in Kamioka in March 2008 where we have arranged important devices, including Germanium detectors, a GC-MASS Spectrometer, and an API-MASS Spectrometer, to evaluate the radioactive contamination and to understand the backgrounds of the detector components. They are commonly used by those who are working on the underground experiments.

The 390m^2 Kavli IPMU Library has a collection of over 22,000 books and journals. 90% of the collection is in all areas of mathematics since 100-year-old math journals are still relevant today. In the library we often find physicists consulting math literature to find language to describe their problem.

The team led by T. Takahashi developed a series of X-ray and gamma-ray imaging systems at the Kavli IPMU to perform various in-vivo imaging experiments. In addition to the laboratory for testing the detectors at Kavli IPMU, they have installed some of their equipment at the Exploratory Oncology Research and Clinical Trial Center at the National Cancer Center and performed various biomedical experiments.

The PFS instrumentation is in the phase to actively integrate and test the hardware and software of the subsystems, and some of them, including the metrology camera, the first spectrograph modules, and all 2394 "Cobra" robotic fiber positioners were already delivered to Maunakea in Hawaii and installed to the Subaru Telescope observatory.

The Kavli IPMU CMB team is developing the polarization modulator, a key instrument for LiteBIRD. The

team has main three facilities. Two 4K cryostats are dedicated to testing the half-meter diameter cryogenic rotational mechanism, the millimeter-wave optical characterization setup using a vector network analyzer, ultralow temperature system such as the dilution refrigerator, and the adiabatic demagnetization refrigerator to cool a transition-edge sensor bolometer at ~100mK. These facilities are located in the Kavli IPMU Lab B, and in three additional lab spaces in the Kashiwa campus: one room in Kashiwa Research Complex 2 (4F, 407) and two rooms in ISSP (one has an optical surface plate). The team also rent a room in Future Center Initiative, the University of Tokyo (UTFC) and held face-to-face collaboration meetings every month before the COVID-19 pandemic.

In 2020, the Kavli IPMU introduced a new large computing cluster with massive fast-access storage. This new cluster enlarged our computing power to 180%, and the total storage size became almost 200%. These new powerful computing resources further advance our exploration of the secret of the universe.

2-3. Competitive and other funding

Describe the results of the Center's researchers to date in securing competitive and other research funding.

- In Appendix 3-6, describe the transition in acquiring research project funding.

H. Murayama received a research grant called FIRST (the Funding Program for World-Leading Innovative R&D on Science and Technology) selected by CSTP (the Council for Science and Technology Policy, Cabinet Office of Japanese Government). The project, SuMIRe (Subaru Measurement of Image and Redshifts) is a large-scale international survey project aiming at uncovering the origin and future of the Universe. N. Yoshida led a new CREST project funded by Japan Science and Technology Agency (JST) "Statistical Computational Cosmology with Big Astronomical Imaging Data". H. Murayama received a JSPS Grant-in-Aid for Scientific Research on Innovative Areas "Why does the Universe accelerate? – Exhaustive study and challenge for the future –". H. Murayama recently received a JSPS Grant-in-Aid for Transformative Research Areas A "What is dark matter? - Comprehensive study of the huge discovery space in dark matter". Y. Suzuki received research grants, and has succeeded in constructing the world's largest liquid Xenon detector (XMASS) to make an observation of Dark Matter in the underground experiment. S. Moriyama and K. Martens received a grant to implement the Kavli IPMU/Kamioka technology at XENONnT. K. Inoue received a research grant to construct a mini balloon inside the KamLAND detector, and set limits on the lifetime of neutrinoless double beta decay. M. Nakahata received a research grant to build Evaluating Gadolinium's Action on Detector Systems (EGADS). He has built a 200-ton scale model of Super-Kamiokande detector with 240 50-cm phototubes, and a novel selective water filtration system. M. Vagins received a research grant for modifying EGADS to detect neutrinos from nearby supernovae. N. Katayama led a Japan Aerospace Exploration Agency (JAXA) project "Development of polarization modulator for the LiteBIRD project" and a JSPS Core-to-Core Program "International Center for Observational Proof of Inflationary Universe". T. Takahashi received a JSPS Grant-in-Aid for Scientific Research on Innovative Areas "Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams" to promote a gamma-ray imaging project for medical research.

2-4. State of joint research

Describe the results of joint research conducted with other research organizations both in and outside Japan.

Members of the Kavli IPMU collaborate widely with researchers from other research organizations. For instance, among the 40 most significant papers listed in Appendix 1-1, 32 of them involved collaborators at institutions outside Japan.

The Kavli IPMU leads several large projects. The SuMIRe project is led by H. Murayama (core researcher PI), N. Tamura (project manager) and M. Takada (project scientist). It involves both physicists and astronomers from the Academia Sinica Institute for Astronomy and Astrophysics (ASIAA, Taiwan), Jet Propulsion Laboratory of NASA, Caltech, Princeton University, Johns Hopkins University, Laboratoire d'Astrophysique Marseille, Universidad São Paulo, the Laboratório Nacional de Astrofísica (Brazil), Max Planck Institute for Astrophysics, and a Chinese consortium. The underground experiments, KamLAND (led by K. Inoue), XMASS (led by Y. Suzuki and K. Martens) and Super-Kamiokande (led by Y. Suzuki, M. Vagins and M. Nakahata), an accelerator experiment, Belle II, an accelerator-based long-baseline neutrino oscillation experiment T2K (Tokai-to-Kamioka), and Cosmic Microwave Background Polarization experiments, POLARBEAR, Simons Array, and LiteBIRD (led by M. Hazumi, N. Katayama and T. Matsumura) are all operated by large international collaborations and have all, except LiteBIRD, produced world-class scientific results already.

So far the Kavli IPMU has signed 24 cooperative research agreements or memoranda of understanding (MOU), among which 22 include foreign institutes. In Jan 2016, the Kavli IPMU signed a MOU with the Institute of Statistical Mathematics (ISM) to enhance a mutual partnership between astrophysics and statistics to analyze big data from Subaru using information statistics. We signed the agreement with the Department of Physics at the University of Oxford for the purpose of the Kavli IPMU Oxford D.Phil. Several doctoral students in astrophysics or particle physics at the University of Oxford are supervised by our faculty

members, and are provided the opportunity to conduct research in collaboration with Kavli IPMU researchers. For example, T. Vladisavljevic, one of the first joint Oxford/Kavli IPMU graduate students, received his Ph.D. in 2019. L. Cook, who was also a joint Oxford/Kavli IPMU graduate student, is developing atmospheric neutrino production modeling methods that build on techniques used by the T2K experiment. His work is set to play a key role in the future neutrino oscillation measurements that combine atmospheric and accelerator neutrino data. T. Ghigna, another joint Oxford/Kavli IPMU graduate student, received his Ph.D. in 2020 and became a Kavli IPMU postdoc now.

2-5. Appraisal by society and scientific organizations

Describe how society and/or scientific organizations in and outside Japan have recognized the Center's research achievements.

- To substantiate the above evaluation, list the main awards received and invitational/Keynote lectures given by the Center's researchers in Appendix 1-3.

Our members received valuable prizes/awards. H. Ooguri was conferred the 2019 Medal of Honor with Purple Ribbon by the Emperor of Japan for his contribution to theory of elementary physics. K. Nomoto was awarded the 2015 Marcel Grossman Award and the 2019 Hans A. Bethe Prize by the American Physical Society. Our PI T. Kajita received the 2015 Nobel Prize in Physics and Japan's Order of Culture. H. Murayama received a research award from the Alexander von Humboldt Foundation. Y. Tachikawa was awarded the 2014 Hermann Weyl Prize and 2016 Fundamental Physics New Horizons Prize. Several members are recognized by international scientific organizations, including the American Mathematical Society, the American Physical Society, the Alexander von Humboldt Foundation, the American Academy for Arts and Sciences, the International Union for Pure and Applied Physics. Almost all the faculty members have had invitations to major meetings.

It deserves special mention that researchers at the Kavli IPMU were invited to write major review articles; K. Nomoto (with C. Kobayashi, N. Tominaga) wrote "Nucleosynthesis in Stars and the Chemical Enrichment of Galaxies" in *Annual Review of Astronomy and Astrophysics*, 51 (2013) 457-509, M. Kawasaki, K. Nakayama, "Axions: Theory and Cosmological Role" in *Annual Review of Nuclear and Particle Science*, 63 (2013) 69-95, N. Yoshida (with V. Bromm) on "The First Galaxies" in *Annual Review of Astronomy and Astrophysics*, 49 (2011) 373-407, H. Ooguri (with R. Kitano, Y. Ookouchi) on "Supersymmetry Breaking and Gauge Mediation" in *Annual Review of Nuclear and Particle Science*, 60 (2010) 491-511, S. Petcov and K. Nakamura on "Neutrino mass, mixing and oscillations" in Review of particle physics, *Physical Review*, D86 (2012) 010001, Y. Tachikawa wrote "A review of the T_N theory and its cousins" in *Progress of Theoretical and Experimental Physics*, 2015 (2015) 11B10238, K. Nomoto and S. C. Leung wrote "Single Degenerate Models for Type Ia Supernovae: Progenitor's Evolution and Nucleosynthesis Yields" in *Space Science Reviews*, 214 (2018) 67, M. Oguri wrote "Strong gravitational lensing of explosive transients" in *Reports on Progress in Physics,* 82 (2019) 126901, and M. Yamazaki wrote "Integrability as duality: The Gauge/YBE correspondence" in *Physics Reports*, 859 (2020) 1-20.

The survey conducted by JSPS in April-July 2011 showed that more than 64 (39)% of the valid responses (313) sent to authors of papers in related fields and leading scientists selected by the program officers knew the name of the institute (Director). More than 70% of them answered that they feel "strongly interested" or that it "sounds appealing" to join research at the Kavli IPMU.

2-6. Feeding Research Outcomes Back into Society

Describe the applications created from research results, their effect in spawning innovation, intellectual properties (IPs) obtained, and joint research activities conducted with corporations, etc.

Unprecedented requirements on instrumentation from our science lead to breakthrough devices that help industry. Building the world's largest camera and spectrograph has certainly required breakthroughs in technologies in many areas. Canon developed a new corrector lens to widen the field of view from 0.5 degrees to 1.5 degrees, with a high-precision aspherical lens. It has enabled a new production process for semiconductors. The company has also built the lens barrel, which employs a ceramic material from Kyocera that achieves a significant reduction in weight and low thermal expansion coefficient suitable for space technology. The sensor was co-developed by Hamamatsu Photonics and NAOJ for a particularly good sensitivity in the red. The precision instruments should also prove critical in space deployments.

iMAGINE-X Inc. is a startup company founded by Kavli IPMU researchers who are engaged in gamma-ray imaging (S. Takeda, T. Orita, A. Yagishita, T. Takahashi) to answer the question of "How can basic science contribute to our society". Sensor technologies they have originally developed for gamma-ray astrophysics have a potential to improve imaging in cancer therapy. iMAGINE-X Inc. and Kavli IPMU are collaborating to develop high-quality commercial detectors based on technological seeds from basic science.

3. Generating Fused Disciplines (within 3 pages)

3-1. State of strategic (or "top-down") undertakings toward creating new interdisciplinary domains

Describe the content of "top-down" measures taken by the Center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields.

Teatime is held at Piazza Fujiwara on the third floor from three o'clock every day. All researchers including visitors are *required* to join the teatime. It is considered an important opportunity for researchers to meet each other, talk to scientists from different fields, discuss science in a relaxed atmosphere and come up with new ideas. The building itself is designed from the ground up to promote interdisciplinary activities as described in 2-2. In 2020, to prevent COVID-19, we held Kavli IPMU social hour using an online communication tool "Gather". Our virtual social hour was written in the morning edition of Nikkei Shinbun on Feb 1, 2021.

All faculty members in all fields are involved when hiring new faculty members, interviewing the candidate, attending the talks, and discussing suitability. This is also considered important for the candidates because they get to know all faculty members. Whether a candidate can take an interdisciplinary approach to research is one of the most important considerations at the time of hiring. The Kavli IPMU does not have departments for each discipline; the operation of the Institute avoids compartmentalization.

M. Gabriel, Professor of Philosophy at U Bonn and the best-selling author of "Why the World Does Not Exist," was invited to visit the Kavli IPMU, to provide the opportunity to researchers in the area of science to interchange with other fundamental research areas. In 2019, the Kavli IPMU signed a MOU with the University of Bonn to promote the advances in philosophical problems.

3-2. State of "bottom-up" undertakings from the center's researchers toward creating new interdisciplinary domains

Describe the content of "bottom-up" measures taken by the Center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields.

In order to encourage interdisciplinary research, the Kavli IPMU has been regularly holding joint seminars of different fields. There are three kinds of these joint seminars: institute-wide colloquia, mathematics-string (MS) theory seminars, and astronomy - particle physics - experimental physics - cosmology (APEC) seminars. In the MS Seminar, we invented a creative format: introduction to non-experts in the first 25 minutes, a 5-minute break, and the technical seminar in the final 60 minutes. This format improved the mutual understanding to a great extent. We are always keen to improve the format further, constantly monitoring its effectiveness. In addition, there are informal seminar series to enhance specific areas of interdisciplinary subjects. We designed our institute-wide colloquia to be interdisciplinary. We also started a new colloquium-style webinar series by Kavli IPMU postdocs to understand each field and each other. In 2020, 7 astronomers, 10 theoretical physicists, and 4 mathematicians gave talks on their research at the postdoc colloquia.

The Kavli IPMU has hosted a number of interdisciplinary workshops. A collaboration between string theorists at the Kavli IPMU and condensed-matter physicists at ISSP emerged from Focus Week "Condensed Matter Physics Meets High Energy Physics" jointly organized by the Kavli IPMU and ISSP in 2010, and resulted in a joint PRL paper in 2012. In 2015, the Kavli IPMU and ISSP held a workshop that brought together world-leading experts from condensed matter physics, gravity and string theory. There were intriguing and fruitful interactions between the field of homological algebra and algebraic geometry (mathematics) and that of two-dimensional quantum gauge theories (physics) at the workshop "Homological Projective Duality and Quantum Gauge Theory". The workshop "Curves and Categories in Geometry and Physics" provided a forum for mathematicians working on geometry, and physicists working on string theory. The Workshop "Particle Physics of the Dark Universe" dealt with dark matter, which is a common problem in particle physics and cosmology. A number of leading researchers got together and spent ample time discussing different aspects of the black holes at the workshop on Black Holes in 2011, ranging from their astronomical observations to their quantum properties in superstring theory and loop quantum gravity. In 2014, the Kavli IPMU hosted an interdisciplinary symposium "Frontiers of Theoretical Science – MATTER, LIFE and COSMOS –" organized jointly with RIKEN iTHES (interdisciplinary Theoretical Science Group) and Osaka TSRP (Theoretical Science Research Project). The research cooperation is founded on two bilateral agreements between the Kavli IPMU and iTHES and between Osaka TSRP and iTHES, respectively. The workshop "Towards Quantum Primitive Form Theory" was held as a joint program of the Kavli IPMU and the Frontiers of Mathematical Sciences and Physics (FMSP) program. It covered developments related to period maps for primitive forms. The Kavli IPMU and the Earth-Life Science Institute (ELSI) joint public lecture on "A Question of Origins" was held at the Tokyo Institute of Technology's Kuramae Hall. It covered the origins of space, the Earth and life. The 1st Kavli IPMU Artist in Residence (AIR) Program Artist Exhibition "re^{n}-Encounter between Science and Art 2018" was held, supported by a JSPS grant, to aim for advancing the fusion of art and science. Since 2015, the Kavli IPMU

hosts an AIR program where artists stay in the institute for about a month to interact with scientists.

As collaborations between statistics and astronomy would prove successful, given the anticipated large data sets from HSC and PFS surveys, the workshop "Statistical Frontiers of Astrophysics" was held. In 2014, we started a JST CREST program jointly with the Institute of Statistical Mathematics, U. Tsukuba, and NTT communications, to explore new frontiers of "astrostatistics" combining statistics with astrophysics to analyze the big data amounting to 25 trillion pixel data from Subaru Telescope in HSC project.

3-3. Results of research in fused research fields

Describe the Center's record and results by interdisciplinary research activities yielded by the measures described in 3-1 and 3-2.

- In Appendix 1-2, list up to 20 of the Center's main papers on interdisciplinary research that substantiate the above record of results, and describe their content.

One of the Center's aims is to bring physicists and mathematicians together to develop new formulations of the fundamental laws of Nature. We strongly encourage and pursue steady communication for mutual inspiration between the disciplines and thereby we see active interactions between mathematicians and physicists, which led to publications. Furthermore, we will try to enhance the connection between astronomy and statistics needed for analyzing large-scale data anticipated from HSC and PFS. In addition, there are unanticipated types of interdisciplinary activities between science and society, and between high energy astrophysics and medical imaging.

-Astronomy and mathematics

An unanticipated interdisciplinary activity emerged between astronomy and mathematics. M. Werner developed a novel mathematical model for the distribution of cosmic voids together with astrophysicists {1}. They proposed that the geometrical concept of a four-dimensional de Sitter configuration of spheres in Euclidean 3-space can be used to describe the number density of cosmic voids as observed.

The best illustration of interdisciplinary activity appeared at our regular teatime. R. Quimby, an astronomer who discovered a class of the brightest supernovae called superluminous supernovae, was puzzled by a claim by the US-based Pan-STARRS group that the observed supernova PS1-10afx was a yet brighter new type. He realized immediately that the light curve and spectra resembled standard type-Ia supernova, while it was 30 times brighter. M. Werner pointed out it was mathematically possible to obtain this magnification by gravitational lensing. Such a possibility appeared implausible at first. However, M. Oguri, a physicist, estimated quickly that there is about one chance in the Pan-STARRS data set. Together with other supernova experts at the Kavli IPMU, they published a paper based on this teatime discussion. About a year later, R. Quimby et al. used the 10m Keck-I telescope to observe the host galaxy, and proved that there was an unresolved faint galaxy in the foreground exactly along the line of sight {2}. This result was published in Science and was covered by more than 80 media internationally [(2) of 9 challenges].

- Physics and mathematics

There has been revived activity to exactly compute partition functions of supersymmetric field theories on curved manifolds. Members of the Kavli IPMU played dominant roles in obtaining exact results in two-dimensional supersymmetric gauge theories, that include work by K. Hori and M. Romo on the discovery of the duality, by R. Eager, K. Hori and Y. Tachikawa on a general formula for the elliptic genus, and by K. Hori and J. Knapp on the systematic construction of the models {3}. Using techniques in string theory, A. P. Braun, Y. Kimura and T. Watari classified elliptic fibrations modulo isomorphism on *K3* surface with large Picard number {4}. Joint work between arithmetic geometry and string theory was done by S. Kondo (METU, joint appointment at the Kavli IPMU) and T. Watari {5}, triggered by Kondo's colloquium in 2010.

H. Murayama worked with the Kavli IPMU mathematicians and string theorists to apply techniques from conformal field theory to make the classification completely systematic. This work imports many recent advances in pure mathematics to physics at accelerator experiments in a truly interdisciplinary fashion {7}. T. Melia collaborated with experimental condensed matter physicists and chemists, and developed his idea for chemical dark matter detectors {16}.

H. Ooguri published a paper with condensed matter physicist M. Oshikawa {10}. They pointed out that there is an axion-like excitation in magnetic material that causes instability and screens the applied electric field. They showed how this effect can be realized experimentally. H. Murayama produced a series of papers with condensed matter physicist H. Watanabe, and also with a nuclear physicist T. Brauner including four PRL papers. In one of them, they discovered an exact mass formula for pseudo-Nambu-Goldstone bosons, akin to the BPS states in supersymmetric gauge theories {11} [(2) of 9 challenges].

K. Saito proposed a new approach to the geometric theory of discrete groups based on the Ising model in physics {12}. M. Kapranov related the concept of perverse schobers, categorical analogs of perverse sheaves, with the study of quantum field theories in the infrared limit {13}. T. Milanov published a paper "The period map for quantum cohomology of P^2", Adv. In Math. Volume 351 (2019), 804—869 where he used an idea learned from two physicists K. Hori and M. Romo. H. Nakajima collaborated with a group of theoretical physicists, S. Gukov, D. Pei and others on topological twists of 3-dimensional supersymmetric quantum field theories. Their results are preliminary, but give steps towards deeper results {14}.

- Astronomy and statistics

The JST CREST project "Statistical Computational Cosmology" led by N. Yoshida is aimed at developing fast imaging data analysis applications for the Subaru HSC survey. They collaborate with people at Institute of Statistics and Mathematics and NTT Communication Science Laboratories, who provided us with the latest Deep Neutral Network (DNN) technologies. They developed an image analysis program that automatically detects supernovae out of numerous transient candidates (including bogus objects) in HSC survey data. It is very important for supernova teams to process a massive amount of the data in a timely manner. They developed a new machine based on Area Under the Curve (AUC) boosting and a partial AUC (pAUC) method, as well as commonly used Random Forest and Convolutional Neural Network (CNN). Their classifier has been used for real-time analysis of HSC survey. Since Nov 2016, a total 52-night transient search has been conducted, and they detected over 65,000 transient objects, out of millions of bogus objects, and identified over 1800 supernovae. The output includes 58 distant Type Ia supernovae that are invaluable for our cosmological analysis using accurate distance measurements [11].

They also performed an ensemble of cosmic structure formation simulations with 8 billion particles for 101 theoretical models. By using the simulation outputs and galaxy catalogs, they developed an emulator that enables fast and accurate computations of statistical quantities. Their emulator and the simulation database have been used by domestic and foreign researchers. They expect the emulator to be a popular tool for cosmological analysis in the upcoming years {18} [(1) of 9 challenges].

- Science and society

H. Yokoyama, who specializes in modern science theory, and Y. Ikkatai study gender stereotypes that contribute to fewer women in physics and mathematics by focusing on social norms, images, and cultures. They led the JST-RISTEX policy research project (Oct 2017–March 2021) and completed the project by submitting seven English and three Japanese papers over three years. They thought that the reason why there were so few women in Japanese mathematics and physics was influenced by the strong image that these disciplines were suitable for men and not for women [Y. Ikkatai et al. 2020] 06, A02). Furthermore, in the background of such an image, they realized that there is strong misogyny in Japanese society that excellent women are not necessary {19}. So, they investigated a male image of mathematics and physics, and keywords and its gendered image [Y. Ikkatai et al. 2020]. They also revealed that parents with low gender-equal attitudes are less likely to help girls go on to university, and high school teachers unconsciously recommend physical choices only to boys [Y. Ikkatai et al. 2019]. Based on this, they published a model paper in the third year, and further examined ways to improve the gendered image of such a society. They have confirmed that gender equality information that eliminates misogyny and information that girls who remove the math stereotype threat can also do math well are effective [(2) of 9 challenges].

- High energy physics and medical imaging

The team led by T. Takahashi has been organizing interdisciplinary activities to develop advanced detectors which could meet the needs in the field of nuclear medicine. For this purpose, they have established a network with researchers from National Cancer Center, the Department of Medicine at Keio University, the Department of Medicine at Osaka University, RIKEN, and the Centre for Advanced Imaging at The University of Queensland. Under this network, they have started various bio-medical imaging experiments by using the imaging system developed at the Kavli IPMU. Their goal is to establish the *in vivo* imaging system to evaluate biodistribution of radiopharmaceuticals. Nuclear medicine detects radio-labeled substances in the nano-molar or pico-molar range. This sensitivity advantage, together with the wide selection of radio-labeled compounds, allows nuclear medicine studies to be targeted to the very specific biological processes. However, the performances at the current stage are still limited, because of the lack of spectral resolution to resolve multiple emission lines from different target radionuclides and to estimate the scattering component inside the targets.

They have been developing a series of X-ray and gamma-ray imaging systems, which enable us to perform multi-radionuclide imaging with a high energy resolution and with a high spatial resolution. The imagers are based on a large-area cadmium telluride (CdTe) diode detector developed for hard X-ray and gamma-ray space observations {20}. Compared to Si, CdTe has a higher quantum efficiency for a typical operating energy range of 10-150 keV and shows a good uniformity over 9 cm^2. And importantly, it has a high energy resolution of DE=1-2 keV(FWHM), which is required to resolve multiple X-ray and gamma-ray lines emitted from multiple molecular probes attached with different radionuclides. They have also established spectral analysis methods to isolate and identify all acquired signals, including scattered rays, fluorescent X-rays, and signals from target radionuclides. They have succeeded to demonstrate the performance by using the systems. Specifically, they successfully visualized lymph nodes and thyroids of mice with our *in vivo* imaging, using three different tracers labelled with ^{125}I, ^{111}In, and ^{99m}Tc, by using the multi-pinhole imaging system, which is capable of high spatial (~300 μm) and energy resolution in a small field-of-view. Also, by using a new slat type collimator made of Tungsten using 3D printing technology, they have succeeded in visualizing faint emission of characteristic X-rays from the decay of ^{211}At accumulated in a tumor resides in a tumor-bearing mouse. These multi-nuclide imaging systems will be useful in a wide field of biomedical research [(2) of 9 challenges].

4. Realizing an International Research Environment (within 4 pages)

4-1. International Circulation of Best Brains

4-1-1. Center's record of attracting and retaining top-world researchers from abroad

Describe the participation of top-world researchers as PIs and their stays as joint researchers at the Center.

・ In Appendix 3-2, give the number of overseas researchers among all the Center's researchers, and the yearly transition in their numbers. In Appendix 4-2 give the achievements of overseas researchers staying at the center to substantiate this fact.

From the developing stage, we had a firm belief that the key to gaining international recognition is to bring together top-level leaders and talented young researchers worldwide, and create an environment where researchers in different fields learn each other's way of thinking and work together toward common goals. We have established such a fascinating research environment here at the Kavli IPMU. It functions as the center for "brain circulation". The total number of Principal Investigators (PIs) is 28, among which 11 are on-site PIs. All of our 28 PIs (7 non-Japanese: 25%) are world-leading scientists and ensure an international environment for research activities at the Kavli IPMU. A. Bondal, Professor of "Steklov Mathematical Institute of Russian Academy of Science", is a leading expert and a founder of the theory of derived categories. He holds a joint professorship at the Kavli IPMU and stays six months a year at ordinary times. M. Kapranov is a distinguished mathematician in algebraic variety, derived category, and gauge theories. We attracted him to one of our first tenured positions. His presence is a significant boost to our international standing. S. Katsanevas's scientific interests include neutrino physics and astroparticle physics. He is the Director of the Astroparticle Physics and Cosmology, Université Paris Diderot, and plays a crucial role in bridging the Kavli IPMU and European communities together. Y.-K. Kim, Professor at the University of Chicago, is a world-leading experimental particle physicist. D. Spergel is one of the best theoretical astrophysicists in the world. He is a member of the HSC and PFS projects' executive committees. M. Vagins has been leading the EGADS project. The SK detector's refurbishment work successfully finished in Jan 2019. With "Gd" one expects to collect the world's first diffuse supernova neutrinos [(5) in 9 challenges].

A large fraction of our researchers are non-Japanese. Out of 89 faculty members and postdoctoral researchers employed by the Kavli IPMU, 42 (47%) are non-Japanese. During FY 2019, we had 909 (1245) visitors (the numbers in the parentheses count multiple visits). Among them, 463 (555) are international, and many of them are world-class scientists. The numbers of visitors each year for the recent five years are (multiple visits in a given year are counted as one):

Year	2016	2017	2018	2019	2020
Total	728	738	1025	909	55 (1465*)
International	464	436	560	463	10 (777*)

(*) Number of participants for online conferences in 2020

We invited many prominent researchers to stimulate young researchers. Nobel laureates in Physics: George Smoot (2010), Jerome Friedman (2011), David J. Gross (2009, 2011, and 2017), Brian P. Schmidt (2012), Gerard 't Hooft (2015), Barry Barish (2017), and Fields Medalists Shing-Tung Yau (2009 & 2017), Maxim Kontsevich (2010), Edward Witten (2014), and Andrei Okounkov (2017) visited us and gave lectures and seminars. We also invited Freeman Dyson (2014), IAS Professor Emeritus, and Fabiola Gianotti (2013), the Director-General of CERN. Lisa Randall (2014) from Harvard gave not only seminars but also public lectures as outreach activities to encourage the participation of women in science.

4-1-2. Employment of young researchers at the Center and their job placement after leaving the Center

Describe the Center's employment of young researchers, including postdoctoral researchers, and the positions they acquire after leaving the Center.

・ Enter the following to substantiate the facts provided above:

- In Appendix 4-3, describe the Center's state of international recruitment of postdoctoral researchers, the applications received, and selections made.
- In Appendix 3-2, give the percentage of postdoctoral researchers employed from abroad
- In Appendix 4-4, describe the positions that postdoctoral researchers acquire upon leaving the Center.

Our policy for mobilizing and circulating the world's best brains is to recruit the brightest young people as post-doctoral researchers and provide them with the best research environment to realize outstanding accomplishments during their three-year term at the Kavli IPMU. These post-doctoral researchers have become strong candidates for either faculty positions or other post-doctoral positions at prestigious research institutions. Every year we have about 700 applications on average, mostly (90%) from abroad. We have been able to recruit postdocs from many top-level research institutions in the world, such as Harvard, Princeton, MIT, etc. By the end of FY 2020, we employed 242 postdocs, and 193 had left the Kavli IPMU, some before the three-year term expiration. Some postdoc researchers who have left the Kavli IPMU have found faculty positions at many top-level institutions: Durham U., McGill U., Stony Brook U., ICRR, Osaka, and CNRS. Others have found another postdoc position at prestigious institutions: Oxford, Harvard, MPI, Caltech, CERN, YITP, and KEK, etc. The number of researchers currently in a faculty position became

115 in FY 2020. Also, 47 postdocs affiliated with us were supported by the JSPS Postdoctoral Fellowship.

As for young faculty members, F. Takahashi was recruited as Associate Professor at Tohoku University, K. Maeda as Associate Professor at Kyoto University, A. Mikhailov as Assistant Professor at Instituto de Fisica Teorica da Universidade Estadual Paulista (São Paulo, Brazil). N. Yoshida became the youngest Full Professor at the Faculty of Science at UTokyo and now has a joint appointment with the Kavli IPMU. T. Takayanagi, S. Sugimoto, and S. Mukohyama were hired as Full Professor at YITP of Kyoto University. Y. Tachikawa was promoted to Associate Professor at UTokyo and came back to the Kavli IPMU as Full Professor in 2016. C. Schnell was promoted to Professor of Stony Brook University. He was selected as a Simons Fellows in 2021.

4-1-3. Overseas satellites and other cooperative organizations

・ In Appendix 4-1, describe the state of cooperation with overseas satellites and other cooperative organizations. In Appendix 4-5, describe the state of the Center's agreements concluded with these organizations.

The Kavli IPMU's UC Berkeley Satellite was established in 2009 based on a comprehensive academic exchange agreement signed by UTokyo and UC Berkeley, brokered by H. Murayama. It provides a framework for collaboration in a wide range of fields. A few collaborative papers have been published annually through the Satellite activity. More than 10 researchers at the Kavli IPMU and the Satellite are visiting mutually for collaborations.

The Kavli IPMU had signed 27 cooperative research agreements with overseas institutes and international collaborations by 2020. These cover mathematics, physics, and astronomy, and include Princeton University, DESY, TRIUMF, KIAA, and CNRS. TRIUMF and the Kavli IPMU established a joint position, by which we hired a tenure-track assistant professor for neutrino experiments in 2013. The agreements on international collaborations include SDSS III and IV, interim Palomar Transient Factory (iPTF), Prime Focus Spectrograph (PFS) Subaru Telescope, the Hyper-Kamiokande, and others.

4-1-4. Examples of the success cases

Describe the Center's efforts over the past 3 years in making it a place that expands and accelerates the international circulation of the world's best brains. Give about 5 examples of their success cases and describe their concrete contents and effect in narrative.

1. Many Kavli IPMU researchers play significant roles in international collaborations. T. Takahashi is a leading astroparticle physicist working in the H.E.S.S. collaboration, which detected a gamma-ray burst in very high energy gamma for the first time and identified a very high energy gamma-ray region in the Crab Nebula in 2019. He has been developing X-ray and gamma-ray detectors for space experiments, and has started a new collaboration with JAXA/ISAS and Keio University School of Medicine to apply these detectors to biomedical research. H. Nakajima, who received the Cole Prize in Algebra in 2003, is a distinguished mathematician and a leader in the study of gauge theories. M. Takada is the leader of the HSC project, where fruitful scientific results continue to come out following the publications of 40 papers in PASJ. Other faculty members also play leading roles in each field and some are PIs of international projects such as Belle II, T2K, KamLAND-Zen, PFS, and LiteBIRD. H. Ooguri received the 2018 Hamburg Prize for Theoretical Physics. His de Sitter swampland conjecture paper gave a strong impact on cosmology and became the most cited paper in high energy theory in 2018.
2. Some Kavli IPMU faculty members are supervising a few doctoral students from the University of Oxford. So far, we have accepted nine students, and five have defended their Ph.D. theses. The Kavli IPMU is also working with another international graduate program in physics (GSGC), which we hope will be extended to astronomy. A group of UTokyo and Kavli IPMU faculty members, including Y. Kawahigashi (representative), T. Kohno, A. Bondal, M. Kapranov, I. Ueda, and Y. Yamazaki, have been planning to submit a proposal for a student exchange program between Hamburg University, entitled "Higher algebraic structures and their concrete," to the JSPS and German Research Foundation (DFG).
3. The Kavli IPMU has appointed K. Martens the first Director of the Kamioka-branch. The fact that a foreign researcher whose first language is not Japanese can take such a leadership role demonstrates that the Kavli IPMU has established a truly international environment and support system.
4. Regarding postdocs hiring, we adopt the world standard timetable. That is, we open recruitment in the fall, select candidates from applicants and make offers in the winter, and the successful candidates start their term in the summer or fall. We made a special deal with academicjobsonline.org as the first non-US institution to use the system. We also developed our system for the online job application database, which is now used at other Japanese institutions. Our offer letters include a detailed description of our policy and support system, in addition to salary levels competitive with leading institutions in the US [(5) in 9 challenges].
5. To further raise the Kavli IPMU's profile as a globally visible institute, online science news services such as EurekAlert!, AlphaGalileo and Asia Research News have been used effectively to publicize our research activities to the world. It was initiated in 2014, and the number of international media coverages jumped from about 20 in 2013 to 218 in 2020.

4-2. Center's record of holding international symposia, workshops, research meetings, training meetings and others

・ In Appendix 4-6, describe the main international research meetings held by the Center.

From the WPI program's starting stage, the Kavli IPMU has hosted many conferences, workshops, and seminars every year. The number of major international meetings is; 14 in 2016, 11 in 2017, 21 in 2018, 18 in 2019, 8 in 2020. Focusing on 2019, 430 (30%) out of the 1424 total participants came from foreign institutions. The meeting organizers are required to select speakers and themes to keep the topics' timeliness and discussion at the highest quality. Holding such conferences increases our visibility in the international community and shows our leading roles in various fields. At the same time, Kavli IPMU researchers present numerous seminars and talks at both foreign and domestic institutions and at international conferences.

One clear example of establishing the institute as an international research center of high reputation was manifested at the Kavli IPMU 10th anniversary symposium held in Oct 2017. It had about 200 participants. About 40% of them were foreigners, including two Nobel laureates, Profs. T. Kajita and D. Gross in physics, and two Fields medalists, Profs. A. Okounkov and S.-T. Yau in mathematics. Another prominent example is the Kavli Asian Winter School on Strings, Particles, and Cosmology held annually with the Kavli Foundation's support. This school is a pan-Asian collaborative effort of high energy theorists from China, India, Japan, and Korea to give young researchers in Asia an opportunity to learn about the latest developments in high energy theory from leading experts on the subject. The Kavli IPMU supported its 14th meeting held at the Tohoku University in 2020.

In 2020, almost all conferences and seminars were held online due to COVID-19. We had 1465 participants for online conferences and 777 foreigners among them throughout the year. We also had more than 100 seminars online, obtaining about 3000 participants in FY 2020. It has become possible to get comprehensive participants by holding these meetings online.

We have also made an impact on the globalization of the graduate programs at UTokyo. Our faculty has already contributed to the graduate programs at the Department of Physics and the Department of Mathematical Sciences through the supervision of graduate students and lectures on a voluntary basis. We partnered in two *Programs for Leading Graduate Schools*, one for "Frontiers of Mathematical Sciences and Physics" (FMSP) and the other "Advanced Leading Graduate Course for Photon Science" (ALPS). It offers opportunities for interdisciplinary research to UTokyo graduate students in our international and interdisciplinary environment. For example, Kavli IPMU-FMSP Tutorial Workshop "Geometry and Mathematical Physics" (2013) was attended by about 50 participants, mostly young researchers and graduate students. Another Kavli IPMU-FMSP workshop, "Supersymmetry in Physics and Mathematics" (2014), discussed primitive forms and related subjects in exceptional singularities in geometry and field theory. In addition, our international faculty lectures on scientific writing in English in the Department of Physics, a very popular course among graduate students. So far, more than 110 students have taken the course.

A new graduate program, which was coordinated by H. Murayama and involved departments of physics, mathematics, astronomy, etc., of UTokyo, was as one of the JSPS WISE Program (Doctoral Program for World-leading Innovative & Smart Education) in 2019. This program trains graduate students in physics, mathematics, and astronomy for diverse career opportunities. Also, it gives us leverage so that more Kavli IPMU faculty members can directly supervise graduate students [(7) of 9 challenges].

4-3. System for supporting the research activities of overseas researchers

Describe the Center's preparations to provide an environment conducive for overseas researchers to concentrate on their work, including for example living support in various languages or living support for their families.

The Kavli IPMU is proactive in helping international researchers kick-start their lives in Japan and concentrate on their academic research. Support consists of the assistance needed to get their life in Japan started, such as:

- Obtaining a Certificate of Eligibility and a Professor Visa before arrival.
- Extensive orientation about life in Japan and at the Kavli IPMU, such as a deposit and critical money in keeping with the Japanese custom, grant application systems, *etc.*
- Resident's registration at the local municipal office; our staff accompany researchers to the municipal office for the foreign resident's registration procedure.
- Finding housing; we have made arrangements with real-estate offices with English-speaking staff, and our team often accompanies the visits to properties and signing contracts.
- Opening a bank and credit card account; many banks do not offer English application forms.
- Obtaining a cell phone; a staff helps them signing a contract.
- Daycare on the campus; staff explains how on-campus daycare works, particularly phone calls when breastfeeding is needed, and various needs in daily life, including emergency health care and pregnancy.

・Various needs in daily life, including emergency health care and pregnancy.
・Free "survival Japanese" lessons to newly arriving international researchers and their families. They are also welcome to take more advanced classes if interested.

We subsidize the full-time researchers a half of the tuition at international schools; this is important since children experience great difficulty in the Japanese public school system.

Concerning visitors, it is necessary to help them with mundane but non-trivial problems they encounter during their stays. The Kavli IPMU website provides helpful information for both visitors and employees for professional and daily living issues, including safety. We also set up a system to provide day care support for visitors with small children.

The University well appreciated this attempt, and the Kavli IPMU Administrative Division was honored with the UTokyo President's Award for Operational Improvement and business transformation six times [(6) of 9 challenges]. In addition, the University has made a special effort to provide visitors housing. The Kashiwa International Guesthouse was opened in March 2010, where the Kavli IPMU was allocated 16 units. To further enhance living support, the Kavli IPMU has made a contract with a 24-hour service center for foreigners.

It should be noted that the Kavli IPMU administration helps researchers to prepare research grant applications. We conduct a training session on how to write successful grant proposals and provide help on documents. This encourages researchers to secure research funding such as JSPS Grants-in-Aid without any severe barriers, and we achieved about 36% of the adoption rate on average.

In 2020, due to the COVID-19 pandemic, researchers had to limit their movement. In particular, it has become tough to move across countries. We took special care for such researchers who could not enter Japan as described in "7. Others" of this report in detail.

4-4. Others

Describe the Center's policy for sending Japanese researchers overseas to gain international experience, and give examples of how the Center is working to create career paths for its researchers within a global environment of researcher mobility.

The Kavli IPMU has a policy that all full-time researchers have to spend one to three months abroad each year. This policy provides ample opportunity for young members to expose themselves by giving talks at conferences and seminars abroad. The approach dramatically helps them raise their visibility in the international community, and opportunities for subsequent career developments. We provide 500,000 yen of research support annually, which is intentionally insufficient to pay for the entire trip. The young researchers are supposed to contact host institutions on their own to arrange support and opportunities for talks. This approach is booming, given the fraction of our postdocs moving on to other academic positions. Many international visitors also help them with exposure; some American postdocs remarked that they met far more famous scientists at the Kavli IPMU than at a typical American university.

Their visits also help young researchers learn about the international landscape of research and learn career paths. One young postdoc researcher at the Kavli IPMU moved to Institute for Advanced Study (IAS) in Princeton, and after several years, came back to the Kavli IPMU as a faculty member. Later on, he moved to IAS again for further collaborative activities while keeping his position at the Kavli IPMU.

Other good examples of researcher mobility through the Kavli IPMU are:

1. One mathematician came to the Kavli IPMU as a postdoc after receiving a Ph.D. from UC Berkeley and teaching experience as a lecturer at MIT. After two years of research at the Kavli IPMU, he was appointed as a tenure-track assistant professor at Tsukuba University.
2. Another case is a new idea to stimulate researcher's mobility, based on the agreement between TRIUMF and the Kavli IPMU. For the first five years, an applicant can work in both laboratories with a specific job effort as a tenure-track. After five years, an applicant can choose one of the laboratories for a permanent position. In 2013, one prominent postdoc won this new position and started research under 75% at the Kavli IPMU and the rest at TRIUMF.
3. A former Kavli IPMU postdoc and mathematician obtained a Hakubi assistant professor position at Kyoto University, contributing to Japanese academia's globalization.
4. Another former Kavli IPMU postdoc became an assistant professor in the Department of Mathematics at Kyoto University.
5. In 2018, a postdoc in mathematics obtained an assistant professor position at the University of Edinburgh. Postdocs in experimental physics and cosmology also include one who became an assistant professor at Tsinghua University, and one an associate professor at Shanghai Jiao Tong University.
6. In 2019, one postdoc in astronomy became an assistant professor at NAOJ, while another postdoc in astronomy became an associate professor at Shanghai Jiao Tong University.
7. In 2020, a Japanese postdoc in mathematics got an assistant professor position at Osaka University, and another postdoc became an assistant professor at Okayama University.

We also actively compete for additional resources from funding agencies to support our young researchers to obtain experience and exposure abroad. One program from JSPS provided 86 million yen to send 88 members abroad, and 16 among them stayed abroad longer than two months.

5. Making Organizational Reforms and their Ripple Effects (within 3 pages)

5-1. Decision–making system in the center

Describe the strong leadership that the director is giving on the Center's operation and its effect, and the division of roles and authority between the Center and its host institution.
- In Appendix 3-3, draw a concrete diagram of the Center's management system.

The Director continues to uplift the Kavli IPMU by recruiting the very best scientists worldwide and promoting the science carried out at the Kavli IPMU in both the scientific community and the public sector. Toward achieving this goal, the Director receives advice at different levels from the Executive Board (EB), Steering Committee (SC), and External Advisory Committee (EAC).

The EB, consisting of the Director, three Deputy Directors, and the Administrative Director, is held regularly, typically once a month, to ensure smooth operation and swift decision making on daily matters. The EB members also take an essential role when the Director makes direct access to the University President's office.

The EAC members, consisting of seven internationally well-known outstanding experts, meet at least once a year and provide valuable advice to the University President on the activities and achievements at the Kavli IPMU.

In Jan 2011, the Todai Institutes for Advanced Study (TODIAS) was established, and the Kavli IPMU became the first institute (5-3. System reforms advanced by WPI program and their ripple effects). This new framework introduced no difference in the decision-making system of the Kavli IPMU. The SC consists of the EB and a couple of PIs, serves as the personnel committee for faculty, and reports the TODIAS Steering Committee's decisions. TODIAS is renamed UTIAS in April 2015.

On Feb 1, 2014, the Office for Research Strategies was opened, with the support UTokyo, reporting directly to the Director to strengthen the research activities by pursuing the external funds. A new university research administrator (URA) was hired to start the office activities.

5-2. Arrangement of administrative support staff and effectiveness of support system

Describe the assignment of the Center's administrative support staff who have English language and other specialized skills, effort made in establishing the support system, and the system's effectiveness.

From the beginning, the Director eagerly desired to establish a "Utopia for researchers" to make an environment where international researchers could devote all their attention to research. Many bilinguals were hired as supporting administrative staff to help international researchers to start their lives in Japan.

At the end of FY 2020, the number of administrative staff was 38, and the number of research support staff at the Kavli IPMU was 28. The administrative division's daily administrative matters that the Administrative Director supervises with the help of the General Manager. There are nine staff members in the general affairs section (including three public relation specialists and one in charge of the library), four in the accounting section, five in the international relations section (including one in charge of lodgings and one Japanese language class instructor), four in the budget control, five in the purchasing section, four in the Kamioka Satellite office, and one for planning & assessment.

Out of 38, half of the staff members are bilingual, and two have a particle physics background. This team handles all logistics for newly arriving staff and visitors, in particular those from abroad. The team helps to organize international conferences and workshops and filing research grant applications and other paperwork. They are also responsible for managing various public outreach activities such as public lectures, publication of the Kavli IPMU Monoshiri Newspaper, and updating the Kavli IPMU website covering a wide variety of information.

The public relations officers manage press releases and press conferences in a timely fashion with a good relationship with UTokyo's public relations office and the Kavli Foundation. We have built a system to work with international media outlets. We are members of interactions.org, an international organization of significant particle physics laboratories acting as an outlet to the global media. Currently, we post press releases to EurekAlert! in the US, managed by AAAS, AlphaGalileo in Europe, and Asia Research News in Asia. Three staff members have skills in computing support, including managing servers. One staff member is an artist helping scientists with visualization for publications and press release material. A member has a background in finances with excellent human skills and works with donors to attract private donations.

As proposed by the Director at the beginning of the Kavli IPMU, the daily teatime at three o'clock is now a "healthy" habit of the Kavli IPMU residents encouraging their informal and interdisciplinary discussions. The administrative staff assists in a systematic arrangement for this activity every day. Discussions during teatime often stimulate researchers to publish multidisciplinary papers.

5-3. System reforms advanced by WPI program and their ripple effects

Concisely itemize the system reforms made to the Center's research operation and administrative organization, and describe their background and results.

Describe the ripple effects that activities to disseminate experience and know-how accumulated by the Center, such as the followings,

have/had on the host institution (or other research institutes, if any):
- System reforms made through the Center's leading activities to its research operation and administrative organization
- Experience and know-how accumulated by the Center as it has worked to establish itself as top world-level research institutes.
Other than the above, give examples, if any, of cooperative activities by the Center and the whole WPI Program or other WPI centers, to disseminate experience and know-how accumulated by the WPI program and/or the WPI centers.

It must be stressed that the UTIAS is a crucial system reform stimulated by the WPI program. In Jan 2011, UTokyo established the TODIAS (afterward renamed as UTIAS) and approved the Kavli IPMU as the first member institute within this new and permanent organization. This was the most drastic organizational reform since 1949 at UTokyo. It was established as a university-wide organization and comprises research institutes, each demonstrating its function as a world-leading center of knowledge, aiming to enhance the University's academic excellence as a whole and further advance its internationalization.

The UTIAS structure enabled the Kavli IPMU to request operating funds from MEXT, giving the Kavli IPMU a means to acquire resources to sustain itself permanently. In FY2015, the UTIAS received five permanent posts and finally 13 posts in 2017 to guarantee outstanding research and education in the research division.

When launched by the WPI program in Oct 2007, the (Kavli) IPMU was given a status of "special district" within UTokyo where top-down management, flexible hiring system, and merit-based salary system had been made possible. Inspired by the WPI program and stimulated by real experiences inside the Kavli IPMU, UTokyo has intensified the following system reforms to make the Kavli IPMU a world-leading institute: merit-based salary scale, joint (split) appointments, tenured position with non-traditional external funding, "Nenpo" system, flexible management of positions, assist by bilingual administrative staff, and Kavli endowment and naming.

The former Director H. Murayama is the first example of a split appointment with an institution outside Japan and a merit-based salary. For example, one professor, N. Yoshida, started a split appointment between the Faculty of Science and the Kavli IPMU with a split effort of 60/40%. Another professor, M. Hazumi, made a joint appointment between KEK and the Kavli IPMU with a split effort of 80/20%. A tenure-track assistant professor (now an associate professor at the Kavli IPMU), M. Hartz, was hired under a newly established joint TRIUMF-Kavli IPMU agreement, as briefly mentioned in 4-4. We have nine joint appointments within two years from 2020.

All these reforms give high mobility for faculty, which could be a possible catalyst for destructing the university's compartmentalization. The impact of this change will be felt not only in UTokyo but also across the nation, with other institutions likely to make similar changes.

We take the role of an evangelist to make these reforms permeate the system to boost the overall competitiveness of research in Japan. One of the examples we have achieved to spread these reforms can be seen in the Administrative Director's contribution to Tokushima University on the program established by the Cabinet Office project "Promotion of Regional Industries and Universities". He gave a lecture to the President and board members of Tokushima University on the detailed successful experience of the WPI program at the Kavli IPMU. He has been assigned as a member of the External Evaluation Committee of the newly established laboratory at the university [(6) in 9 challenges].

5-4. Support by Host Institution

The following two items concern the support that the host institution provides the Center. Describe the measures that the host institution has taken to sustain and advance the Center's project. That include those items of support that it committed to at the time of the initial project proposal submittal or in its revised commitment following the project's interim evaluation.

5-4-1. Record of host institution support and its effects

・ In Appendix 6-1, describe the concrete measures being taken by the host institution.

At the time of the original proposal, UTokyo made many exceptions to the Kavli IPMU as a "special district" within the University: flexible salary system, longer appointments than traditional fixed-term positions, moving some PIs with advantageous arrangements with retirements from traditional departments, employment after retirement, etc. UTokyo also committed to building the main research building specifically for the Kavli IPMU and a new international lodge near the Kashiwa campus, which became a main residential facility for international researchers who have moved to the Kavli IPMU, and short-term visitors. After the Kavli IPMU was established, it also provided extra assistant professor positions to aid PIs to be freed from duties to be involved in research at the Kavli IPMU. Former UTokyo President J. Hamada decided to accept Kavli's donation despite some concerns and opposition within the University.

As described in the previous section 5-3, the creation of TODIAS (later UTIAS) in 2011 is an outstanding support, providing a permanent place for the Kavli IPMU within the University. Under this structure, UTIAS requested funding to MEXT to sustain the activity and won 13 permanent positions in UTIAS in 2017. Following the interim evaluation, UTokyo made several measures to make the Kavli IPMU sustainable. Finally, the University provided the Kavli IPMU with 10 tenure positions at the President's discretion. The University also secures nine people from the administrative bureau of the University. During the WPI

program committee meeting in 2020, President M. Gonokami declared that "we will maintain IPMU as our permanent institute at its current high level of activities, after the WPI program support ends" by strengthening the Kavli Foundation fund, and securing budget request for permanent institute. The success of the Kavli IPMU has given credibility to UTokyo, a bond which is secured by the value of knowledge obtained by university research [(9) in 9 challenges].

5-4-2. Position of the Center within the host institution's mid-term plan

・ To Appendix 6-2, excerpt the places, in the host institution's "Mid-term objectives" and/or "Mid-term plan" that clearly show the positioning of the WPI center within its organization.

Based on the President's Action Scenario FOREST2015, the University founded TODIAS in 2011 as a university-wide organization to pursue academic excellence and globalization of research environment, and placed the Kavli IPMU in TODIAS. Under this action scenario, UTokyo is taking any means necessary to support the Kavli IPMU.

In 2016, the University's "third phase" mid-term research objectives, and a mid-term plan were issued. This third term continues until the end of FY 2021. Two goals are clearly stated in the action plan: "Education" and "Research Level." They are:

- As for the progressive start to realize the objective, establish the "international excellent graduate school" to gather young excellent people from all over the world under the fascinating system of the world top level research initiative.
- Intensive investment should be accelerated on those highly appreciated institutes from over the world such as the UTIAS.

President's Action Plan "Vision 2020" emphasized the importance of "Expansion and Establishment of Internationally-renowned Bases for Research." The President recognized the Kavli IPMU perfectly matches his vision as a role model for the rest of the University.

In 2017, UTokyo was named a "Designated National University Corporation" by MEXT. This system requires universities to be at the top level in Japan in research quality, collaboration with society, and international cooperation. We believe that the Kavli IPMU has contributed to this appointment with a high global citation rate of published papers and the number of international co-authored articles. Later, in March 2020, it was decided the Kavli IPMU would continue to be a member institute at the UTIAS.

In addition to the WPI program committee's annual review, the University reviews us with an External Advisory Committee every year. The committee consists of world-leading scientists, currently chaired by J. Friedman (U. Chicago) together with J. Ellis (King's College London), G. Felder (ETH Zurich), M. Hayashi (JSPS), T. Nakada (Lausanne), S. Schafer-Nameki (Oxford), N. Smith (SNOLAB), and Y. Ruan (U. Michigan). Their report is transmitted to the President and Vice President of the University.

5-5. Others

Describe efforts advanced to foster young researchers (e.g., start-up funding, autonomous research environment) and to enlist female researchers.

・ In Appendix 3-1, 3-2, give the transition in the number and ratio of female researchers.

All postdoctoral fellows receive an annual research fund of 500,000 yen from the Kavli IPMU. Researchers at or above professor rank receive startup funds according to their needs. Effective startup of their research activity is expected to win the Grants-in-Aid sooner to develop the research drastically. The Kavli IPMU organizes an introductory guide on how to win the Grant-in-Aid, especially for international researchers.

To enlist female researchers, the Director, Deputy Directors, PIs, and faculty members are making an effort to showcase the excellent research environment and promising future in the Kavli IPMU on many occasions. In FY2013, A. Leauthaud, previously a Kavli IPMU postdoc, was appointed as an assistant professor, the first female faculty member. H. Yokoyama was appointed as the first female member of our Steering Committee in 2019. We now have nine female postdocs (15%), and 9% of researchers are female in 2020. However, only two women are PIs (M. Nojiri and Y.-K. Kim) (7%). Continuous efforts to search for a new woman PI and to increase the number of female faculty members as well as the number of female researchers have been kept through every opportunity, e.g., international conferences, workshops, advertising research activities, and our engaging intellectual environment, including daycare system on campus. To encourage more young female students to pursue science, the ICRR and Kavli IPMU invites junior-high and high school girls and their parents to hear from women researchers about their work, try experiments, and ask women researchers career questions.

6. Outreach Activities

Describe what was accomplished in the center's outreach activities during the period from 2007 through March 2020 in Appendix 5a. List up to three of the Center's outreach activities carried out during the period between FY 2017 and FY 2020 that have

contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program in Appendix 5.

The Kavli IPMU has been extremely active in the outreach to the general public and high-school students, because we believe our science would excite the public, improve scientific literacy, and attract the young minds to science, technology, engineering, and mathematics which are crucial for the future of the country. We mobilized more than 60,000 people in our outreach events, organized schools for high-school students, and female students in particular. We also attract keen attention from the media, both domestically and internationally. The number of the media coverage exceeds 4400 so far. Nearly a million copies have been printed of popular books written by our members.

In March 2016, the Kavli IPMU hosted the public lecture "East and West View of the Universe". Y. Nomura and a Chinese philosophy expert T. Nakajima gave a talk and discussed the East and West views of the Universe, and how physicists and philosophers view the cosmos. In Dec 2015, we held the 1st Kavli IPMU-ELSI joint public lecture "Question of Origins" to discuss the origin of the Universe, life and Earth, the history of science and concept of human [(8) of 9 challenges].

The Kavli IPMU led the Space Warps project. It is a citizen science project where everyone can be a part of real research on the Internet. Einstein predicted that massive objects, such as stars, would bend the space around them such that passing light rays follow curved paths. This is called strong lensing. To date, human beings are better suited in distinguishing the lens features from other objects that look like lenses. As cosmic surveys are getting bigger we have asked citizen scientists to help find such lenses. We received over a million classifications within one week of the project launch with the help of over 5000 registered users. The group led by A. More discovered 29 new lens candidates from the CFHT Legacy Survey based on about 11 million classifications performed with the help of citizen scientists (A. More et al. MNRAS 455 (2016) 1191-1210). Some keen citizen scientists have mastered tools to make models for lenses to understand them further [(8) of 9 challenges].

H. Ooguri was elected to the Japan Writers' Association. He was nominated to the Association by the Vice-Chair M. Mita and the Board member M. Murakami. He published a new book titled as "Quest to the Truth – Dialogue between Buddhism and Astrophysics".

The Kavli IPMU invited M. Gabriel, Professor of Philosophy at U Bonn and the best-selling author of "Why the World Does Not Exist", to speak at our public lecture event "Universe x World" held at Miraikan science museum. More than 200 people came to the event to listen to lectures by M. Gabriel and Y. Nomura, and their discussion. Transcripts of these talks were published in the Japanese magazine "Gendai Shiso (Contemporary Philosophy)".

Since 2016, the Kavli IPMU has co-hosted a science career event together with the UTokyo's Institute for Solid State Physics, and the Institute for Cosmic Ray Research, specifically aimed at female undergraduate and graduate students. In Japan, the number of women who choose careers in science, particularly physics, is still extremely low. Students with an interest in physics are faced with many challenges, including a lack of female leaders who can give them advice, and few peers to share their issues. At the event, a number of speakers talked about their own career paths, and discussion times were extended to encourage participants to meet other participants to build up their support network. Lately, an after-event dinner has been introduced for students wishing to have more time to get to know other participants. In the past, participants have commented that listening to working women with science careers talk about their own career choices has been a great help in thinking about their own future choices. Others have said that it was worth their time to meet other students with similar interests to their own [(8) of 9 challenges].

The science movie "The Man from the 9 Dimensions" supervised by H. Ooguri, received the 2016 Best Educational Production Award, and continues to be shown worldwide. It has been running continuously for three years, both in English and Japanese. Now, Chinese and Spanish versions have been made, and a German version premiered in Hamburg in fall 2019. In 2018, it was shown in Bogoda, Chicago, Hamburg, Hong Kong, Bangalore and Mumbai, as well as in several locations in Japan. H. Ooguri gave public talks together with the movie at some of these locations.

H. Murayama appeared on NHK documentary series Last Lecture as "Physicist Hitoshi Murayama". The show aired on NHK-BS1 on 20 Feb 2019. More than 100 university undergraduates and graduate students in the UTokyo came to hear Murayama's lecture, which was made for the program. The Last Lecture series focuses on the presenter of the episode, who is asked to prepare a talk as if it was his or her last day on Earth. H. Murayama titled his talk, "The Monkey who does Science". He talked about why he became interested in science, when he decided to become a researcher, and shared many stories from his years working in physics. He also talked about the competitive environment of research, and about the projects and papers he is currently involved with. His story about how he became H. Murayama the researcher was well received by viewers, and the episode became the fifth most-watched show on NHK's online channel on 22 Feb 2019. Because of its popularity, NHK-BS1 aired a re-run of the program [(8) of 9 challenges].

The Kavli IPMU collaborated with CoREF (Consortium for Renovating Education of the Future) to find a way to place the latest advances in scientific research into the high school curriculum. An event was carried out to test the development of an interactive lesson called "From high school physics to frontier research

of the Universe", which H. Murayama spoke and took part in. High school students and teachers were invited to try learning about the universe [(8) of 9 challenges].

We held Elegant Mathematics exhibition exploring the beauty and role of mathematics in everyday life at UTokyo's Kashiwa Library, and at the Kavli IPMU during Open Campus. The Elegant Mathematics exhibition was originally developed by Y. Ito during her time at Nagoya University, as part of an activity with the local students to create a mathematics museum. She also gave a public talk during Open Campus regarding her work supervising the exhibition, which was attended by about 110 visitors [(8) of 9 challenges].

On 19 April 2019, H. Ooguri made a guest appearance on public broadcaster NHK General's popular TV show "Chiko-chan's Don't Sleep Through Life". Prior to the airing, a TV film crew had visited the Kavli IPMU to record footage inside the Kavli IPMU building and the Director's office. H. Ooguri appeared on the show as an expert to explain what gravity is to a general audience. "Chiko-chan's Don't Sleep Through Life" tackles questions that pop up in everyday life through the eyes of its main character, a 5-year-old girl called Chiko-chan. The show features various experts who help explain everyday things to Chiko-chan.

The Kavli IPMU has released "はてな宇宙 (Ask A Scientist)" video series where the Kavli IPMU researchers address the mysteries of the Universe in very simple words. To commemorate Princeton University Emeritus Professor J. Peebles' achievement in receiving the 2019 Nobel Prize in Physics for his theoretical discoveries in cosmology, Kavli IPMU Deputy Director M. Sasaki explained J. Peebles Nobel Prize-winning research in a special episode of Ask A Scientist. M. Sasaki highlighted three points, including the understanding of the presence of helium following the Big Bang, changes in the cosmic microwave background, and the structure of the Universe. The video was first shown during Open Campus (Oct 25 and 26) at Kashiwa Campus, and later uploaded to the Kavli IPMU's YouTube Channel, where it has been viewed 1800 times to date. So far we have released 35 videos and 5 special ones for Nobel physics prizes, which were posted on YouTube and continue to attract viewers [(8) of 9 challenges].

During the COVID-19 pandemic, we have continued outreach activities online.

We held an online talk series by four researchers featured in the Kavli IPMU Monoshiri Newspaper, which is a wall newspaper by the Kavli IPMU and aims to present easy-to-digest physics and mathematics talks that can be enjoyed by all, including people without a background in science. Each introduced research from their personal experience for around 30 minutes for junior and senior high school students and adults to enjoy the presentations remotely. [(8) of 9 challenges]

The Kavli IPMU and the Japan Association of Communication for Science and Technology (JACST) presented an online talk by Y. Toda, titled "Fundamental Talks, Vol.01: Mathematics – how to interact with objects in non-everyday manner". Fundamental Talks is to be a 10-part series of seminars. Researchers from cutting-edge science, social sciences and contemporary art will be speakers for the events.

We hold a Kavli IPMUxICRR joint general lecture every year. The lecture in 2020 was "Explorations of the unknown and outer-most limits of the Universe and as New Physics" online for the audience of junior high school students and above. H. Takeo talked about the Belle II experiment and N. Koji (Associate Professor of ICRR) talked about gamma-ray bursts seen from the ground. We held another online Kavli IPMU x ICRR Joint Public Lecture: "New era of Space telescopes", where H. Tagoshi (ICRR) and J. Silverman gave lectures for junior high school students and above. We held the 6th Kavli IPMU, ELSI, and IRCN Joint Public Lecture online: "A Question of Origins". K. Fujishima (ELSI), H. Miyamoto, (IRCN) and T. Watari delivered public lectures for high-school students and above online. Moderated by a political science expert, the discussion also touched on cutting-edge scientific research and the theme, "What does it mean to ask a question of origins?" [(8) of 9 challenges].

We held an online screening of the film "Secrets of the Surface: The Mathematical Vision of Maryam Mirzakhani" illustrating the life and mathematical work of Maryam Mirzakhani, the first woman and the first Iranian to be honored with the Fields medal. We invited the Film Director George Csicsery and other specialists on Mathematics including M. Yamazaki and had a panel discussion.

7. Others

In addition to the above 1.-6. evaluation items, note any of the Center's leading activities, distinctive features or other important points that denote its status as an "internationally visible research center."

In 2012, IPMU was named after Mr. Fred Kavli by accepting a donation from the Kavli Foundation of the United States and establishing an endowment. The motivation to bear Kavli's name was two-fold: endowment and prestige. Because of the steady and flexible endowment income that can be carried over fiscal years, it already allowed us to overstretch our finances to go aggressively after postdoc candidates and research objectives. The stable endowment income also will enable us to acquire a loan from UTokyo to help with cash flow in our research projects. The prestige factor is difficult to quantify, but it appears to have made a big splash within the community that the WPI institute was now recognized internationally with this donation. The "Kavli IPMU" is the first research center in Japan named after a donor of endowment,

a symbol of system reform. Fortunately, in FY 2015, the UTIAS (the University of Tokyo Institutes for Advanced Study) won five (to be increased to nine in FY2016) permanent posts to guarantee outstanding research and education in the UTIAS. The Kavli Foundation regards this progress due to solid support by UTokyo, and they decided to increase a donation as an adequate matching fund.

For UTokyo, of course, there has been no previous experience to accept endowment from a foreign foundation. It provided an opportunity for UTokyo to reexamine and reform the systems for managing donated funds.

In 2014, the Kavli IPMU and Hamamatsu Photonics K.K. established the Endowed Research Unit: Dark Side of the Universe and K. Nomoto was assigned as the post of Hamamatsu Professor, and H. Murayama was also appointed as Hamamatsu Professor from FY 2019.

One more activity resulting in strengthened global visibility of the Kavli IPMU is the following. In 2012, UTokyo signed an agreement to deliver courses through online education provider Coursera. This rapidly growing Massive Open Online Course (MOOC) provider offers courses online for anyone to take for free. H. Murayama was chosen as the first instructor of the MOOC courses provided by UTokyo. His course was popular and signed up by nearly 50,000 people from more than 140 countries worldwide. H. Murayama delivered a speech titled "Science for peace and development today and tomorrow" at United Nations (UN) Headquarters on the occasion of CERN's 60th anniversary. The UN web TV has widely broadcasted his spirit of founding the Kavli IPMU.

As a measure of our international visibility, we studied citation records obtained from the Web of Science by Clarivate Analytics. In CY2020, 507 refereed papers were published (589 when including WPI-related). Over the past 5 years, we have consistently produced many scientific papers: 349 (466) in CY2015, 353 (450) in CY2016, 306 (392) in CY2017, 403 (519) in CY2018 and 394 (496) in CY2019. Among the WPI papers published in CY2020, the rate of highly cited "top 1% of papers" was 27 (4.6%). We produced 4859 refereed papers excluding review papers from the institute's inception to Dec 2020. Among them, 293 papers have over 100 citations and 787 over 50 citations, and the average number of citations per paper is 34.4. We found that the progress made in publishing valuable scientific articles over the last five years has been enormous. These numbers are comparable to or better than those of world-leading institutes covering similar research areas as our Institute, such as the Institute for Advanced Study (Princeton), the Kavli Institute for Theoretical Physics (Santa Barbara), Yukawa Institute for Theoretical Physics (Kyoto), Perimeter Institute (Canada), and International Center for Theoretical Physics (Trieste), in the same period.

Dr. France Córdova, Director of National Science Foundation (NSF), visited and exchanged frank opinions regarding essential science support. For a few days, a local journalist with no math background was invited to Kavli IPMU, where he interacted with mathematicians in their daily work. His positive story on math was published in a national newspaper. We have since accepted another journalist from the USA.

A painter was invited to the institute for a month. Researchers welcomed him and attended his talk, workshop, and studio tour. A public exhibition of art pieces based on his stay was popular with visitors.

To achieve our mission to solve the most fundamental questions about our Universe, we believe it essential that all of us treat each other with respect, maintain our professional working environment free of harassment, challenge our preconceptions, and educate ourselves on our own biases. Under the strong leadership of the Director, we have been making various efforts to promote diversity:

- Bias training for personnel committees
- Revision of harassment training
- Best practices for selections and recruitments
- Codes of conduct for members and visitors
- Diversity requirements on our workshops
- Leadership opportunities for female and international scientists
- BLM inspired on-line discussions
- Weekly women's lunch

We also had an online colloquium entitled "Effective Evaluation Practices: Evidence for Research on Bias and its Consequences" by Joyce Yen, the Director of the ADVANCE Center for Institutional Change at the University of Washington, Seattle, in 2020. These initiatives have been gradually inspiring the university-wide movements as codes of conduct and diversity statements of UTokyo.

The worldwide COVID-19 pandemic significantly reduced people's movements. The same is true for researchers in the related field of the Kavli IPMU. The number of conferences and seminars performed on-site was tiny in 2020, and many came using an online video conference. We could not have regular "tea-time," which played an essential role in communications between different fields in IPMU. As described in 3-1, we started new virtual tea-time using "gather.town". We are sure that these movements to the online system will open a new wider world of researchers' communications.

In particular, foreign researchers' adoption became very tough because new entries into Japan are limited due to COVID-19. While proceeding with the procedure with the highest priority given to regular adoption after coming to Japan, the Kavli IPMU has been making an effort to minimize the disadvantages of foreign researchers adopted when they cannot enter Japan due to denial of landing by applying temporary employment abroad to them.

The impact of the COVID-19 has severely restricted the movement of young researchers, especially postdocs, putting them in severe circumstances worldwide. In 2020, we recruited six short-term postdocs, "Postdocs en passant", who could not move to their new appointments due to visa/travel restrictions but could come to Japan.

Under such circumstances, the Kavli IPMU has prevented researchers' infections and supports their research activities as much as possible. To protect the researcher's health, which we must prioritize more than anything, the Kavli IPMU restricted entry into the building by prohibiting any person not belonging to an IPMU-related building. Also, an apparatus at the building entrance measures visitors' body temperature automatically, and an audio alarm comes out when it detects a high body temperature. All members are also encouraged to disinfect their hands with alcohol disinfectants provided at all building places.

8. Center's Response to Results of FY 2020 Follow-up (including Site Visit Results)

* Describe the Center's response to results of FY 2020 follow-up. Note: If you have already provided this information, please indicate where in the report.

[SITE VISIT REPORT]

7. Actions required and recommendations

(1) One positive thing we learned from COVID-19 is that internet lectures draw interests from people young, and old, any time of the day, and anywhere in the world. Kavli IPMU internet lectures should continue with these in mind. Not only in Japanese but also in various foreign languages taking advantage of the international character of the laboratory.

We definitely agree with this comment. As we report at Appendix 5b, Outreach Activities and Their Results, we experienced that we can show our activities to wide variety of people by using internet tools effectively. Under the COVID-19 situation we are not allowed to meet together in person and at first we thought this is very bad condition from the point of view of outreach since we thought that only in person communication gives us the reality. We organized "Monoshiri online talks" based on the speakers who has once appeared in the regular Monoshiri Newspaper issued by the Kavli IPMU. About 1800 audiences joined for 4 lectures covering various topics on Mathematics, experimental physics, cosmology and diversity.

(2) Several efforts exist to deal with outflow of data from HSC and PFS, and perhaps other projects.

A. Data Analysis Committee has been formed to recommend computational infrastructure upgrades needed to accommodate the data resulting from these experiments.
B. "Cosmology with Big Astronomical Data Using Innovative Image Analysis Methods"
C. Collaboration with ISM which started in previous years.

Needless-to-say, all these efforts must be harmonious toward one goal.

In addition to this combination, big data handling technology and computational infrastructure should be formed for CMB project, LiteBIRD in coming years. We also decided to strengthen the collaboration at the Rubin Observatory and the LSST community. We will prepare for required computational infrastructure to show our proactive contribution and initiative on these projects.

(3) University bonds, secured by "the value of knowledge obtained by university research" will be offered in Japan. Scientists and government agencies understand "the value of knowledge obtained by university research". To increase the quality of the human-race, "university research is valuable" must be understood by everyone. WG hopes that all the Kavli IPMU public lectures will emphasize this point.

We are planning a public lecture to mark 15 years of WPI-supported activities next year. It is true that ties with the university have been secured by the government because it is understood that "the value of knowledge obtained by university research" is effective in raising the quality of the human race.

[FOLLOW UP REPORT]

1. 4. Actions required and recommendations

(1) Kavli IPMU maintains a very good relationship between the university president and other university

management teams. It has contributed to UT by offering ideas for system reforms, as well as improving UT's international position. The PC would like Kavli IPMU to maintain a close relationship with the new president, who will take office in the spring of 2021.

The new President T. Fujii was a former executive member in charge of finance, social relationship and fundraising. Last year, the Kavli Foundation and UTokyo renewed contracts, boosting its endowment to US$10 million. Director H. Ooguri assisted executive T. Fujii at the time he visited the Kavli Foundation in California. One of the challenging initiatives of new President T. Fujii will be the diversity initiative. Director H. Ooguri has strengthened this point since after he took over the directorship of the Kavli IPMU. Also, the new executive member, Vice President H. Aihara, who is now Project Professor at the Kavli IPMU, is in charge of WPI matters in UTokyo. We are confident we can maintain close and good relationship between the new UTokyo directorate.

(2) Japan's copyright law prevents Japanese academia from quickly releasing lecture materials to the public on line. This is a university issue, and its management must solve this problem quickly.

This is also a government issue as the main obstruction is the copyright laws and their interpretations. We are in contact with the copyright division of the Agency of Cultural Affairs, and we have been told: The Agency "is examining a possibility of copyright restrictions for research purposes and its scope" and "is studying rules and practices in other countries."

(3) Diversity initiatives are an important step for improving any organization. Kavli IPMU's initiatives should be a role model for UT as well for other institutes and companies.

Diversity has been one of the most important concerns for Director H. Ooguri. The Kavli IPMU Code of Conduct was established to clearly emphasize a diversity point of view. It initiates the UTokyo Code of Conduct afterwards. H. Ooguri appointed a foreign tenured faculty as the Director of the Kamioka branch, and also appointed a female professor as a member of the top decision-making committee.

(4) Some organized effort should be taken by Kavli IPMU, UT, and MEXT to imbed the successes achieved by Kavli IPMU in the way research is done in Japan.

The Kavli IPMU has opened the door to a new research scheme in Japan. UTokyo's specific action has been inevitable to achieve the present success. UTokyo established a new concept organization, UTIAS, which can incubate Kavli IPMU as a special district in the university under its wing. We set up the decision-making Steering Committee with minimum number of members instead of ordinal all faculty committee. MEXT played a great role to the started-from-scratch Kavli IPMU, securing budget requests for the permanent institute. UTokyo remains a top university in Japan, and has been sustained at an extraordinary level. The success of Kavli IPMU as WPI institute has been conveyed to various stages of academia in Japan as a Kavli IPMU evangelist. One example showing how we have achieved spreading these reforms can be seen in the Administrative Director's contribution to Tokushima University on the program established by the Cabinet Office project "Promotion of Regional Industries and Universities". He gave a lecture to the President and board members of Tokushima University on the successful experience of the WPI program at the Kavli IPMU. He has been assigned as a member of the External Evaluation Committee of the newly established laboratory at the university.

(5) Kavli IPMU still needs to address the issue of the gender balance as few of its PIs are female.

We have introduced significant changes to our faculty and postdoc search processes to improve our diversity, following recommendations by J. Yen, the diversity expert at the University of Washington, Seattle. For postdocs, this has led to immediate improvement in diversity. We are revamping our "Science and Society" research program, led by H. Yokoyama, to strengthen research to improve the STEM diversity. We submitted FY2022 budget request to UTokyo under the title "Diversity initiative". We will plan to invite female researchers and female undergraduate students as intern status. They will be able to stay for half year to study basic science at the Kavli IPMU. As for the matching of this program, we have already started an international solicitation for a female project assistant professor for diversity research.

Appendix 1-1 List of Papers Underscoring Each Research Achievement

* List papers underscoring each research achievement [1] ~ [20] listed in the item 2-1 "Research results to date" of 2. "Advancing Research of the Highest Global Level" (up to 40 papers) and provide a description of the significance of each (within 10 lines).
* For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is the same. If a paper has many authors, underline those affiliated with the Center.
* If a paper has many authors (say, more than 10), all of their names do not need to be listed.
* Place an asterisk (*) in front of those results that could only have been achieved by a WPI center.

*Research results 1: Primordial Black Holes

*1. R.g. Cai, S. Pi and M. Sasaki, "Gravitational Waves Induced by non-Gaussian Scalar Perturbations", *Physical Review Letters,* **122** (2019) no.20, 201101
DOI:10.1103/PhysRevLett.122.201101

Gravitational waves (GWs) induced by non-Gaussian curvature perturbations are computed. It is found that there appears a particular feature on the high-frequency side of the spectral peak of the induced GWs which, if observed, is a smoking gun of the primordial non-Gaussianity. Furthermore, if PBHs with masses of 10^{20}g to 10^{22}g are identified as cold dark matter of the Universe, the corresponding GWs must be detectable by LISA-like detectors, irrespective of the degree of non-Gaussianity.

*2. H. Niikura, M. Takada, N. Yasuda, R. H. Lupton, T. Sumi, S. More, T. Kurita, S. Sugiyama, A. More, M. Oguri, M. Chiba) "Microlensing constraints on primordial black holes with Subaru/HSC Andromeda observations", *Nature Astronomy*, **3** (2019), 524
DOI:10.1038/s41550-019-0723-1

Primordial black holes (PBHs) have long been suggested as a viable candidate for the elusive dark matter. The abundance of such PBHs has been constrained using a number of astrophysical observations, except for a hitherto unexplored mass window of $M_{PBH} = [10^{-14}, 10^{-9}]$ solar masses. Here we carry out a dense-cadence, 7-hour-long observation of M31 with the Subaru Hyper Suprime-Cam (HSC) to search for microlensing of stars in M31 by PBHs lying in the halo regions of the Milky Way and M31. Given our simultaneous monitoring of tens of millions of stars in M31, if such light PBHs make up a significant fraction of dark matter, we expect to find many microlensing events. However, we identify only a single candidate event, which translates into stringent upper bounds on the abundance of PBHs in the mass range $M_{PBH} \simeq [10^{-11}, 10^{-6}]$ solar masses.

*Research results 2: B-mode Polarization of Cosmic Microwave Background

*3. M. Hazumi et al. (LiteBIRD collaboration including T. Ghigna, N. Katayama, T. Matsumura, Y. Sakurai, S. Stever, H. Sugai, S. Takakura), "LiteBIRD satellite: JAXA's new strategic L-class mission for all-sky surveys of cosmic microwave background polarization", *Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE) International Society for Optics and Photonics*, **11443** (2020), 114432F
DOI:10.1117/12.2563050

LiteBIRD, the Lite (Light) satellite for the study of B-mode polarization and Inflation from cosmic background Radiation Detection, is a space mission for primordial cosmology and fundamental physics. LiteBIRD plans to map the cosmic microwave background (CMB) polarization over the full sky with unprecedented precision. Its main scientific objective is to carry out a definitive search for the signal from cosmic inflation, either making a discovery or ruling out well-motivated inflationary models. The measurements of LiteBIRD will also provide us with an insight into the quantum nature of gravity and other new physics beyond the standard models of particle physics and cosmology. This is an overview paper of the LiteBIRD project, including scientific objectives, mission requirements, top-level system requirements, operation concept, and expected scientific outcomes.

*Research results 3: Pure Gravity Mediation and Theories of the Higgs Boson

*4. M. Ibe and T. T. Yanagida, "The Lightest Higgs Boson Mass in Pure Gravity Mediation Model", *Physics Letters*, **B709** (2012), 374-380
DOI:10.1016/j.physletb.2012.02.034

The Pure Gravity Mediation (PGM) was proposed just after when the strong evidence of the Higgs boson was discovered at the LHC in December 2011. This is the first paper of the PGM, in which it was shown that the observed Higgs boson mass of about 125 GeV is naturally explained in the model. Furthermore, it was also

stressed that there is no phenomenological and cosmological problems in the PGM. Because of its simple and beautiful structure of the SUSY breaking and mediation mechanism and its consistency with all experimental results, this PGM model has been widely accepted as the most motivated and interesting scenario beyond the standard model in the particle physics community. In fact, there are a lot of follow-up papers. For example, the paper by the Princeton group (N. Arkani-Hamed et al., arXiv:1212.6971) is one of them. The PGM provides now a strong motivation for the future 100 TeV hadron collider discussed seriously at CERN.

note: T. T. Yanagida is mistakenly affiliated with ICRR in this article, but his correct affiliation is the Kavli IPMU.

***Research results 4: Particle phenomenological studies of dark matters**

*5. S. Matsumoto, S. Shirai, M. Takeuchi, "Indirect Probe of Electroweakly Interacting Particles at the High-Luminosity Large Hadron Collider," *Journal of High Energy Physics,* **06** (2018), 049
DOI:10.1007/JHEP06(2018)049

Indirect detection of thermal dark matter candidates that have a weak charge of the standard model at high-energy (hadron) collider experiments has been proposed; the dark matter candidates can be indirectly searched for by precisely observing Drell-Yan processes into SM lepton pairs. This study has been evaluated high at the collider physics community as we are now in the era of searching for new physics from precision at high-energy collider experiments. The study has also called for further developments at the Kavli IPMU (S. Matsumoto, S. Shirai, M. Takeuchi, 2018; T. Katayose, S. Matsumoto, S. Shirai, 2021).

*6. X. Chu, C. Garcia-Cely, H. Murayama, "Velocity Dependence from Resonant Self-Interacting Dark Matter", *Physical Review Letters,* **122** (2019) 7, 071103
DOI:10.1103/PhysRevLett.122.071103

The dark matter density distribution in small-scale astrophysical objects may indicate that dark matter is self-interacting, while observations from clusters of galaxies suggest that the corresponding cross section depends on the velocity. Using a model-independent approach, we show that resonant self-interacting dark matter can naturally explain such a behavior. In contrast to what is often assumed, this does not require a light mediator. We present explicit realizations of this mechanism and discuss the corresponding astrophysical constraints. The resonant dark matter has also been further studied to quantitatively discuss the resonant scattering in more detail by a follow-up paper (H. Murayama et al., 2019).

*7. Y. Hochberg, E. Kuflik, H. Murayama, T. Volansky, J. G. Wacker, "Model for Thermal Relic Dark Matter of Strongly Interacting Massive Particles", *Physical Review Letters,* **115** (2015), 021301
DOI:10.1103/PhysRevLett.115.021301

A recent proposal is that dark matter could be a thermal relic of 3→2 scatterings in a strongly coupled hidden sector. The authors present explicit classes of strongly coupled gauge theories that admit this behavior. These are QCD-like theories of dynamical chiral symmetry breaking, where the pions play the role of dark matter. The number-changing 3→2 process, which sets the dark matter relic abundance, arises from the Wess-Zumino-Witten term. The theories give an explicit relationship between the 3→2 annihilation rate and the 2→2 self-scattering rate, which alters predictions for structure formation. This is a simple calculable realization of the strongly interacting massive-particle mechanism.

***Research results 5: Dark Matter Detection**

*8. K. Abe et al. (XMASS collaboration including K. Hiraide, K.Ichimura, Y. Kishimoto, K. Kobayashi, S. Moriyama, M. Nakahata, H. Ogawa, H. Sekiya, A. Takeda, M. Yamashita, B.S.Yang, J. Liu, K. Martens, Y. Suzuki, Y. Takeuchi), "Improved search for two-neutrino double electron capture on ^{124}Xe and ^{126}Xe using particle identification in XMASS-I", *Progress of Theoretical and Experimental Physics*, **2017** (2018) 5, 053D03
DOI:10.1093/ptep/pty053

We conducted an improved search for the simultaneous capture of two K-shell electrons on the ^{124}Xe and ^{126}Xe nuclei with the emission of two neutrinos using 800.0 days of data from the XMASS-I detector. A novel method to discriminate γ-ray/X-ray or double electron capture signals from β-ray background using scintillation time profiles was developed for this search. No significant signal was found when fitting the observed energy spectra with the expected signal and background. Therefore, we set the most stringent lower limits on the half-lives at 2.1×10^{22} and 1.9×10^{22} years for ^{124}Xe and ^{126}Xe, respectively, with 90%

confidence level. These limits improve upon previously reported values by a factor of 4.5.

*9. E. Aprile et al. (XENON Collaboration including K. Hiraide, K. Martens, S. Moriyama, A. Takeda, M. Yamashita), "Excess electronic recoil events in XENON1T", *Physical Review D,* **102** (2020) 7, 072004
DOI:10.1103/PhysRevD.102.072004

This paper reports results from searches for new physics with low-energy electronic recoil data with the XENON1T detector. The data enable one of the most sensitive searches for solar axions, an enhanced neutrino magnetic moment using solar neutrinos, and bosonic dark matter. An excess over known backgrounds is observed at low energies and most prominent between 2 and 3 keV. The solar axion model has a 3.4σ significance, and a three-dimensional 90% confidence surface is reported for axion couplings to electrons, photons, and nucleons. The neutrino magnetic moment signal is similarly favored over background at 3.2σ, and both results are in strong tension with stellar constraints. With respect to bosonic dark matter, the excess favors a monoenergetic peak at (2.3±0.2) keV (68% C.L.) with a 3.0σ global (4.0σ local) significance over background. This analysis sets the most restrictive direct constraints to date on pseudoscalar and vector bosonic dark matter for most masses between 1 and 210 keV/c^2.

***Research results 6: Cosmic Acceleration**

*10. T. Okumura, C. Hikage, T. Totani, et al. (including S. More, T. Nishimichi, N. Tamura, K. Yabe, N. Yoshida), "The Subaru FMOS galaxy redshift survey (FastSound). IV. New constraint on gravity theory from redshift space distortions at z~1.4", *Publications of the Astronomical Society of Japan,* **68** (2016), 38
DOI:10.1093/pasj/psw029

The authors give a new constraint on gravity theory by measuring the redshift-space clustering of galaxies of FastSound survey. FastSound is a spectroscopic galaxy survey using Subaru telescope with a new instrument Fiber Multi Object Spectrograph (FMOS), which enables the first cosmological study at a high redshift range of 1.19<z<1.55. They obtain 4.2σ detection of the anisotropy in redshift-space clustering due to the peculiar motion of galaxies known as "redshift-space distortions (RSD)", which is a key observable to test gravity theories on cosmological scales. Their result is consistent with the prediction of general relativity within the 1σ confidence level. This is a first clear confirmation that general relativity is valid even in such a high-redshift universe.

*11. N. Yasuda et al. (including M. Tanaka, N. Tominaga, T. Morokuma, N. Suzuki, I. Takahashi, K. Maeda, S. Ikeda, N. Yoshida), "The Hyper Suprime-Cam SSP transient survey in COSMOS: Overview", *Publications of the Astronomical Society of Japan,* **71** (2019), 74
DOI: 10.1093/pasj/psz050

This is the first overview paper on our Subaru/Hyper-Suprime Cam (HSC) Transient survey. Type Ia Supernova Cosmology aims to perform the most precise measurement of dark energy. The survey was performed for the 1.77 deg2 ultra-deep layer and 5.78 deg^2 deep layer in the Subaru Strategic Program over six- and four-month periods from 2016 to 2017, respectively. The ultra-deep layer reaches a median depth per epoch of 26.4, 26.3, 26.0, 25.6, and 24.6 mag in g, r, i, z, and y bands, respectively; the deep layer is ∼0.6 mag shallower. In total, 1824 supernova candidates were identified. Based on light-curve fitting and derived light-curve shape parameter, we classified 433 objects as Type Ia supernovae (SNe); among these candidates, 129 objects have spectroscopic or COSMOS2015 photometric redshifts and 58 objects are located at z > 1. Our unique data set doubles the number of Type Ia SNe at z > 1 and enables various time-domain analyses of Type II SNe, high-redshift superluminous SNe, variable stars, and active galactic nuclei.

***Research results 7: SuMIRe**

*12. H. Aihara et al. (HSC collaboration including K. Bundy, C. Hikage, S. Huang, A. Leauthaud, H. Miyatake, A. More, S. More, Y. Moritani, R. Murata, H. Murayama, T. Morokuma, H. Niikura, M. Oguri, N. Okabe, M. Ouchi, A. Shimono, J. D. Silverman, J. Speagle, N. Sugiyama, N. Suzuki, M. Takada, N. Tamura, N. Tominaga, E. L. Turner, K. Yabe, N. Yasuda), "The Hyper Suprime-Cam SSP Survey: Overview and survey design", *Publications of the Astronomical Society of Japan,* **70** (2018), S4
DOI: 10.1093/pasj/psx066

Hyper Suprime-Cam (HSC) is a wide-field imaging camera on the prime focus of the 8.2-m Subaru telescope on the summit of Mauna Kea in Hawaii. A team of scientists from Japan, Taiwan, and Princeton University is using HSC to carry out a 300-night multi-band imaging survey of the high-latitude sky. The survey includes

three layers: the Wide layer will cover 1400 deg2 in five broad bands (grizy), with a 5 σ point-source depth of r ≈ 26. The Deep layer covers a total of 26 deg2 in four fields, going roughly a magnitude fainter, while the UltraDeep layer goes almost a magnitude fainter still in two pointings of HSC (a total of 3.5 deg2). Here we describe the instrument, the science goals of the survey, and the survey strategy and data processing. This paper serves as an introduction to a special issue of the Publications of the Astronomical Society of Japan, which includes a large number of technical and scientific papers describing results from the early phases of this survey.

*13. C. Hikage, M. Oguri, T. Hamana, et al. (including S. More, M. Takada, F. Köhlinger, H. Miyatake, H. Aihara, A. Ducout, R. Murata, H. Murayama, N. Sugiyama, D. N. Spergel), "Cosmology from cosmic shear power spectra with Subaru Hyper Suprime-Cam first-year data", *Publications of the Astronomical Society of Japan,* **71** (2018), 43
DOI: 10.1093/pasj/psz010

They perform a cosmological analysis from cosmic weak lensing shear power spectra using the Subaru Hyper Suprime-Cam (HSC) survey first-year shear catalog. Thanks to the depth and the excellent-image quality of HSC, they obtain a high-significance measurement of the cosmic shear tomographic power spectra with a total signal-to-noise ratio of 16. For a flat Λ cold dark matter model, they find $S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.45} = 0.800^{+0.029}_{-0.028}$ from the HSC tomographic cosmic shear analysis alone. In comparison with Planck cosmic microwave background constraints, the results prefer slightly lower values of S_8 at 2 sigma level as with other lensing surveys such as DES and KiDS and may indicate physics beyond Lambda CDM model. They study the effect of possible additional systematic errors that are unaccounted for in their fiducial cosmic shear analysis, and find that they can shift the best-fit values of S_8 by up to 0.6σ in both directions. The full HSC survey data will contain several times more area, and will lead to significantly improved cosmological constraints.

***Research results 8: Derived Category of Coherent Sheaves and Counting Invariants**

*14. A. Bayer, E. Macri and Y. Toda, "Bridgeland stability conditions on 3-folds I: Bogomolov-Gieseker type inequalities", *Journal of Algebraic Geometry*, **23** (2014) 117-163
DOI: 10.1090/S1056-3911-2013-00617-7

Although Bridgeland stability condition is an important notion in mirror symmetry, its existence for projective Calabi-Yau 3-folds is still an open problem. In this paper, the authors constructed candidates of Bridgeland stability conditions on any projective 3-fold via double tilting of the category of coherent sheaves. Their construction led to the conjectural inequality evaluating the third Chern characters of certain two-term complexes of sheaves on 3-folds. Their inequality is interpreted to be the generalization of the classical Bogomolov-Gieseker inequality for algebraic surfaces, which have been desired for algebraic geometers for more than 30 years. Their inequality conjecture turned out to imply Fujita's conjecture for 3-folds, a classical and open problem in algebraic geometry.

*15. D. Maulik and Y. Toda, "Gopakumar-Vafa invariants via vanishing cycles", *Inventiones Mathematicae*, **213** (2018) 3, 1017-1097
DOI: 10.1007/s00222-018-0800-6

They proposed the definition of Gopakumar-Vafa invariants on Calabi-Yau 3-folds using perverse sheaves of vanishing cycles, which modify the earlier definitions by Hosono-Saito-Takahashi and Kiem-Li. We then formulated several conjectures relating GV invariants with Gromov-Witten and Pandharipande-Thomas invariants. Among them, they proved GV/PT correspondence for local surfaces with irreducible curve classes.

***Research results 9: Langlands Correspondence and p-adic Cohomology Theory**

*16. T. Abe, "Langlands correspondence for isocrystals and existence of crystalline companion for curves", *Journal of the American Mathematical Society*, **31** (2018), 921-1057
DOI: 10.1090/JAMS898

In this paper, the LC for p-adic theory is established and Deligne's conjecture on the existence of crystalline companion is proven in the curve case, which completes the research program T. Abe proposed a couple of years ago. The main difficulty is to construct a framework of p-adic cohomology theory. We already had "good" cohomology theory so called rigid cohomology by Berthelot. However, this theory is not sufficient since we need "variation theory". This is the same situation that in many applications, Hodge theory is not enough and Hodge modules are needed. For this, Berthelot introduced arithmetic $\mathcal{D}$-module theory. Thanks

to works by Berthelot, Caro, Kedlaya, and others, this theory was almost satisfactory for quasi-projective varieties. In this paper, Abe removed this limitation and made it work over certain algebraic stacks, which was indispensable to apply Lafforgue's technique to our situation.

*17. T. Abe, "Enhanced bivariant homology theory attached to six functor formalism", arXiv:2008.01948, Preprint

This is the article establishing the bivariant homology theory in the infinity-categorical setting. Even though six functor formalism has already been established in a very general situation by Gaitsgory and Rozenblyum, it is not straightforward to extract useful information from it. He deduced a bivariant homology theory from their formalism in this paper.

***Research results 10: Primitive Forms and Mirror Symmetry**

*18. T. Milanov, "The Eynard–Orantin recursion for simple singularities", *Communications in Number Theory and Physics*, **9** (2015) no. 4, 707-739
DOI: 10.4310/CNTP.2015.v9.n4.a3

The Eynard–Orantin recursion is only local in a sense that the spectral curve is a disjoint union of small discs. In this paper, he has extended the local spectral curve to an actual Riemann surface. This result allows him to think of Gromov–Witten theory as a Conformal Field Theory on the spectral curve and hence ideas from physics can be used to understand Gromov–Witten theory and vice versa.

*19. T. Milanov, "The period map for quantum cohomology of P^2", *Advances in Mathematics,* **351** (2019), 804-869
DOI: 10.1016/j.aim.2019.05.011

They invert the period map defined by the second structure connection of quantum cohomology of P^2. For small quantum cohomology, the inverse is given explicitly in terms of the Eisenstein series E4 and E6, while for big quantum cohomology the inverse is determined perturbatively as a Taylor series expansion whose coefficients are quasi-modular forms.

***Research results 11: Secondary Polytopes and the Algebra of the Infrared**

*20. M. Kapranov, V. Schechtman. "Perverse sheaves on real hyperplane arrangements", *Annals of Mathematics*, **183** (2016), 619-679
DOI: 10.4007/annals.2016.183.2.4

A classification of perverse sheaves smooth with respect to a stratification given by an arrangement of hyperplanes in the complex space with real equations. A description is given in terms of diagrams of vector spaces labeled by the real cells of the arrangements.

*21. A. Bondal, M. Kapranov, V. Schechtman, "Perverse schobers and birational geometry", *Selecta Mathematica*, **24** (2018) 85–143
DOI: 10.1007/s00029-018-0395-1

Perverse schobers are conjectural categorical analogs of perverse sheaves. They show that such structures appear naturally in Homological Minimal Model Program which studies the effect of birational transformations such as flops, on the coherent derived categories. More precisely, the flop data are analogous to hyperbolic stalks of a perverse sheaf. In the first part of the paper, they study schober-type diagrams of categories corresponding to flops of relative dimension 1, in particular, they determine the categorical analogs of the (compactly supported) cohomology with coefficients in such schobers. In the second part, they consider the example of a "web of flops" provided by the Grothendieck resolution associated to a reductive Lie algebra g and study the corresponding schober-type diagram. For g=sl(3) we relate this diagram to the classical space of complete triangles studied by Schubert, Semple and others.

*22. H. Nakajima, "Towards geometric Satake correspondence for Kac-Moody algebras -- Cherkis bow varieties and affine Lie algebras of type A", arXiv:1810.04293, Preprint

They gave a provisional construction of the Kac-Moody Lie algebra module structure on the hyperbolic restriction of the intersection cohomology complex of the Coulomb branch of a framed quiver gauge theory,

as a refinement of the conjectural geometric Satake correspondence for Kac-Moody algebras proposed in an earlier joint paper with Braverman and Finkelberg.

***Research results 12: Discovery of New Connection between Finite Group and Calabi-Yau Geometry**

*23. H. Ooguri and M. Yamazaki, "Emergent Calabi-Yau Geometry", *Physical Review Letters*, **102** (2009), 161601
DOI: 10.1103/PhysRevLett.102.161601

In this paper, H. Ooguri and M. Yamazaki showed how the smooth geometry of Calabi-Yau manifolds emerges from the thermodynamic limit of the statistical mechanical model of crystal melting. In particular, they showed that that the thermodynamic partition function of molten crystals is equal to the classical limit of the partition function of the topological string theory by relating the Ronkin function of the characteristic polynomial of the crystal melting model to the holomorphic 3-form on the corresponding Calabi-Yau manifold.

***Research results 13: Supersymmetric Gauge Theories**

*24. O. Aharony, N. Seiberg, and Y. Tachikawa, "Reading between the lines of four-dimensional gauge theories", *Journal of High Energy Physics*, **1308** (2013), 115
DOI: 10.1007/JHEP08(2013)115

It has been long known that every gauge theory on a flat spacetime has two continuous parameters, the gauge coupling constant and the theta angle. But the subtle behavior of gauge theories on nontrivial spacetime topology always confused researchers. In this paper, it was pointed out that on general spacetime manifolds, there are additional discrete parameters necessary to specify a gauge theory completely. These parameters control what kind of line operators are available in this gauge theory, and are best described by the cohomology of classifying spaces, a concept known in mathematics for a long time but having not many applications in physics until this paper came out. Discussions with mathematicians at the Kavli IPMU, and having an access to the library at the Kavli IPMU that comprehensively covers books in all areas of mathematics, both old and new, were essential to the completion of the paper.

***Research results 14: Methods in Quantum Field Theory and String Theory**

*25. D. Harlow and H. Ooguri, "Constraints on Symmetries from Holography", *Physical Review Letters,* **122** (2019), 191601
DOI: 10.1103/PhysRevLett.122.191601

In this letter, they use the Anti-de Sitter/Conformal Field Theory (AdS/CFT) correspondence to establish a set of old conjectures about symmetries in quantum gravity. These are that no global symmetries are possible, that internal gauge symmetries must come with dynamical objects that transform in all irreducible representations, and that internal gauge groups must be compact. These conjectures are not true from a bulk perspective, they are nontrivial consequences of the non-perturbative consistency of the correspondence. More details of and background for these arguments are presented in an accompanying paper. This letter is selected by Editors' Suggestion.

*26. G. Obied. H. Ooguri, L. Spodyeiko, and C. Vafa, "De Sitter Space and the Swampland," arXiv:1806.08362, Preprint

It has been notoriously difficult to construct a meta-stable de Sitter (dS) vacuum in string theory in a controlled approximation. This suggests the possibility that meta-stable dS belongs to the swampland. In this paper, we propose a swampland criterion in the form of $|\nabla V| \geq c \cdot V$ for a scalar potential V of any consistent theory of quantum gravity, for a positive constant c. In particular, this bound forbids dS vacua. The existence of this bound is motivated by the abundance of string theory constructions and no-go theorems which exhibit this behavior. We also extend some of the well-known no-go theorems for the existence of dS vacua in string theory to more general accelerating universes and reinterpret the results in terms of restrictions on allowed scalar potentials.

*27. B. Henning, T. Melia, "Constructing Effective Field Theories via their Harmonics", *Phys. Rev. D,* **100** (2019) 1, 016015.

DOI:10.1103/PhysRevD.100.016015

They consider the construction of operator bases for massless, relativistic quantum field theories, and show this is equivalent to obtaining the harmonic modes of a physical manifold (the kinematic Grassmannian), upon which observables have support. This enables them to recast the approach of effective field theory (EFT) through the lens of harmonic analysis. They explicitly construct harmonics corresponding to low mass dimension EFT operators.

*Research results 15: *F*-Theory: Its Phenomenology Applications and Duality

*28. H. Hayashi, R. Tatar, Y. Toda, T. Watari, M. Yamazaki, "New Aspects of Heterotic-*F* theory duality", *Nuclear Physics*, **B806** (2009), 224-299
DOI: 10.1016/j.nuclphysb.2008.07.031

String theory has several different formulations, and *F*-theory is known to be the most promising one in order to study the origin of flavor structure of the standard model particles. There had been a few problems left unsolved in the formulation of *F*-theory, however, because of high-level mathematics involved, and further progress using *F*-theory had been blocked for more than a decade. The team of physicists and a mathematician at the IPMU and other institutes solved these problems, and this article has become one of a few foundational papers that enabled explosive progress in 2008-2010. Aside from solving theoretical problems in the formulation of *F*-theory, this article also discovered that matter fields are described by smooth wavefunctions (without singularity) in internal space, which also has an immediate consequence in the enhancement factor of proton decay.

*29. Y. Enoki, T. Watari, "Modular Forms as Classification Invariants of 4D N=2 Heterotic--IIA Dual Vacua", *Journal of High Energy Physics*, **06** (2020) 021
DOI: 10.1007/JHEP06(2020)021

The paper is on the classification of Heterotic—Type IIA string dual vacua with SO(3,1) Lorentz symmetry and N=2 supersymmetry. For classification of such vacua, lattice and the Heterotic string new supersymmetric index have been used in the literature, but it was also known that that set of information is not enough to distinguish multiple different branches of moduli space of such vacua. The paper formulated another classification invariant by generalizing a Harvey—Moore paperback in 1995.

*Research results 16: Application to Condensed Matter Physics

*30. N. Ogawa, T. Takayanagi, T. Ugajin, "Holographic Fermi Surfaces and Entanglement Entropy", *Journal of High Energy Physics*, **1201** (2012), 125
DOI: 10.1007/JHEP01(2012)125

One unsolved problem in condensed matter systems is the analysis of Fermi surfaces in strongly interacting systems, *e.g.*, the strange metal phase of high T_c superconductors. In this paper, the authors gave a systematic study of Fermi surfaces by using the entanglement entropy in AdS/CFT correspondence for the first time. The analysis of entanglement entropy remarkably fixes the form of metric in the gravity description in a very strong way. This powerful analysis leads to the conclusion that any strongly coupled and large *N* quantum systems should have an anomalous specific heat which clearly differs from the Landau Fermi liquids but agrees with the strange metal phase. They also found a condition for the presence of Fermi surfaces in terms of the metric of gravity dual.

*Research results 17: Studying neutrino physics with T2K and Hyper-K experiments and CP violation with Belle II

*31. K. Abe et al. (including K. Abe, M. Hartz, Y. Hayato, E. Kearns, M. Nakahata, K. Nakamura, S. Nakayama, T. Nakaya, K. Okumura, B. Quilain, H. Sekiya, M. Shiozawa, H. Sobel, Y. Suzuki, Y. Takeuchi, M. Vagins, T. Vladisavljevic), "Search for CP Violation in Neutrino and Antineutrino Oscillations by the T2K Experiment with 2.2×10^{21} Protons on Target", *Physical Review Letters*, **121** (2018), 171802
DOI:10.1103/PhysRevLett.121.171802

The T2K experiment measures muon neutrino disappearance and electron neutrino appearance in

accelerator-produced neutrino and antineutrino beams. With an exposure of $14.7(7.6)\times10^{20}$ protons on target in the neutrino (antineutrino) mode, 89 ν_e candidates and seven anti-ν_e candidates are observed, while 67.5 and 9.0 are expected for $\delta_{CP}=0$ and normal mass ordering. The obtained 2σ confidence interval for the CP-violating phase, δ_{CP}, does not include the CP-conserving cases ($\delta_{CP}=0, \pi$). The best-fit values of other parameters are $\sin^2\theta_{23}=0.526_{-0.036}^{+0.032}$ and $\Delta m^2_{32}=2.463_{-0.070}^{+0.071}\times10^{-3}$ eV^2/c^4.

*32. T2K collaboration (including K. Abe, L. Cook, M. Hartz, Y. Hayato, E. Kearns, L. Marti-Magro, M. Nakahata, K. Nakamura, S. Nakayama, T. Nakaya, K. Okumura, B. Quilain, H. Sekiya, M. Shiozawa, H. Sobel, Y. Suzuki, Y. Takeuchi, M. Vagins, T. Vladisavljevic), "Constraint on the matter–antimatter symmetry-violating phase in neutrino oscillations", *Nature*, **580** (2020) 7803, 339-344
DOI:10.1038/s41586-020-2177-0

This paper reports a measurement of the matter-antimatter symmetry-violating phase δ_{CP} using long-baseline neutrino and antineutrino oscillations observed by the T2K experiment that shows a large increase in the neutrino oscillation probability, excluding values of δ_{CP} that result in a large increase in the observed antineutrino oscillation probability at three standard deviations (3σ). The 3σ confidence interval for δ_{CP}, which is cyclic and repeats every 2π, is $[-3.41, -0.03]$ for the so-called normal mass ordering and $[-2.54, -0.32]$ for the inverted mass ordering. Our results indicate CP violation in leptons and our method enables sensitive searches for matter-antimatter asymmetry in neutrino oscillations using accelerator-produced neutrino beams. Future measurements with larger datasets will test whether leptonic CP violation is larger than the CP violation in quarks.

*33. T. Higuchi et al. (Belle II SVD Collaboration including H. Aihara, C. Joo, T. Morii, A. Paladino), "The Silicon Vertex Detector of the Belle II Experiment" proceedings of the 27th International Workshop on Vertex Detectors (VERTEX 2018), **348** (2019), 24
DOI:10.22323/1.348.0024

The silicon vertex detector (SVD) for the Belle II experiment at the SuperKEKB accelerator in Japan is responsible for detecting particle's origins. It comprises four cylindrical layers with ladder-like double-sided silicon detector (DSSD) arrays on each layer. The ladders produced under stringent quality control showed good mechanical tolerance with a DSSD distortion $<\sim300\,\mu$m and with an electrical efficiency >99%. The SVD was commissioned with cosmic-ray events for two months and had been installed on the Belle II detector. The so-called "phase 3" of the experiment with the SVD will start in March 2019. The production procedure of SVD modules has been established. Stringent quality control demonstrated constantly excellent electrical and mechanical module quality. Measured energy deposition on the sensor by a cosmic ray during the commissioning is consistent with the expectation. The estimated radiation dose on the SVD, integrated over 10 years, is expected to be within a manageable level according to another commissioning.

*Research results 18: Evolution of Galaxies

*34. J. D. Silverman et al. (including M. Tanaka), "The Impact of Galaxy Interactions on Active Galactic Nucleus Activity in zCOSMOS", *The Astrophysical Journal*, **743** (2011), 2
DOI: 10.1088/0004-637X/743/1/2

Close encounters between galaxies are expected to be a viable mechanism, as predicted by numerical simulations, by which accretion onto supermassive black holes can be initiated. To test this scenario, the authors construct a sample of 562 galaxies ($M_*>2.5\times10^{10}\ M_{sun}$) in kinematic pairs over the redshift range $0.25<z<1.05$ that are more likely to be interacting than a well-matched control sample of 2726 galaxies not identified as being in a pair, both from the zCOSMOS 20k spectroscopic catalog. Galaxies that harbor an active galactic nucleus (AGN) are identified on the basis of their X-ray emission ($L_{0.5\text{-}10\ keV} > 2\times10^{42}$ erg s^{-1}) detected by Chandra. They find a higher fraction of an AGN in galaxies in pairs relative to isolated galaxies of similar stellar mass.

*35. X. Ding, J. Silverman, T. Treu, A. Schulze, M. Schramm, S. Birrer, D. Park, K. Jahnke, V. N. Bennert, J. S. Kartaltepe, A. M. Koekemoer, M. A. Malkan, D. Sanders, "The Mass Relations between Supermassive Black Holes and Their Host Galaxies at 1 < z < 2 HST-WFC3", *The Astrophysical Journal,* **888** (2020), 37
DOI:10.3847/1538-4357/ab5b90

Correlations between the mass of a supermassive black hole (SMBH) and the stellar mass (M_*) of its host galaxy suggest an evolutionary connection. A powerful test of a coevolution scenario is to measure the mass relation M_{BH}-M_* at high redshift and compare with local estimates. Thus, we acquired Hubble Space Telescope

imaging of 32 active galactic nuclei at z ~ 1.5 to measure the host galaxy stellar mass. We find that the observed ratio of M_{BH} to total M_* is 2.7× larger at z ~ 1.5 than in the local universe, while the scatter is equivalent between the two epochs. With consideration of observational biases, a nonevolving mass ratio is consistent with the data at the 2σ-3σ confidence level. Therefore, our results cannot distinguish whether SMBHs and their total host stellar mass proceed in lockstep or whether the growth of the former somewhat overshoots the latter.

*36. M. Ata, M., F.-S. Kitaura, K.-G. Lee, B. C. Lemaux, D. Kashino, O. Cucciati, M. Hernandez-Sanchez, O. Le Fèvre, "BIRTH of the COSMOS field: primordial and evolved density reconstructions during cosmic high noon", *Monthly Notices of the Royal Astronomical Society*, **500** (2021), 3194-3212
DOI:10.1093/mnras/staa3318

This work presents the first comprehensive study of structure formation at the peak epoch of cosmic star formation over 1.4 ≤ z ≤ 3.6 in the Cosmic Evolution Survey (COSMOS) field, including the most massive high-redshift galaxy proto-clusters at that era. We apply the extended COSMIC BIRTH algorithm to account for a multitracer and multisurvey Bayesian analysis at Lagrangian initial cosmic times. Combining the data of five different spectroscopic redshift surveys (zCOSMOS-deep, VUDS, MOSDEF, ZFIRE, and FMOS-COSMOS), we show that the corresponding unbiased primordial density fields can be inferred, if a proper survey completeness computation from the parent photometric catalogs, and precise treatment of the non-linear and non-local evolution on the light-cone is taken into account, including (i) gravitational matter displacements, (ii) peculiar velocities, and (iii) galaxy bias. The reconstructions reveal a holistic view on the known proto-clusters in the COSMOS field and the growth of the cosmic web towards lower redshifts.

***Research results 19: Formation of First Stars and Black Holes**

*37. S. Hirano, T. Hosokawa, N. Yoshida, R. Kuiper, "Supersonic gas streams enhance the formation of massive black holes in the early universe", *Science,* **357** (2017), 1375-1378
DOI:10.1126/science.aai9119

The paper presents the results from radiation-hydrodynamics simulations of the formation of a massive black hole in the early Universe. The simulations show, for the first time, that a black hole with a few ten thousand solar masses can be formed by rapid gas cooling and collapse induced by the baryonic streaming motions. The early formation process can explain the existence of super-massive black holes when the age of the Universe was just seven hundred million years, as suggested by recent observations, and also the abundance of such massive black holes is consistent with the observation. The paper offers a promising theoretical model of the formation and evolution of supermassive black holes.

***Research results 20: Supernovae and Evolution of Chemical Elements**

*38. K. Maeda et al. (including K. Nomoto, M. Tanaka), "An asymmetric explosion as the origin of spectral evolution diversity in type Ia supernovae", *Nature*, **466** (2010), 82-85
DOI:10.1038/nature09122

Type Ia supernovae form an observationally uniform class of stellar explosions, in that more luminous objects have smaller decline-rates. This one-parameter behavior allows type Ia supernovae to be calibrated as cosmological "standard candles", and led to the discovery of an accelerating Universe. Recent investigations, however, have revealed that the true nature of type Ia supernovae is more complicated. Here the authors report that the spectral diversity is a consequence of random directions from which an asymmetric explosion is viewed. Their findings suggest that the spectral evolution diversity is no longer a concern when using type Ia supernovae as cosmological standard candles. Furthermore, this indicates that ignition at an offset from the center is a generic feature of type Ia supernovae.

*39. S. M. Adams, C.S. Kochanek, J. F. Beacom, M. R. Vagins, and K.Z. Stanek, "Observing the Next Galactic Supernova", *The Astrophysical Journal*, **778** (2013), 164
DOI:10.1088/0004-637X/778/2/164

In this paper, the authors model the distance, extinction, and magnitude probability distributions of a Galactic core-collapse supernova (ccSN), its shock breakout radiation, and its massive star progenitor. They find, at very high probability (~100%), that the next Galactic SN will easily be detectable in the near-IR and that near-IR photometry of the progenitor star very likely (~92%) already exists in the 2MASS survey. Most ccSNe (~98%) will also be easily observed in the optical. The benefits of neutrino detection experiments quickly

disseminating a likely position (~3 deg) are discussed, coupled with a review of the process by which neutrinos from a Galactic ccSN would be detected and announced. They describe the Kavli IPMU's newly-operational, gadolinium-based EGADS detector and its currently unique potential for providing instant, independent, high-confidence supernova neutrino alerts to the world.

*40. C. Simpson et al. (The Super-Kamiokande Collaboration including K. Abe, Y, Hayato, J. Kameda, Y. Kishimoto, M. Miura, S. Moriyama, M. Nakahata, Y. Nakajima, S. Nakayama, H. Sekiya, M. Shiozawa, A. Takeda, T. Kajita, K. Okumura, E. Kearns, J. L. Stone, M. B. Smy, H. W. Sobel, K. Scholberg, C. W. Walter, K. Nakamura, Y. Takeuchi, T. Nakaya, R. A. Wendell, Y. Koshio, L. Cook, M. Yokoyama, A. Goldsack, K. Martens, M. Murdoch, B. Quilain, Y. Suzuki, M. R. Vagins), "Sensitivity of Super-Kamiokande with Gadolinium to Low Energy Anti-neutrinos from Pre-supernova Emission", *The Astrophysical Journal,* **885** (2019), 133 DOI:10.3847/1538-4357/ab4883

Supernova detection is a major objective of the SK experiment. In the next stage of SK, gadolinium (Gd) sulfate will be added to the detector (SK-Gd), which will improve the ability of the detector to identify neutrons. A core-collapse supernova will be preceded by an increasing flux of neutrinos and anti-neutrinos over a timescale of hours, some of which may be detected at SK-Gd. This could provide an early warning of an imminent core-collapse supernova, hours earlier than the detection of the neutrinos from core collapse. Electron anti-neutrino detection will rely on inverse beta decay events below the usual analysis energy threshold of SK, so Gd loading is vital to reduce backgrounds while maximizing detection efficiency. Assuming normal neutrino mass ordering, more than 200 events could be detected in the final 12 hours before core collapse for a 15-25 solar mass star at around 200 pc, which is representative of the nearest red supergiant to Earth (Betelgeuse).

Appendix 1-2 List of Papers of Representative of Interdisciplinary Research Activities

* List **up to 20 papers** underscoring each interdisciplinary research activity and give brief accounts (within 10 lines).
* For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is the same. If a paper has many authors, underline those affiliated with the Center.
* If a paper has many authors (say, more than 10), all of their names do not need to be listed.

Collaboration of Astronomy and Mathematics

1. G. W. Gibbons, M. C. Werner, N. Yoshida and S. Chon, "On de-Sitter geometry in cosmic void statistics", *Monthly Notices of the Royal Astronomical Society*, **438** (2014), 1603-1610
DOI: 10.1093/mnras/stt2298

A Kavli IPMU mathematician and astrophysicists develop a novel mathematical model for the distribution of cosmic voids. Recent wide-field galaxy surveys show that the large-scale galaxy distribution appears as a complex network of filaments of voids of various physical sizes. Kavli IPMU scientists proposed that the geometrical concept of a four-dimensional de Sitter configuration of spheres in Euclidean 3-space can be used to describe the number density of cosmic voids. Their model reproduces the observed number distribution when realistic observational effects owing to survey geometry is taken into account, and thus the model provides a new geometrical perspective on self-similarity in cosmology.

2. R. M. Quimby, M. Oguri, A. More, S. More, T. J. Moriya, M. C. Werner, M. Tanaka, G. Folatelli, M. C. Bersten, K. Maeda, and K. Nomoto, "Detection of the Gravitational Lens Magnifying a Type Ia Supernova", *Science*, **344** (2014), 396
DOI: 10.1126/science.1250903

The US group Pan-STARRS claimed to have discovered a new and very bright type of supernova PS1-10afx at redshift 1.39. During the daily teatime, R. M. Quimby (astronomer), M. C. Werner (mathematician), M. Oguri (physicist) consider that it is not a superluminous supernova, but due to the magnification via the gravitational lensing of an unobserved galaxy even though it requires an extraordinary coincidence that the lens is exactly along the line of sight to the host galaxy. They estimated that such a coincidence is possible in the Pan-STARRS data set and confirm that the proposed explanation by observing the spectrum of the host galaxy of PS1-10afx after it had faded away. Their new observation using the Keck 1 telescope also showed [O II] emission doublet is observed with redshift 1.117, which indicates that the foreground galaxy acted as the hypothesized lens. This result was covered very widely in media more than 80 times.

Physics papers that advance mathematics

3. K. Hori and J. Knapp, "Linear sigma models with strongly coupled phases - one parameter models", *Journal of High Energy Physics*, **1311** (2013), 070
DOI: 10.1007/JHEP11(2013)070

Based on the duality discovered in K. Hori and M. Romo (arXiv:1308.2438), the paper systematically constructs two-dimensional (2,2) supersymmetric gauged linear sigma models with strongly coupled phases, in which a continuous subgroup of the gauge group is totally unbroken. The construction leads to predictions of equivalences of D-brane categories, systematically extending earlier examples. There is another type of surprise. Two distinct superconformal field theories corresponding to Calabi-Yau threefolds with different Hodge numbers, $h^{2,1}=23$ versus $h^{2,1}=59$, have exactly the same quantum Kähler moduli space. The strong-weak duality of (1) plays a crucial rôle in confirming this, and also is useful in the actual computation of the metric on the moduli space. This work partially implements Center's Research objective "enumerate and classify solutions of string theory that will lead to the development of new types of geometries."

4. P. Braun, Y. Kimura and T. Watari, "On the classifications of elliptic fibrations modulo isomorphism on *K3* surface with large Picard number", arXiv:1312.4421, Preprint

This paper addresses genuine mathematics problems, which turned out to be well-motivated in a study on string compactification (arXiv:1401.5908, the same authors; accepted by JHEP, which acknowledges mathematician T. Shioda). One of the problems was to determine the modular group of elliptic fibration that a *K3* surface admits precisely. A complete answer to this problem is given in this paper. This problem had to be solved to exploit Heterotic-*F* theory duality. The other problem was to estimate how

many classifications of elliptic fibration modulo isomorphism is finer relatively to classification of elliptic fibration by the geometry of singular fibres. The former classification corresponds to vacuum classification in physics, while the latter to vacuum classification by their gauge groups. This paper derived an upper bound on how many distinct fibrations modulo isomorphism there can be for a given set of singular fibre geometry.

5. S. Kondo, T. Watari, "String-theory realization of modular forms for elliptic curves with complex multiplication", *Communications in Mathematical Physics*, **367** (2019), 89-126
DOI:10.1007/s00220-019-03302-0

For an algebraic variety whose defining equations have coefficients in some algebraic number field (rather than the complex number field C), so-called the L-function is defined, which encapsulates how the Galois group acts on the algebraic variety. It has been known that the L-functions for some classes of algebraic varieties are equal to the Mellin transform of appropriately chosen modular forms. Although there is a mathematical proof for that statement, the connection between the Galois group action and modular transformation is a total mystery from math perspectives. This paper finds a systematic relation between the modular forms defined in arithmetic geometry and a class of genus-1 chiral correlation functions in string theory, when it comes to elliptic curves with complex multiplication. The modular transformation is now the basis transformation of the genus-1 world-sheet homology group.

Physics papers that became possible thanks to latest mathematics.
6. H. Ooguri, P. Sulkowski, M. Yamazaki, "Wall Crossing As Seen By Matrix Models", *Communications in Mathematical Physics*, **307** (2011), 429-462
DOI: 10.1007/s00220-011-1330-x

This paper gives interpretation of the Donaldson-Thomas invariants in mathematics based on supersymmetric field theory in physics. The number of BPS bound states of D-branes on a Calabi-Yau (CY) manifold depends on two sets of data, the BPS charges and the stability conditions. For D0 and D2-branes bound to a single D6-brane wrapping a CY 3-fold X, both are naturally related to the Kähler moduli space $M(X)$. They construct unitary one-matrix models, which count such BPS states for a class of toric CY manifolds at infinite 't Hooft coupling. The matrix model for the BPS counting on X turns out to give the topological string partition function for another CY manifold Y, whose Kähler moduli space $M(Y)$ contains two copies of $M(X)$, one related to the BPS charges and another to the stability conditions. The two sets of data are unified in $M(Y)$. In addition, the matrix models compute spectral curves and mirror maps relevant to the remodeling conjecture.

7. B. Henning, X. Lu, T. Melia, H. Murayama, "2, 84, 30, 993, 560, 15456, 11962, 261485, ...: Higher dimension operators in the SM EFT", *Journal of High Energy Physics*, **08** (2017), 016
DOI:10.1007/JHEP08(2017)016

This paper solved a problem that has been in the community for more than a quarter century. When we look for new physics beyond the Standard Model from shorter distances, our effects appear as corrections in the Effective Field Theory suppressed by small distances. Yet the classification of such effects had not been done systematically because of redundancies due to equations of motion and integration by parts. The authors proposed to apply techniques from conformal field theory to make the classification completely systematic. After this work, they further developed methods for chiral Lagrangian employing the Hodge theory, and implementing outer automorphisms with the twining characters that rely on the generalized notion of folding Dynkin diagrams. This work imports many recent advances in pure mathematics to physics at accelerator experiments in a truly interdisciplinary fashion, and they acknowledged our own H. Nakajima for help.

8. H. Murayama, M. Yamazaki, T. T. Yanagida, "Do We Live in the Swampland?" *Journal of High Energy Physics*, **12** (2018), 032
DOI:10.1007/JHEP12(2018)032

Director H. Ooguri made a bold statement that the cosmological constant is not allowed in a consistent theory of quantum gravity and hence the dark energy must be time-dependent. This statement was made in the form of broad conjecture that forbids the gradient of the potential energy be too small. Yet the initial version of the conjecture did not apply to certain known cases in the Standard Model as well as many promising new physics theories. They suggested the second derivative needs to be

incorporated to make the conjecture consistent. In the end, H. Ooguri implemented this point in a way more ambitious than H. Murayama imagined. After this development, he also showed that the new form of the conjecture could lead to observable consequences at LiteBIRD and/or PFS, major initiatives of the Kavli IPMU.

9. J. A. Dror, T. Hiramatsu, K. Kohri, H. Murayama and G. White, "Testing the Seesaw Mechanism and Leptogenesis with Gravitational Waves", *Physical Review Letters*, **124** (2020) 041804
DOI:10.1103/PhysRevLett.124.041804

T. Yanagida and M. Fukugita were two of the founders of the Kavli IPMU, and are famous for their theory of leptogenesis, explaining our own existence from the origin of neutrino mass. Yet this theory eluded experimental tests given the very high energy scale of its physics. This paper pointed out that it can lead to observable effects in stochastic gravitational wave in most versions of the theory. In particular, this prediction is relevant for the future progress of KAGRA and the proposed DECIGO mission to JAXA, as well as Hyper-Kamiokande. It combines the algebraic topology and computer simulations and is interdisciplinary. The paper further stimulated works on grand unification, supersymmetry, and inflation. It was chosen as an Editors' Suggestion by Physical Review Letters.

Condensed matter physics and particle/string theory
10. H. Ooguri, M. Oshikawa, "Instability in magnetic materials with dynamical axion field", *Physical Review Letters,* **108** (2012), 161803
DOI: 10.1103/PhysRevLett.108.161803

H. Ooguri worked with a condensed matter physicist M. Oshikawa on a subject of axion-type particle which is a candidate for dark matter. The detection of axion has been a difficult problem experimentally, while they found an axion-like excitation in condensed matter system. It has been pointed out that axion electrodynamics exhibits instability in the presence of a background electric field. They show that the instability leads to a complete screening of an applied electric field above a certain critical value and the excess energy is converted into a magnetic field. They clarify the physical origin of the screening effect and discuss its possible experimental realization in magnetic materials where magnetic fluctuations play the role of the dynamical axion field. Chosen as "Editors' Suggestion."

11. H. Watanabe, T. Brauner, and H. Murayama, "Massive Nambu-Goldstone Bosons", *Physical Review Letters*, **111** (2013), 021601
DOI: 10.1103/PhysRevLett.111.021601

When perturbed by explicit symmetry breaking terms, the so-called "pseudo-Nambu-Goldstone bosons" acquire mass which can in most cases be estimated but not exactly predicted. They discovered that the exact formula is derived based on Lie algebra only when the perturbation is due to the symmetry generator, such as for the chemical potential. It turned out that this formula has wide-ranging applications to many systems in condensed matter physics and nuclear physics. This paper is written in collaboration with a condensed matter physicist and a nuclear physicist.

Mathematics inspired by Physics
12. K. Saito, "Limit Elements in the Configuration Algebra for a Cancellative Monoid", *Publications of the Research Institute for Mathematical Sciences*, **46** (2010), 37-113
DOI: 10.2977/PRIMS/2

Modeling on the classical theory of nearest neighbor Ising models on square lattices where the input data of Boltzmann weight is replaced by an abstract notion of labels on the wedge of the Cayley graph of a cancellative monoid (Γ,G), he introduces an infinitely generated Hopf algebra to count the configurations in the graph. Then, the space $\Omega(\Gamma,G)$ of all free energies form a compact subset of the algebra. The main theorem states i) an existence of a fibration structure $\pi: \Omega(\Gamma,G)\to\Omega(P_{\Gamma,G})$ where the target space $\Omega(P_{\Gamma,G})$ is the space of all opposite sequences to the growth series $P_{\Gamma,G}$ of (Γ,G), and ii) a residual representation of the traces of the fiber of the fibration. This gives a quite new approach to the geometric theory of discrete groups inspired from physics, and some follow-up papers began to appear (*e.g.* http://de.arxiv.org/abs/1311.4450, MR3049573 *J. Algebra* 385 (2013), 314–332).

13. M. Kapranov, Y. Soibelman, L. Soukhanov, "Perverse schobers and the Algebra of the Infrared",

arXiv:2011.00845, Preprint

They relate the Algebra of the Infrared of Gaiotto-Moore-Witten with the theory of perverse schobers which are (conjectural, in general) categorical analogs of perverse sheaves. A perverse schober on a complex plane C can be seen as an algebraic structure that can encode various categories of D-branes of a 2-dimensional supersymmetric field theory, as well as the interaction (tunneling) between such categories. They show that many constructions of the Algebra of the Infrared can be developed once we have a schober on C. These constructions can be seen as giving various features of the analog, for schobers, of the geometric Fourier transform well known for D-modules and perverse sheaves.

14. S. Gukov, P.-S. Hsin, H. Nakajima, S. Park, D. Pei, N. Sopenko, "Rozansky-Witten geometry of Coulomb branches and logarithmic knot invariants", arXiv:2005.05347, Preprint

By studying Rozansky-Witten theory with non-compact target spaces we find new connections with knot invariants whose physical interpretation was not known. This opens up several new avenues, which include a new formulation of q-series invariants of 3-manifolds in terms of affine Grassmannians and a generalization of Akutsu-Deguchi-Ohtsuki knot invariants.

Particle phenomenology and astronomy

15. S. Horigome, K. Hayashi, M. Ibe, M. N. Ishigaki, S. Matsumoto, S. Hajime, "J-factor estimation of Draco, Sculptor and Ursa Minor dwarf spheroidal galaxies with the member/foreground mixture model", *Monthly Notices of the Royal Astronomical Society*, **499** (2020), 3320-3337
DOI:10.1093/mnras/staa2909

They have proposed a novel analysis method to evaluate J-factors of dSphs (~ average of dark matter density squared at dSphs) based on the mixture model describing member stars belonging to the dSphs and foreground stars located in between the dSphs and us (the solar system). They have also applied the method to actual data sets (Draco, Sculptor and Ursa Minor dSphs) and confirmed that it works very well to control systematic uncertainty caused by the contamination of the foreground stars on the evaluation of the J-factors.

16. P. C. Bunting, G. Gratta, T. Melia, S. Rajendran, "Magnetic Bubble Chambers and Sub-GeV Dark Matter Direct Detection", *Physical Review D*, **95** (2017), 095001
DOI:10.1103/PhysRevD.95.095001

A new application of single-molecule magnet crystals has been proposed as magnetic bubble chambers for the direct detection of eV-MeV dark matters. The spins in these macroscopic crystals effectively act as independent nano-scale magnets. When anti-aligned with an external magnetic field they form meta-stable states with a relaxation time that can be very long at sufficiently low temperatures. The Zeeman energy stored in this system can be released through localized heating, caused by e.g. the scattering/absorption of dark matter, resulting in a spin avalanche that amplifies the effects of the initial heat deposit, enabling detection. The temperature and external magnetic field set the detection threshold for a single-molecule magnet crystal. This detector concept can search for hidden photon dark matter in the meV-eV mass range with sensitivities exceeding current bounds by several orders of magnitude.

17. C. Smorra, Y. V. Stadnik, P. E. Blessing, M. Bohman, et al., "Direct limits on the interaction of antiprotons with axion-like dark matter", *Nature*, **575** (2019), 310-314
DOI:10.1038/s41586-019-1727-9

They have presented a direct search for interactions of antimatter with dark matter and place direct constraints on the interaction of ultralight axion-like particles with antiprotons. If antiprotons have a stronger coupling to these particles than protons do, such a matter-antimatter asymmetric coupling could provide a link between dark matter and the baryon asymmetry in the Universe. They have analyzed spin-flip resonance data in the frequency domain acquired with a single antiproton in a Penning trap to search for spin-precession effects from ultralight axions, which have a characteristic frequency governed by the mass of the underlying particle. Their analysis constrains the axion–antiproton interaction parameter to values greater than 0.1 to 0.6 GeV in the mass range from 2×10^{-23} to 4×10^{-17} eV, improving the sensitivity by up to five orders of magnitude compared with astrophysical antiproton bounds.

Astronomy and statistics

18. T. Nishimichi, M. Takada, R. Takahashi, K. Osato, M. Shirasaki, T. Oogi, H. Miyatake, M. Oguri, R. Murata, Y. Kobayashi, N. Yoshida, "Dark Quest I. Fast and Accurate Emulation of Halo Clustering Statistics and Its Application to Galaxy Clustering", *The Astrophysical Journal*, **884** (2019), 29
10.3847/1538-4357/ab3719

They have developed a fast-statistical analysis tool for the large-scale structure of the Universe. Their emulator is based on the Principal Component Analysis, the Gaussian Process Regression for the large-dimensional input and output data vector. The emulator predicts the galaxy-matter cross-correlation with an accuracy better than two percent and the galaxy-galaxy auto-correlation with an accuracy better than four percent. We can incorporate the emulator in a Markov-Chain Monte-Carlo program to infer the main cosmological parameters such as the matter density and the density fluctuation amplitude.

Science and society

19. Y. Ikkatai, A. Inoue, A. Minamizaki, K. Kano, E. McKay, H. M. Yokoyama, "Masculinity in the public image of physics and mathematics: a new model comparing Japan and England", *Public Understanding of Science*. (2021), 1-17
DOI:10.1177/09636625211002375

Factors contributing to the masculine image of physics and mathematics are examined within the framework of our expanded model. We conducted online questionnaires in Japan and the UK, and found that both physics and mathematics occupations and mathematical stereotypes were associated with a masculine image. Only in Japan did we find that social factors, such as attitudes towards intellectual women, were also associated with the view of mathematics as masculine. Also, only in the UK had people been told or heard that choosing a particular subject would make them less attractive to the opposite sex. These results suggest that social factors influence the masculine image of physics and mathematics, and that this could vary depending on the country.

Applications of high energy physics to medical imaging

20. K. Furukawa, S. Nagasawa, L. Glesener, M. Katsuragawa, S. Takeda, S. Watanabe, T. Takahashi, "Imaging and spectral performance of a 60 μm pitch CdTe Double-Sided Strip Detector", *Nuclear Instruments and Methods in Physics Research Section A*, **978** (2020), 164378
DOI: 10.1016/j.nima.2020.164378

They evaluated the performance of a fine pitch CdTe Double-sided Strip Detector (CdTe-DSD), which was originally developed for the focal plane detector of a hard X-ray telescope to observe the Sun. The detector has a thickness of 750 μm and has 128 strip electrodes and covers an energy range from 4 keV to 80 keV. The study of the depth of photon interaction and charge sharing effects is of importance to provide good spectroscopic and imaging performance. In order to study the imaging performance, they constructed a simple imaging system using a 5 mm thick tungsten plate that has a pinhole with a diameter of 100 μm. They utilize a Ba-133 radioisotope of 1 mm in diameter as a target source in combination with a 100 μm slit made from 0.5 mm thickness tungsten. They imaged the Ba-133 source behind the 100 μm slit using a 30 keV peak. By applying a charge-sharing correction between strips, they have succeeded in obtaining a position resolution better than the strip pitch of 60 μm.

Appendix 1-3
Major Awards, Invited Lectures, Plenary Addresses (etc.) (within 2 pages)

*Prepare the information below during the period from the start of the center through March 2021.

1. Major Awards

*List main internationally-acclaimed awards received/unofficially announced in order from the most recent.
*For each, write the recipient's name, the name of award, and the date issued.
In case of multiple recipients, underline those affiliated with the center.

Date	Recipient's name	Name of award
April 2020	Ken'ichi Nomoto	Order of the Sacred Treasure
November 2019	Hirosi Ooguri	Medal of Honor with Purple Ribbon
November 2018	Hirosi Ooguri	Hamburg Prize for Theoretical Physics
October 2018	Ken'ichi Nomoto	2019 Hans A. Bethe Prize
December 2017	David Spergel Eiichiro Komatsu	2018 Breakthrough Prize in Fundamental Physics
October 2017	Hitoshi Murayama	Humboldt Research Award
January 2017	Naoki Yoshida	Japan Academy Medal
November 2016	Tadashi Takayanagi	Nishina Memorial Prize
November 2015	Yuji Tachikawa	Fundamental Physics New Horizons Prize
November 2015	Takaaki Kajita	Order of Culture
October 2015	Takaaki Kajita	Nobel Prize
May 2015	Ken'ichi Nomoto	Marcel Grossmann Award
March 2015	Eiichiro Komatsu	Chushiro Hayashi Prize
November 2014	Horasio Casini, Marina Huerta, Shinsei Ryu, Tadashi Takayanagi	New Horizons in Physics Prizes
July 2014	Yuji Tachikawa	Hermann Weyl Prize
November 2013	Takaaki Kajita	Julius Wess Award
May 2013	Yoichiro Suzuki	Giuseppe and Vanna Cocconi Prize
December 2012	Kunio Inoue	Nishina Memorial Prize
March 2012	Takaaki Kajita	Japan Academy Prize
December 2009	Hirosi Ooguri	Nishina Memorial Prize
May 2008	Hirosi Ooguri	Humboldt Research Award
May 2008	Eiichiro Komatsu	IUPAP Young Scientist Prize in Astrophysics
May 2008	Naoki Yoshida	IUPAP Young Scientist Prize in Astrophysics

2. Invited Lectures, Plenary Addresses (etc.) at International Conferences and International Research Meetings

*List up to 20 main presentations in order from most recent.
*For each, write the lecturer/presenter's name, presentation title, conference name and date(s)

Date(s)	Lecturer/Presenter's name	Presentation title	Conference name
2021/1/15	Naoyuki Tamura	Subaru Prime Focus Spectroraph: A next generation facility instrument of the Subaru telescope is coming to First Light	237th American Astronomical Society meeting
2020/10/23	Yukari Ito	The McKay correspondence	Kinosaki Algebraic Geometry Symposium 2020
2019/6/14	Mikhail Kapranov	Perverse schobers and the algebra of the infrared	Resurgence in Mathematics and Physics
2019/5/20	Hirosi Ooguri	Swampland and Its Physical Implications	SUSY 2019
2018/9/15	Tom Melia	Lovely phase space for good vibrations	PRL 60th Anniversary Symposium
2018/8/27	Shigeki Matsumoto	Dark Matter Search at 240-250GeV Lepton Colliders	COSMO 2018
2018/8/18	Hiraku Nakajima	3d N=4 QFT and ring objects on the affine Grassmannian	String-Math 2018,
2017/12/3	Hitoshi Murayama	Dark Matter and Fundamental Physics	Texas 2017
2017/6/26	Yuji Tachikawa	Time-reversal Anomalies of 2+1d Topological Phases	Strings 2017
2016/11/28	Tsutomu Yanagida	Neutrino Masses in the Landscape of Vacuua	13th Int'l Symposium on Cosmology and Particle Astrophysics
2015/12/7	Masahiro Takada	Halo bias	Cosmology and First Light
2014/8/13	Yukinobu Toda	Derived category of coherent sheaves and counting invariants	International Congress of Mathematicians 2014
2014/6/9	Kentaro Hori	1d Index and Wall Crossing	String-Math 2014
2013/6/24	Mihoko Nojiri	Theoretical Results on Physics Beyond the Standard Model 30	2013 Lepton Photon Conference
2013/2/16	Mark Robert Vagins	Astrophysical Neutrino Forecast - Mostly Sunny, with a Good Chance of Supernovas	AAAS 2013 Annual Meeting
2012/7/1	Shinji Mukohyama	Modified Gravity	The Thirteenth Marcel Grossmann Meeting
2011/7/1	Tadashi Takayanagi	Holographic Entanglement Entropy and its New Developments	Strings 2011
2010/5/27	Naoki Yoshida	Chemistry in the Early Universe	41st Annual Conference on APS DAMOP
2009/8/17	Yoichiro Suzuki	Solar and Atmospheric Neutrinos	XXIV Int'l Symposium on Lepton & Photon Interactions at High Energies
2009/1/15	Ken'ichi Nomoto	The Cosmic Explosions: The Violent Supernovae	The Opening Ceremony of the Int'l Year of Astronomy

Appendix 1-4 2020 List of Center's Research Results

Refereed Papers

- List only the Center's papers published in 2020. (Note: The list should be for the calendar year, not the fiscal year.)

(1) Divide the papers into two categories, A and B.
   A. WPI papers
      List papers whose author(s) can be identified as affiliated with the WPI program (e.g., that state "WPI" and the name of the WPI center (WPI-center name)). (Not including papers in which the names of persons affiliated with the WPI program are contained only in acknowledgements.)
   B. WPI-related papers
      List papers related to the WPI program but whose authors are not noted in the institutional affiliations as WPI affiliated. (Including papers whose acknowledgements contain the names of researchers affiliated with the WPI program.)

      Note: On 14 December 2011, the Basic Research Promotion Division in MEXT's Research Promotion Bureau circulated an instruction requiring paper authors to include the name or abbreviation of their WPI center among their institutional affiliations. From 2012, the authors' affiliations must be clearly noted.

(2) Method of listing paper
   - List only refereed papers. Divide them into categories (e.g., original articles, reviews, proceedings).
   - For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is consistent. (The names of the center researchers do not need to be underlined.)
   - If a paper has many authors (say, more than 20), all of their names do not need to be listed.
   - Assign a serial number to each paper to be used to identify it throughout the report.
   - If the papers are written in languages other than English, underline their serial numbers.
   - Order of Listing
      A. WPI papers
         1. Original articles
         2. Review articles
         3. Proceedings
         4. Other English articles

      B. WPI-related papers
         1. Original articles
         2. Review articles
         3. Proceedings
         4. Other English articles

(3) Submission of electronic data
   - In addition to the above, provide a .csv file output from the Web of Science (e.g.) or other database giving the paper's raw data including Document ID. (Note: the Document ID is assigned by paper database.)
   - These files do not need to be divided into paper categories.

(4) Use in assessments
   - The lists of papers will be used in assessing the state of WPI project's progress.
   - They will be used as reference in analyzing the trends and whole states of research in the said WPI center, not to evaluate individual researcher performance.
   - The special characteristics of each research domain will be considered when conducting assessments.

(5) Additional documents
   - After all documents, including these paper listings, showing the state of research progress have been submitted, additional documents may be requested.

A. WPI papers
1. Original articles

No.	Author names and details
1	Muon anomalous magnetic moment in two-Higgs-doublet models with vectorlike leptons Frank, M; Saha, I PHYSICAL REVIEW D 102(11), 115034, DEC 29, 2020
2	Blinded challenge for precision cosmology with large-scale structure: Results from effective field theory for the redshift-space galaxy power spectrum Nishimichi, T; D'Amico, G; Ivanov, MM; Senatore, L; Simonovic, M; Takada, M; Zaldarriaga, M; Zhang, P PHYSICAL REVIEW D 102(12), 123541, DEC 28, 2020
3	Constraints on millicharged particles from cosmic-ray production Plestid, R; Takhistov, V; Tsai, YD; Bringmann, T; Kusenko, A; Pospelov, M PHYSICAL REVIEW D 102(11), 115032, DEC 24, 2020

4	Search for lepton-number- and baryon-number-violating tau decays at Belle Sahoo, D et al. PHYSICAL REVIEW D 102(11), 111101, DEC 24, 2020
5	Search for proton decay via p -> e(+)pi(0) and p -> mu(+)pi(0) with an enlarged fiducial volume in Super-Kamiokande I-IV Takenaka, A et al. PHYSICAL REVIEW D 102(11), 112011, DEC 22, 2020
6	Classification of 5d N=1 gauge theories Bhardwaj, L; Zafrir, G JOURNAL OF HIGH ENERGY PHYSICS (12), 99, DEC 16, 2020
7	An N=1 Lagrangian for the rank 1 E-6 superconformal theory Zafrir, G JOURNAL OF HIGH ENERGY PHYSICS (12), 98, DEC 16, 2020
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564	Spectropolarimetric Analysis of FRB 181112 at Microsecond Resolution: Implications for Fast Radio Burst Emission Mechanism Cho, H; Macquart, JP; Shannon, RM; Deller, AT; Morrison, IS; Ekers, RD; Bannister, KW; Farah, W; Qiu, H; Sammons, MW; Bailes, M; Bhandari, S; Day, CK; James, CW; Phillips, CJ; Prochaska, JX; Tuthill, J ASTROPHYSICAL JOURNAL LETTERS 891(2), L38, MAR 10, 2020
565	Revealing the Dark Threads of the Cosmic Web Burchett, JN; Elek, O; Tejos, N; Prochaska, JX; Tripp, TM; Bordoloi, R; Forbes, AG ASTROPHYSICAL JOURNAL LETTERS 891(2), L35, MAR 10, 2020
566	Detection of Cross-Correlation between Gravitational Lensing and gamma Rays Ammazzalorso, S et al. PHYSICAL REVIEW LETTERS 124(10), 101102, MAR 9, 2020

567	Pololоgy of Superconformal Blocks Sen, K; Yamazaki, M COMMUNICATIONS IN MATHEMATICAL PHYSICS 374(2), pp.785-821, MAR, 2020
568	Bubble mapping with the Square Kilometre Array - I. Detecting galaxies with Euclid, JWST, WFIRST, and ELT within ionized bubbles in the intergalactic medium at z > 6 Zackrisson, E; Majumdar, S; Mondal, R; Binggeli, C; Sahlen, M; Choudhury, TR; Ciardi, B; Datta, A; Datta, KK; Dayal, P; Ferrara, A; Giri, SK; Maio, U; Malhotra, S; Mellema, G; Mesinger, A; Rhoads, J; Rydberg, CE; Shimizu, I MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 493(1), pp.855-870, MAR, 2020
569	High Peak-Current Lightning Discharges Associated With Downward Terrestrial Gamma-Ray Flashes Wada, Y; Enoto, T; Nakamura, Y; Morimoto, T; Sato, M; Ushio, T; Nakazawa, K; Yuasa, T; Yonetoku, D; Sawano, T; Kamogawa, M; Sakai, H; Furuta, Y; Makishima, K; Tsuchiya, H JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES 125(4), e2019JD031730, FEB 27, 2020
570	Expanding 3d N=2 theories around the round sphere Gang, D; Yamazaki, M JOURNAL OF HIGH ENERGY PHYSICS (2), 102, FEB 18, 2020
571	A search for a contribution from axion-like particles to the X-ray diffuse background utilizing the Earth's magnetic field Yamamoto, R; Yamasaki, NY; Mitsuda, K; Takada, M JOURNAL OF COSMOLOGY AND ASTROPARTICLE PHYSICS (2), 11, FEB, 2020
572	High-resolution Near-infrared Polarimetry and Submillimeter Imaging of FS Tau A: Possible Streamers in Misaligned Circumbinary Disk System Yang, Y et al. ASTROPHYSICAL JOURNAL 889(2), 140, FEB 1, 2020
573	Balmer Break Galaxy Candidates at z similar to 6: A Potential View on the Star Formation Activity at z greater than or similar to 14 Mawatari, K; Inoue, AK; Hashimoto, T; Silverman, J; Kajisawa, M; Yamanaka, S; Yamada, T; Davidzon, I; Capak, P; Lin, LW; Hsieh, BC; Taniguchi, Y; Tanaka, M; Ono, Y; Harikane, Y; Sugahara, Y; Fujimoto, S; Nagao, T ASTROPHYSICAL JOURNAL 889(2), 137, FEB 1, 2020
574	Resolving the Crab pulsar wind nebula at teraelectronvolt energies Abdalla, H et al. NATURE ASTRONOMY 4(2), pp.167-173, FEB, 2020
575	Rest-frame UV properties of luminous strong gravitationally lensed Ly alpha emitters from the BELLS GALLERY Survey Marques-Chaves, R; Perez-Fournon, I; Shu, Y; Colina, L; Bolton, A; Alvarez-Marquez, J; Brownstein, J; Cornachione, M; Geier, S; Jimenez-Angel, C; Kojima, T; Mao, S; Montero-Dorta, A; Oguri, M; Ouchi, M; Poidevin, F; Shirley, R; Zheng, Z MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 492(1), pp.1257-1278, FEB, 2020
576	Testing galaxy formation simulations with damped Lyman-alpha abundance and metallicity evolution Hassan, S; Finlator, K; Dave, R; Churchill, CW; Prochaska, JX MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 492(2), pp.2835-2846, FEB, 2020

577	Supergravity as the Dark Side of the Universe Ketov, SV INTERNATIONAL JOURNAL OF MODERN PHYSICS A 35(2-3), 2040038, JAN 30, 2020
578	The Carnegie Supernova Project II Early observations and progenitor constraints of the Type Ib supernova LSQ13abf Stritzinger, MD et al. ASTRONOMY & ASTROPHYSICS 634, A21, JAN 30, 2020
579	HESS detection of very high-energy gamma-ray emission from the quasar PKS 0736+017 Abdalla, H et al. ASTRONOMY & ASTROPHYSICS 633, A162, JAN 28, 2020
580	A type Ia supernova at the heart of superluminous transient SN 2006gy Jerkstrand, A; Maeda, K; Kawabata, KS SCIENCE 367(6476), pp.415-418, JAN 24, 2020
581	The Activation of Galactic Nuclei and Their Accretion Rates Are Linked to the Star Formation Rates and Bulge-types of Their Host Galaxies Yesuf, HM; Faber, SM; Koo, DC; Woo, J; Primack, JR; Luo, YF ASTROPHYSICAL JOURNAL 889(1), 14, JAN 20, 2020
582	Discovery of a Rare Late-type, Low-mass Wolf-Rayet Star in the LMC Margon, B; Manea, C; Williams, R; Bond, HE; Prochaska, JX; Szymanski, MK; Morrell, N ASTROPHYSICAL JOURNAL 888(2), 54, JAN 10, 2020
583	Shuffle algebras and perverse sheaves Kapranov, M; Schechtman, V PURE AND APPLIED MATHEMATICS QUARTERLY 16(3), pp.573-657, 2020
584	Subaru Near-infrared Imaging Polarimetry of Misaligned Disks around the SR 24 Hierarchical Triple System Mayama, S et al. ASTRONOMICAL JOURNAL 159(1), 12, JAN, 2020
585	Contingency Tables with Variable Margins (with an Appendix by Pavel Etingof) Kapranov, M; Schechtman, V SYMMETRY INTEGRABILITY AND GEOMETRY-METHODS AND APPLICATIONS 16, 62, 2020
586	AN ANALOGUE OF DUBROVIN'S CONJECTURE Sanda, F; Shamoto, Y ANNALES DE L INSTITUT FOURIER 70(2), pp.621-682, 2020
587	The ALPINE-ALMA [C II] survey: a triple merger at z similar to 4.56 Jones, GC et al. MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 491(1), pp.L18-L23, JAN, 2020
588	Chemical evolution with rotating massive star yields II. A new assessment of the solar s- and r-process components Prantzos, N; Abia, C; Cristallo, S; Limongi, M; Chieffi, A MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 491(2), pp.1832-1850, JAN, 2020
589	On gauging finite subgroups Tachikawa, Y SCIPOST PHYSICS 8(1), 15, JAN, 2020

2. Review articles
3. Proceedings
4. Other English articles

Appendix 2　FY 2020 List of Principal Investigators

NOTE:

*Underline names of principal investigators who belong to an overseas research institution.

*In the case of researcher(s) not listed in the latest report, attach a "Biographical Sketch of a New Principal Investigator"(Appendix 2a).

*Enter the host institution name and the center name in the footer.

<Results at the end of FY2020> **Principal Investigators Total: 28**

Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Center director Hirosi Ooguri	59	Director Kavli IPMU, UTIAS, The Univ. of Tokyo Director and Fred Kavli Professor Walter Burke Institute for Theoretical Physics California Institute of Technology	Ph.D. Theoretical Physics (Mathematical Physics)	50	10/1/2007	Due to COVID-19 related crisis, particiated online in FY2020. Attends videoconference once a week and joins online meeting and social events for researchers as much as time allows. At ordinary times, stays at Kavli IPMU 6 months a year. Joins videoconference once a week for the rest of 6 months.	Under the COVID-19 related crisis, created opportunities for researchers to gather online, like "Social Hour" and "IPMU Colloquium". At ordinary times, organized an International workshops and colloquiums, and invites foreign researchers to do research discussion.
Hiroaki Aihara	65	Deputy Director Kavli IPMU, UTIAS, The Univ. of Tokyo Executive Director and Vice President The Univ. of Tokyo	Ph.D. Experimental Physics (High Energy Physics)	30	10/1/2007	Stays at Kavli IPMU once a month. Joins videoconference once a week.	
Alexey Bondal	59	Professor Steklov Mathematical Institute Project Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	40	10/1/2007	Due to COVID-19 related crisis, particiated online in FY2020. Attends videoconference once a week and joins online meeting and social events for researchers as much as time allows. At ordinary times, stays at Kavli IPMU 6 months a year. Joins videoconference once a week for the rest of 6 months.	Under the COVID-19 related crisis, in FY2020, encouraged researchers on mathematics online. At ordinary times, arranges seminars and invites foreign researchers to do research discussion.

*Percentage of time that the principal investigator devotes to his/her work for the center vis-à-vis his/her total working hours.

Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Kentaro Hori	55	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Theoretical Physics (String Theory)	80	11/1/2008	Stays at Kavli IPMU full time.	
Kunio Inoue	55	Professor, Director Research Center for Neutrino Science, Tohoku University	Ph.D. Experimental Physics (Neutrino Physics)	45	10/1/2007	Stays at Kamioka Branch once a week.	
Takaaki Kajita	62	Director, Professor ICRR, The Univ. of Tokyo	Ph.D. Experimental Physics (Neutrino Physics)	10	10/1/2007	Stays at Kamioka Branch once a month. Usually stays at ICRR which is right next to Kavli IPMU.	
Mikhail Kapranov	58	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	100	5/16/2014	Stays at Kavli IPMU full time.	
Stavros Katsanevas	67	Professor, Université Paris Denis Diderot Director, European Gravitational Observatory	Ph.D. Astroparticle Physics	10	10/1/2007	Joins videoconference once a month.	Encouraging researches on experimental physics and female researchers.
Masahiro Kawasaki	60	Professor ICRR, The Univ. of Tokyo	Ph.D. Theoretical Physics (Cosmology)	40	8/1/2015	Stays at Kavli IPMU twice a week.	
Young-Kee Kim	58	Louis Block Distinguished Service Professor Dept. of Physics, University of Chicago	Ph.D. Physics	10	4/1/2017	Joins videoconference once a month. At ordinary times, stays at Kavli IPMU once a year.	Encouraging researches on neutrino physics and astroparticle physics.
Toshiyuki Kobayashi	58	Professor Graduate School of Mathematical Sciences, The Univ. of Tokyo	Ph.D. Mathematics	30	6/1/2011	Stays at Kavli IPMU once a month. Joins videoconference once a month	

Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Toshitake Kohno	65	Professor School of Interdisciplinary Mathematical Sciences Meiji University	Ph.D. Mathematics	40	10/1/2007	Stays at Kavli IPMU once a week. Joins videoconference once a week.	
Eiichiro Komatsu	46	Director Dept. of Physical Cosmology, Max Planck Institute for Astrophysics	Ph.D. Theoretical Physics (Cosmology)	20	2/1/2008	Joins videoconference once a month. At ordinary times, stays at Kavli IPMU twice a year.	Attended a research project's on line meeting as one of the representatives and did research discussions with the collaborators at the Kavli IPMU.
Kai Uwe Martens	57	Associate Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Experimental Neutrino Physics, Dark Matter Direct Detection	80	10/1/2008	Usually stays at Kamioka Branch.	
Shigeki Matsumoto	48	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Theoretical Physics (Cosmology)	80	10/1/2010	Stays at Kavli IPMU full time.	
Shigetaka Moriyama	51	Professor Kamioka Observatory, Institute for Cosmic Ray Research, The Univ. of Tokyo	Ph.D. Experimental Physics (Neutrino Physics)	20	2/1/2008	Usually stays at Kamioka Branch.	
Hitoshi Murayama	57	MacAdams Professor of Physics and Center for Japanese Studies, University of California, Berkeley Professor, Principal investigator Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Particle theory, Cosmology	20	10/1/2007	Due to COVID-19 related crisis, mainly particiated online in FY2020. At ordinary times, stays 20% at Kavli IPMU, and 80% at UC Berkeley of which a half of the time at Kavli IPMU Berkeley satellite.	Under the COVID-19 related crisis, in FY2020, encouraged researchers at the Kavli IPMU online. At ordinary times, organizes international workshops, invites young researchers to the Berkeley Week.
Masayuki Nakahata	61	Professor Kamioka Observatory, Institute for Cosmic Ray Research, The Univ. of Tokyo	Ph.D. Astroparticle physics	40	10/1/2007	Usually stays at Kamioka Branch.	

Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Hiraku Nakajima	59	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	35	4/1/2018	Stays at Kavli IPMU full time.	
Mihoko Nojiri	58	Professor Institute of Particle and Nuclear Studies , High Energy Accelerator Research Organization	Ph.D. Theoretical Physics (Particle Theory)	20	10/1/2007	Stays at Kavli IPMU twice a week.	
Yasunori Nomura	47	Director, Berkeley Center for Theoretical Physics, Univ. of California, Berkeley Professor, Dept. of Physics, Univ. of California, Berkeley Senior Faculty Scientist, Physics Division, Lawrence Berkeley National Laboratory	Ph. D. Theoretical Physics (Particle Theory)	15	1/1/2010	Due to COVID-19 related crisis, particiated online in FY2020. Attends videoconference once a week and joins online meeting and social events for researchers as much as time allows. At ordinary times, stays at Kavli IPMU one month in a year and organizing workshops for graduate students and postdocs.	Under the COVID-19 related crisis, in FY2020, encouraged researchers at the Kavli IPMU online. At ordinary times, attends the WPI site visit, organizes international workshops, invites PhD Students from USA to do research discussion.
David Spergel	60	Emeritus Professor Department of Astrophysical Sciences, Princeton University Director, Center for Computational Astrophysics, Flatiron Institute	Ph.D. Cosmology	40	10/1/2007	Joins videoconference once a month. Cooporates in evaluation of tenure-track faculty. At ordinary times, stays at Kavli IPMU once a year.	Encouraging researches on cosmology.
Naoshi Sugiyama	59	Vice President Director Professor Graduate School of Science Nagoya University	Ph.D. Cosmology	30	10/1/2007	Stays at Kavli IPMU once a month. Joins videoconference once a month.	

Name	Age	Affiliation (Position title, department, organization)	Academic degree, Specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Masahiro Takada	47	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Astronomy	80	3/1/2008	Stays at Kavli IPMU full time.	
Tadayuki Takahashi	61	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Experimental Physics	80	4/1/2018	Stays at Kavli IPMU full time.	
Yukinobu Toda	41	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	80	1/1/2008	Stays at Kavli IPMU full time.	
Mark Robert Vagins	55	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. High Energy Physics	80	5/16/2008	Stays at Kavli IPMU full time.	
Naoki Yoshida	47	Project Professor, PI Kavli IPMU, UTIAS, The Univ. of Tokyo Professor Department of Physics, The Univ. of Tokyo	Ph.D. Cosmology	40	4/1/2012	Stays at Kavli IPMU twice a week.	

Principal investigators unable to participate in project in FY 2020

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken

Appendix 3-1 FY 2020 Records of Center Activities

1. Researchers and other center staffs, satellites, partner institutions

1-1. Number of researchers and other center staffs

* Fill in the number of researchers and other center staffs in the table blow.
* Describe the final goals for achieving these numbers and dates when they will be achieved described in the last "center project."

a) Principal Investigators

(full professors, associate professors or other researchers of comparable standing)

(number of persons)

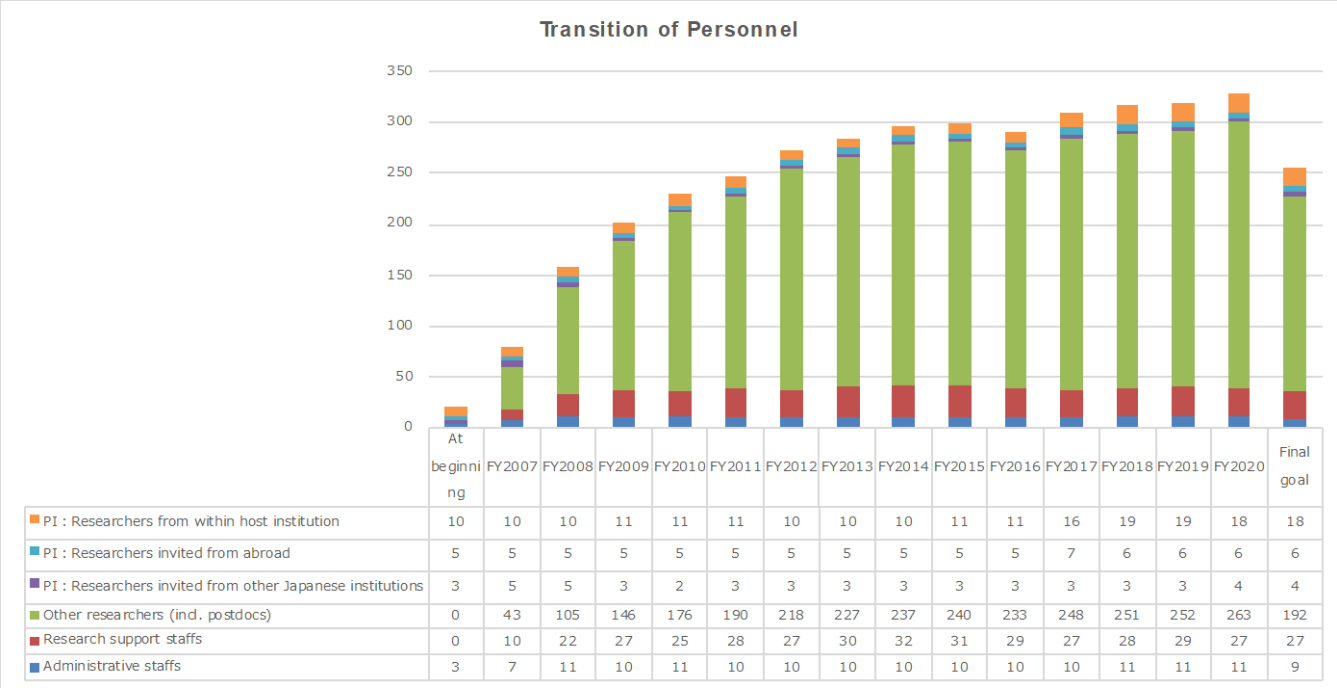
	At the beginning of project	At the end of FY 2020	Final goal (Date: 3, 2022)
Researchers from within the host institution	10	18	18
Researchers invited from abroad	5	6	6
Researchers invited from other Japanese institutions	3	4	4
Total principal investigators	18	28	28

b) Total members

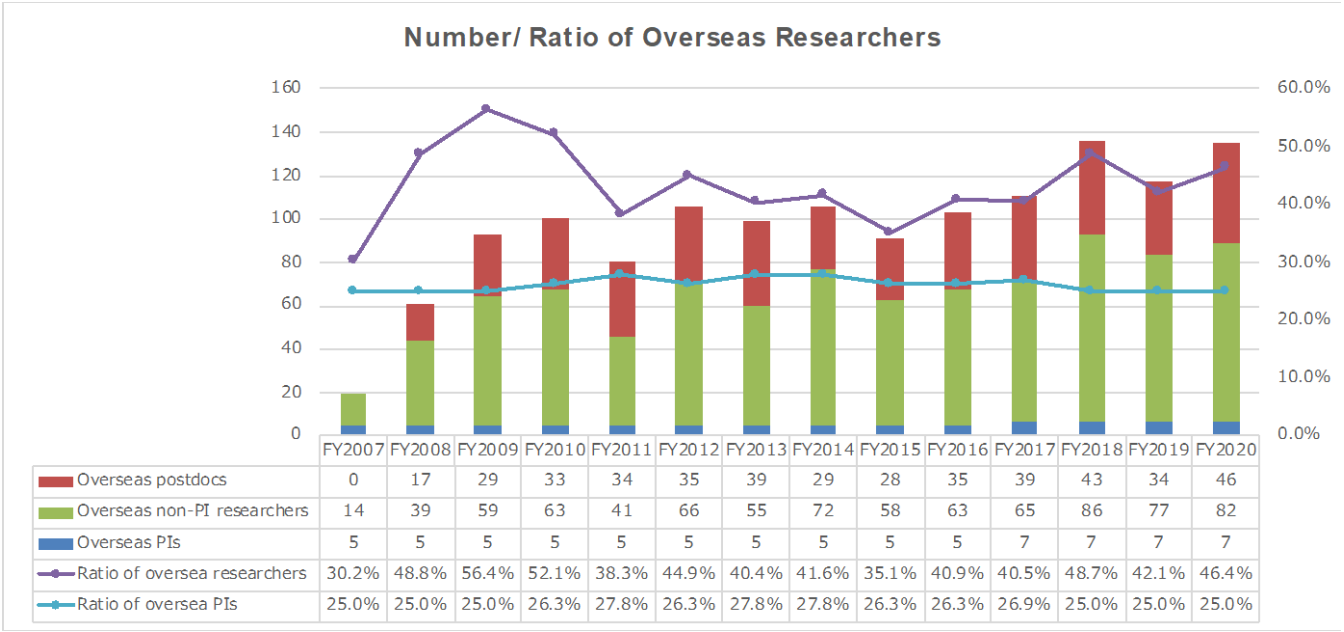
	At the beginning of project		At the end of FY 2020		Final goal (Date: 3, 2022)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	18		291		220	
Overseas researchers	5	28	135	46	113	51
Female researchers	0	0	27	9	26	12
Principal investigators	18		28		28	
Overseas PIs	5	28	7	25	7	25
Female PIs	0	0	2	7	2	7
Other researchers	0		202		142	
Overseas researchers	0	0	82	41	71	50
Female researchers	0	0	16	8	14	10
Postdocs	0		61		50	
Overseas postdocs	0	0	46	75	35	70
Female postdocs	0	0	9	15	10	20
Research support staffs	0		27		27	
Administrative staffs	3		11		9	
Total number of people who form the "core" of the research center	21		329		256	

Appendix 3-2　Annual Transition in the Number of Center Personnel

*Make a graph of the annual transition in the number of center personnel since the start of project.

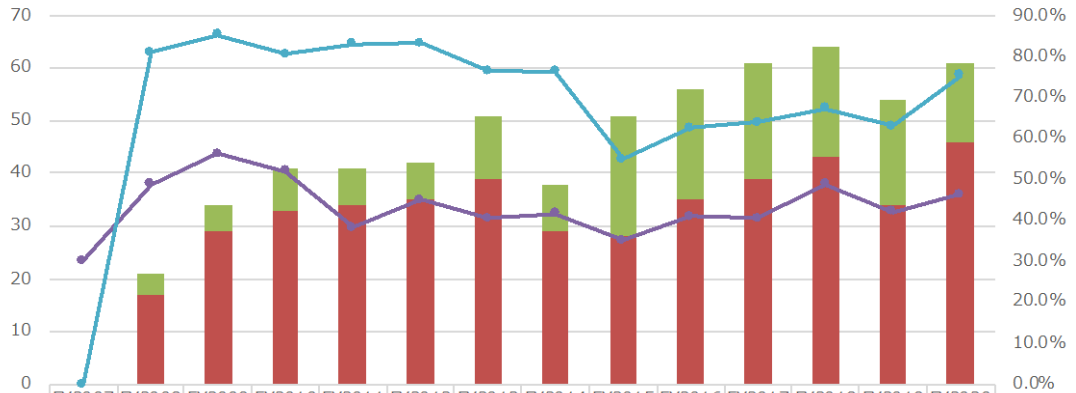


	At beginning	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Final goal
PI : Researchers from within host institution	10	10	10	11	11	11	10	10	10	11	11	16	19	19	18	18
PI : Researchers invited from abroad	5	5	5	5	5	5	5	5	5	5	5	7	6	6	6	6
PI : Researchers invited from other Japanese institutions	3	5	5	3	2	3	3	3	3	3	3	3	3	3	4	4
Other researchers (incl. postdocs)	0	43	105	146	176	190	218	227	237	240	233	248	251	252	263	192
Research support staffs	0	10	22	27	25	28	27	30	32	31	29	27	28	29	27	27
Administrative staffs	3	7	11	10	11	10	10	10	10	10	10	10	11	11	11	9



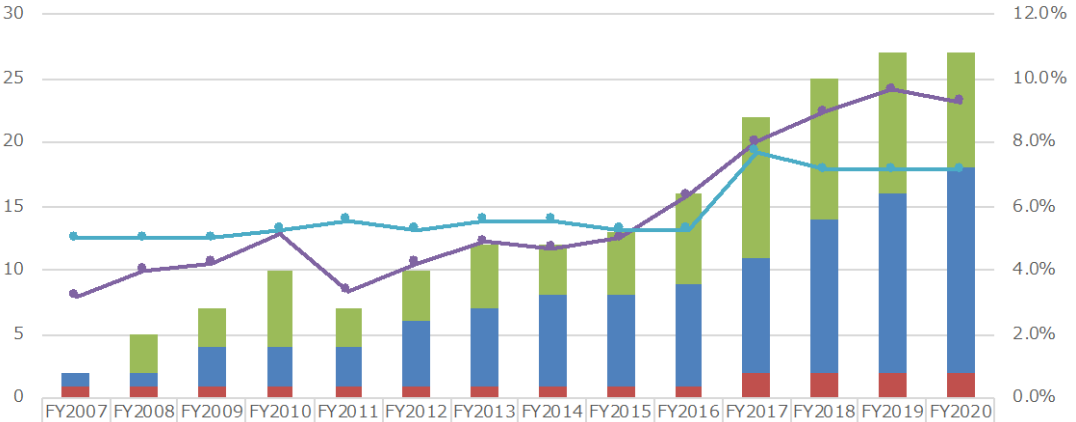
	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
Overseas postdocs	0	17	29	33	34	35	39	29	28	35	39	43	34	46
Overseas non-PI researchers	14	39	59	63	41	66	55	72	58	63	65	86	77	82
Overseas PIs	5	5	5	5	5	5	5	5	5	5	7	7	7	7
Ratio of oversea researchers	30.2%	48.8%	56.4%	52.1%	38.3%	44.9%	40.4%	41.6%	35.1%	40.9%	40.5%	48.7%	42.1%	46.4%
Ratio of oversea PIs	25.0%	25.0%	25.0%	26.3%	27.8%	26.3%	27.8%	27.8%	26.3%	26.3%	26.9%	25.0%	25.0%	25.0%

Number/ Ratio of Overseas Postdoc



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
Japanese postdocs	0	4	5	8	7	7	12	9	23	21	22	21	20	15
Overseas postdocs	0	17	29	33	34	35	39	29	28	35	39	43	34	46
Ratio of oversea researchers	30.2%	48.8%	56.4%	52.1%	38.3%	44.9%	40.4%	41.6%	35.1%	40.9%	40.5%	48.7%	42.1%	46.4%
Ratio of overseas postdocs	0.0%	81.0%	85.3%	80.5%	82.9%	83.3%	76.5%	76.3%	54.9%	62.5%	63.9%	67.2%	63.0%	75.4%

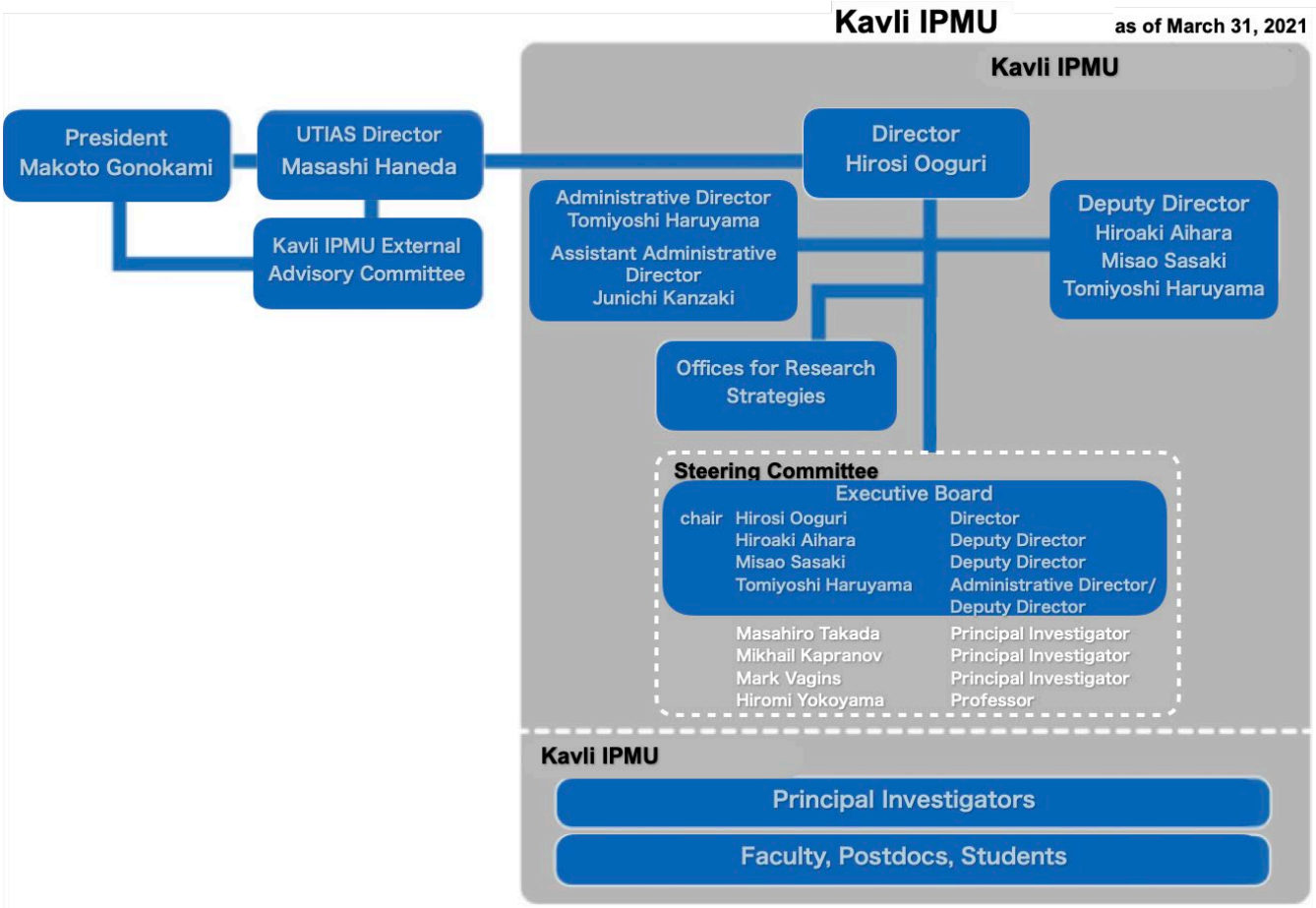
Number/ Ratio of Female Researcher



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
Female postdocs	0	3	3	6	3	4	5	4	5	7	11	11	11	9
Female non-PI researchers	1	1	3	3	3	5	6	7	7	8	9	12	14	16
Female PIs	1	1	1	1	1	1	1	1	1	1	2	2	2	2
Ratio of female researchers	3.2%	4.0%	4.2%	5.2%	3.3%	4.2%	4.9%	4.7%	5.0%	6.3%	8.0%	9.0%	9.6%	9.3%
Ratio of female PIs	5.0%	5.0%	5.0%	5.3%	5.6%	5.3%	5.6%	5.6%	5.3%	5.3%	7.7%	7.1%	7.1%	7.1%

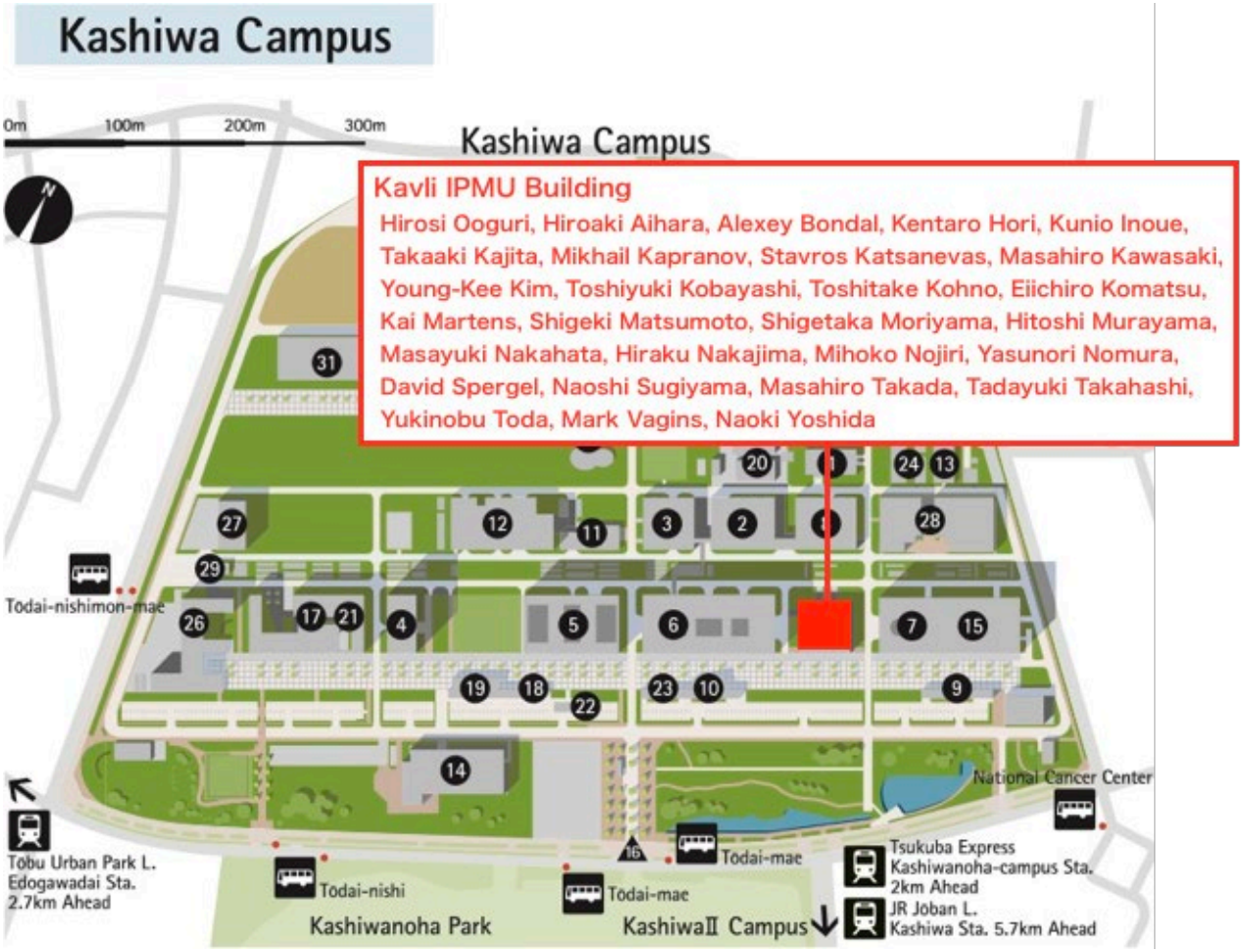
Appendix 3-3 Diagram of Management System

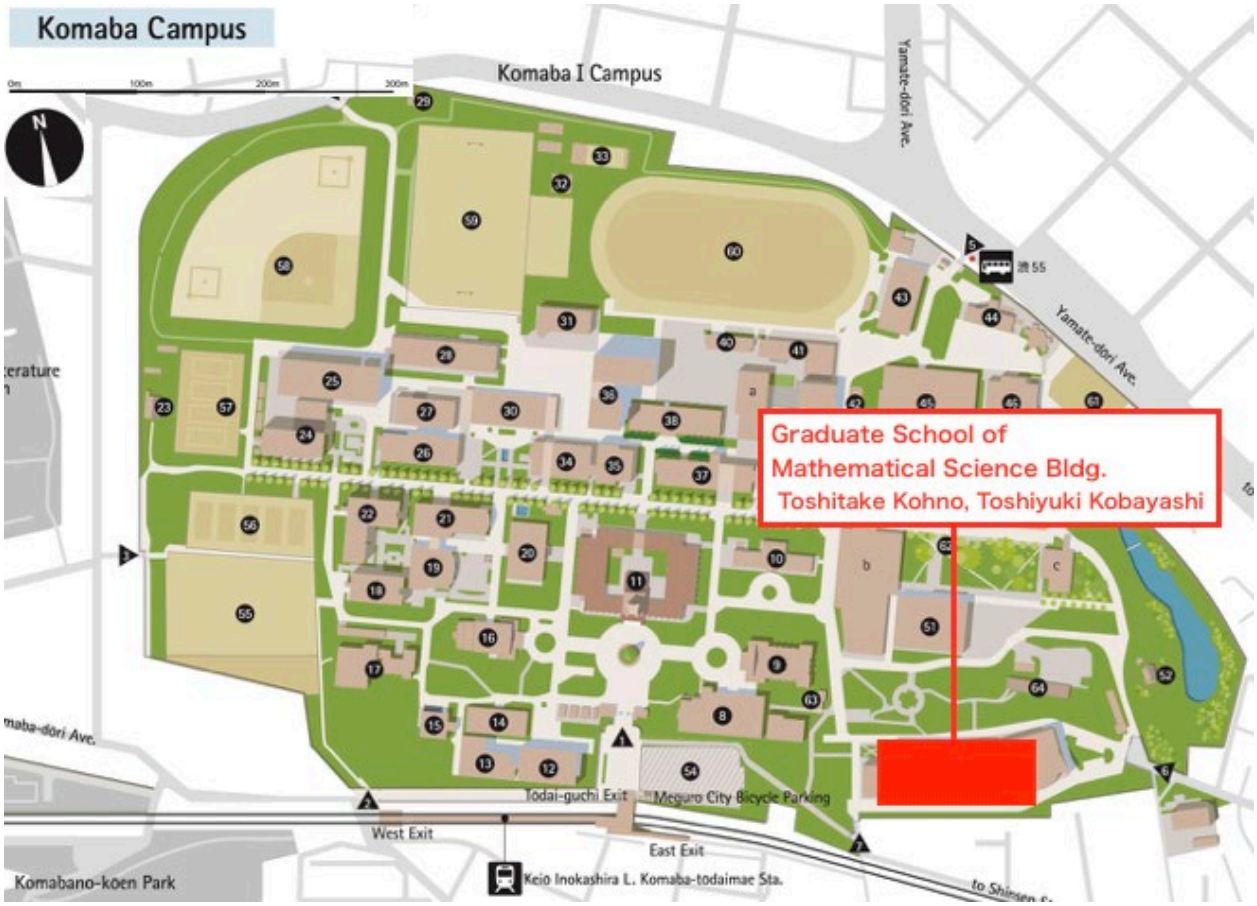
- Diagram the center's management system and its position within the host institution in an easily understood manner.
- If any changes have been made in the management system from that in the latest "center project" last year, describe them. Especially describe any important changes made in such as the center director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).

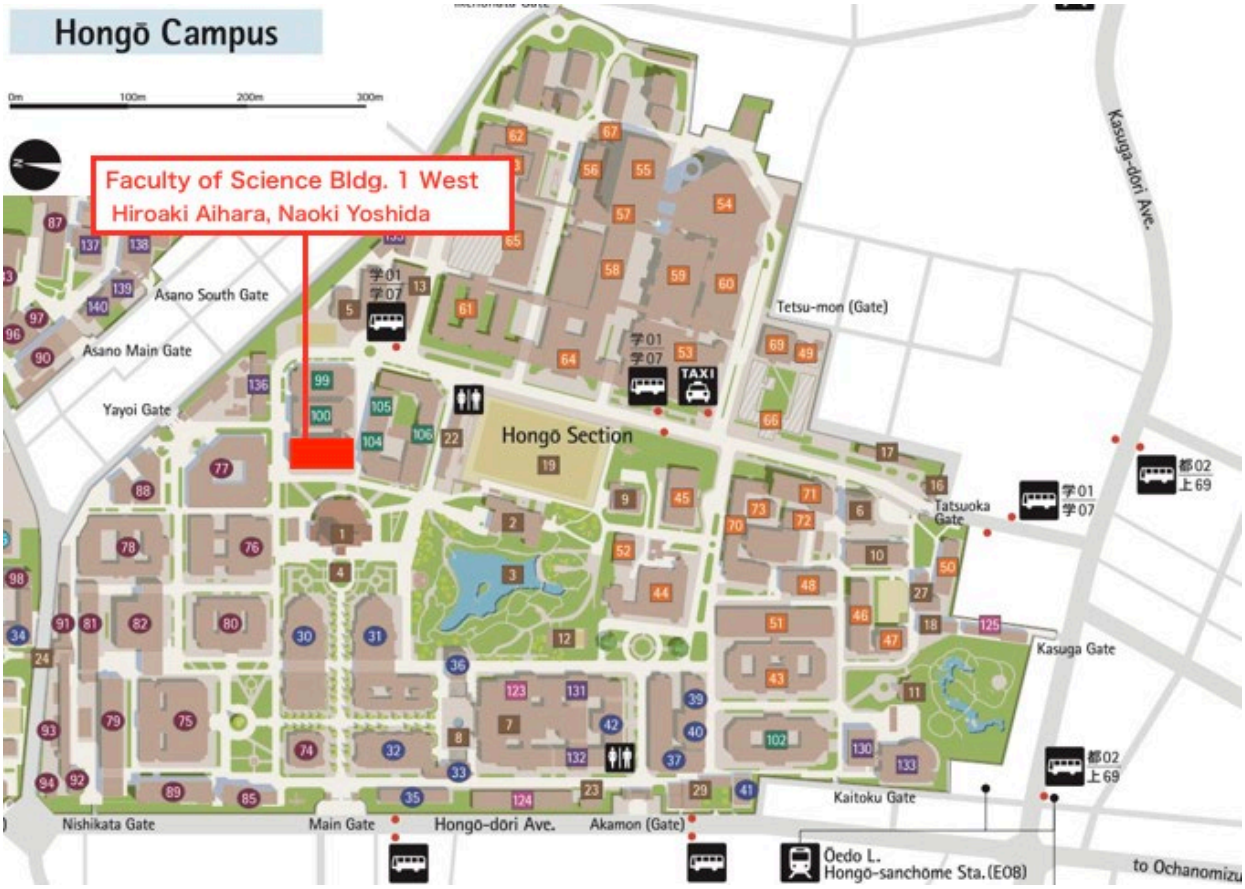


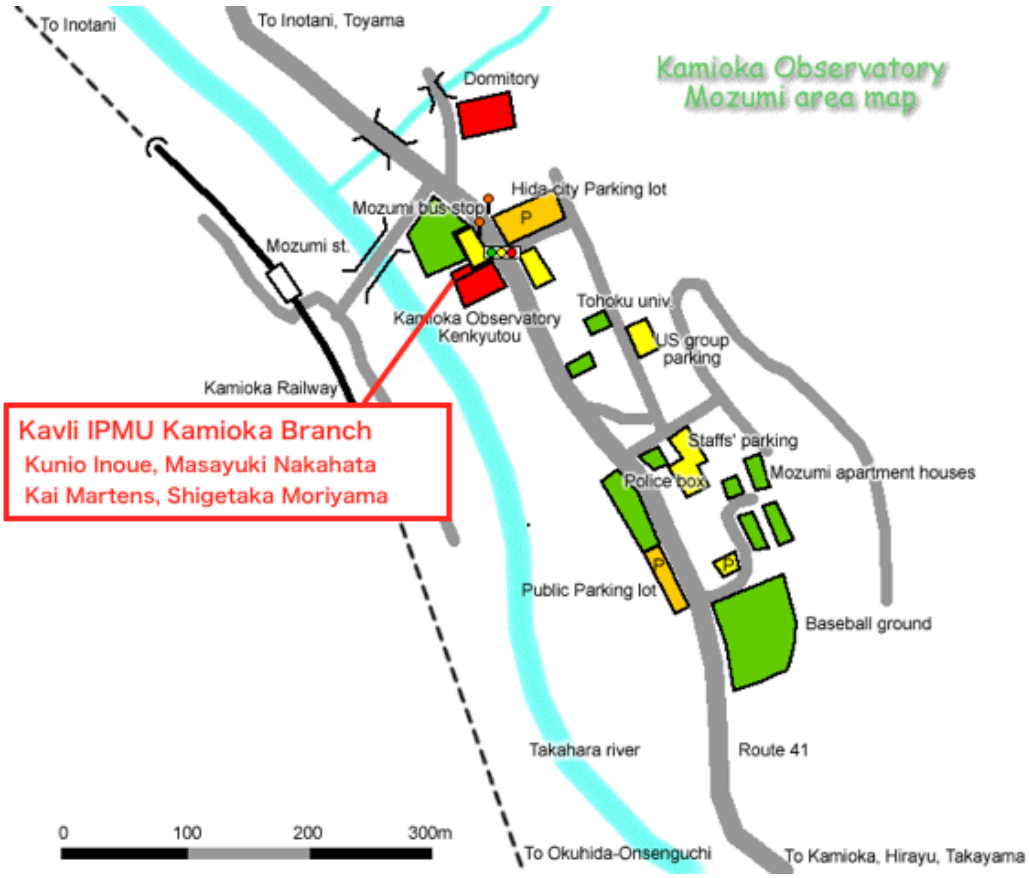
Appendix 3-4　Campus Map

- Draw a simple map of the campus showing where the main office and principal investigator(s) are located.




Komaba Campus
Komaba I Campus
Yamate-dori Ave.
Graduate School of
Mathematical Science Bldg.
Toshitake Kohno, Toshiyuki Kobayashi
Todai-guchi Exit
Meguro City Bicycle Parking
West Exit
East Exit
Komabano-koen Park
Keio Inokashira L. Komaba-todaimae Sta.


Hongō Campus
Faculty of Science Bldg. 1 West
Hiroaki Aihara, Naoki Yoshida
Kasuga-dori Ave.
Asano South Gate
Asano Main Gate
Yayoi Gate
Tetsu-mon (Gate)
Hongō Section
Tatsuoka Gate
Kasuga Gate
Kaitoku Gate
Nishikata Gate
Main Gate
Hongō-dori Ave.
Akamon (Gate)
Oedo L.
Hongō-sanchōme Sta. (E08)
to Ochanomizu


To Inotani
To Inotani, Toyama
Kamioka Observatory
Mozumi area map
Dormitory
Hida-city Parking lot
Mozumi bus-stop
Mozumi st.
Kamioka Observatory
Kenkyutou
Tohoku univ.
US group
parking
Kamioka Railway
Kavli IPMU Kamioka Branch
Kunio Inoue, Masayuki Nakahata
Kai Martens, Shigetaka Moriyama
Staffs' parking
Police box
Mozumi apartment houses
Public Parking lot
Baseball ground
Takahara river
Route 41
0
100
200
300m
To Okuhida-Onsenguchi
To Kamioka, Hirayu, Takayama

Appendix 3-5 Project Expenditures in FY2020

1) Overall project funding

* In the "Total costs" column, enter the total amount of funding required to implement the project, without dividing it into funding sources.
* In the "Amount covered by WPI funding" column, enter the amount covered by WPI within the total amount.
* In the "Personnel," "Project activities," "Travel," and "Equipment" blocks, the items of the "Details" culumn may be changed to coincide with the project's actual content.

(Million yens)

Cost items	Details (For Personnel - Equipment please fill in the breakdown of fiscal expenditure, and the income breakdown for Research projects.)	Total costs	Amount covered by WPI funding
Personnel	Center director and administrative director	67	67
	Principal investigators (no. of persons):17	225	0
	Other researchers (no. of persons):128	778	322
	Research support staffs (no. of persons):32	133	106
	Administrative staffs (no. of persons):11	83	83
	Subtotal	1286	578
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):12	5	5
	Cost of dispatching scientists (no. of persons):4	4	4
	Research startup cost (no. of persons):64	19	11
	Cost of satellite organizations (no. of satellite organizations):1	4	4
	Cost of international symposiums (no. of symposiums):8	1	1
	Rental fees for facilities	6	6
	Cost of consumables	76	31
	Cost of utilities	36	32
	Other costs	402	59
	Subtotal	553	153
Travel	Domestic travel costs	3	2
	Overseas travel costs	6	2
	Travel and accommodations cost for invited scientists (no. of domestic scientists):0 (no. of overseas scientists):1	1	1
	Travel cost for scientists on transfer (no. of domestic scientists):2 (no. of overseas scientists):14	8	8
	Subtotal	18	13
Equipment	Depreciation of buildings	98	0
	Depreciation of equipment	167	55
	Subtotal	265	55
Research projects (Detail items must be fixed)	Project supported by other government subsidies, etc. *1	169	0
	KAKENHI	155	0
	Commissioned research projects, etc.	20	0
	Joint research projects	29	0
	Ohers (donations, etc.)	18	0
	Subtotal	391	0
Total		2513	799

Costs (Million yens)

WPI grant in FY 2020	770
Costs of establishing and maintaining facilities	0
Costs of equipment procured	183
General-purpose computing systems and infrastructures (Number of units:1)	98
Cryostat for testing BBM2 (Number of units:1)	15
Others	70

*1. Funding sources that include government subsidies (including Enhancements promotion expenses (機能強化促進経費), National university reform reinforcement promotion subsidy (国立大学改革強化推進補助金) etc.), indirect funding, and allocations from the university's own resources.
*2 When personnel, travel, equipment (etc.) expenses are covered by KAKENHI or under commissioned research projects or joint research projects, the amounts should be entered in the "Research projects" block.

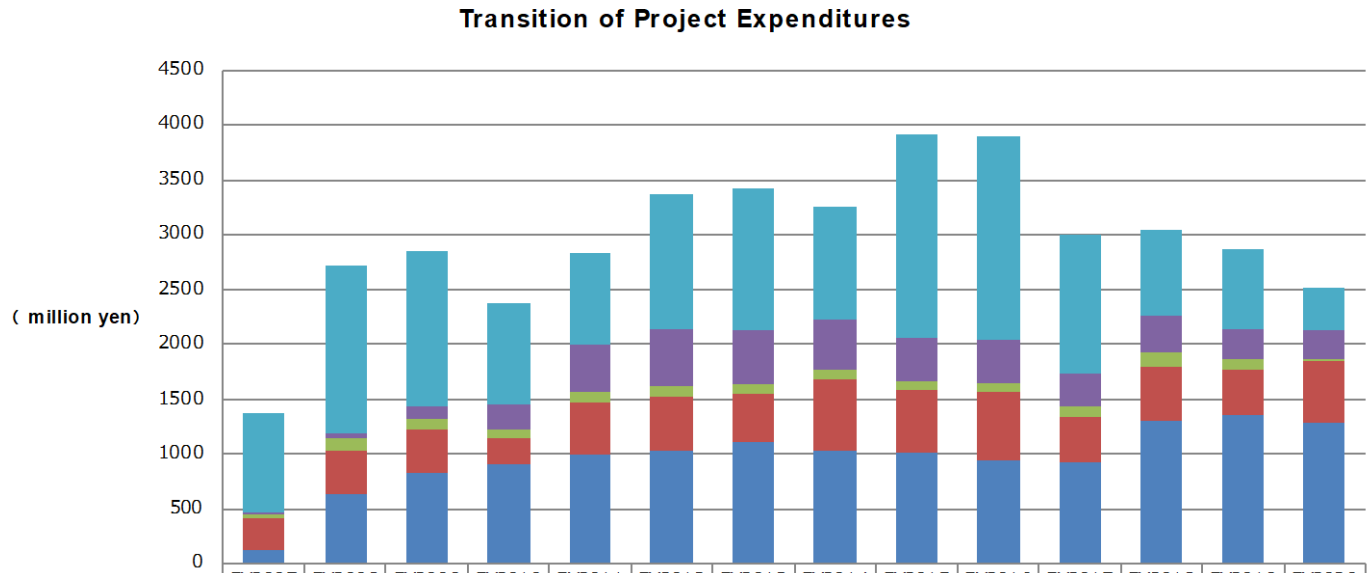
2) Costs of satellites

(Million yens)

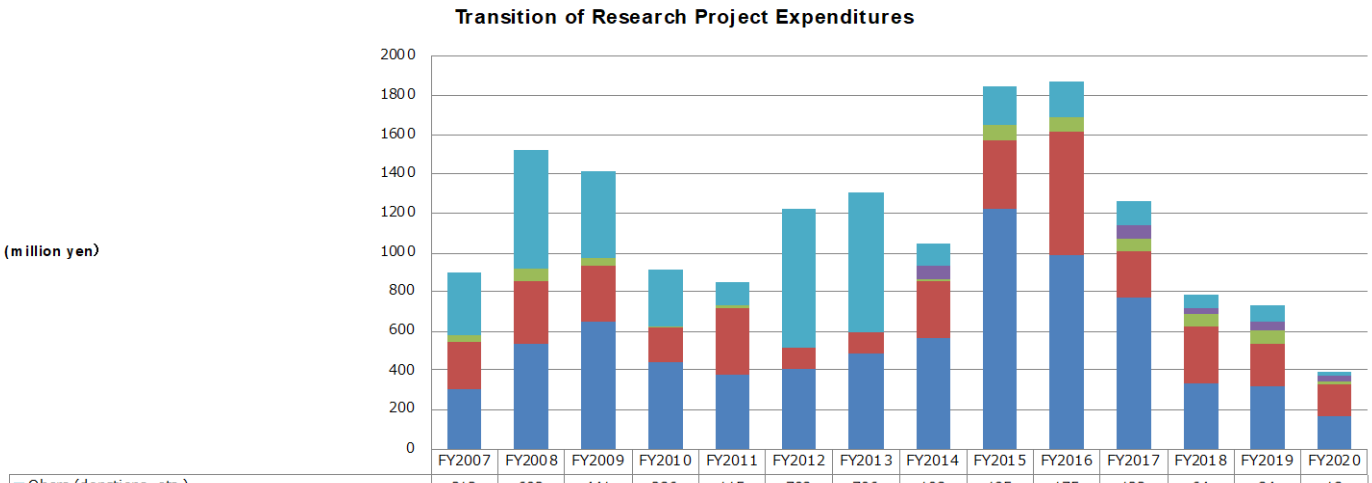
Cost items	Details	Total costs	Amount covered by WPI funding
Personnel	Principal investigators (no. of persons):0		
	Other researchers (no. of persons):1		
	Research support staffs (no. of persons):0		
	Administrative staffs (no. of persons):0		
	Subtotal	4	4
Project activities	Subtotal	0	0
Travel	Subtotal	0	0
Equipment	Subtotal	0	0
Research projects	Subtotal	0	0
Total		4	4

Appendix 3-6　Annual Transition in the Amounts of Project Funding

*Make a graph of the transition in the number of overall project funding.



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
Research Projects	896	1524	1410	911	846	1225	1301	1040	1843	1866	1259	783	730	391
Equipment	25	48	117	231	425	538	488	454	397	387	295	335	268	265
Travel	25	112	88	80	92	96	90	92	91	82	104	119	98	18
Project Activities	288	388	404	234	486	486	444	655	573	619	408	494	411	553
Personnel	132	635	825	906	987	1027	1101	1021	1005	948	925	1310	1357	1286



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
Ohers (donations, etc.)	313	602	441	286	115	708	706	108	195	175	123	64	84	18
Joint research projects	0	0	0	0	0	0	0	73	0	0	60	30	43	29
Commissioned research projects, etc.	36	64	33	11	11	0	0	5	75	75	67	65	63	20
KAKENHI	240	322	290	170	344	111	112	285	346	633	242	289	220	155
Project supported by other government subsidies, etc. *1	307	536	646	444	376	406	483	569	1227	983	767	335	320	169

*1 Definition is as shown in Appendix 3-5 (Project Expenditures)

Appendix 4-1 FY 2020 Status of Collaboration with Overseas Satellites

- If satellite and partner institutions have been established, fill in required items of the form below.

1. Satellites and partner institutions

- List the satellite and partner institutions in the table below (including the domestic satellite institutes).
- Indicate newly added and deleted institutions in the "Notes" column.

<Satellite institutions>

Institution name	Principal Investigator(s), if any	Notes
University of California Berkeley	Hitoshi Murayama, Yasunori Nomura	

< Partner institutions>

Institution name	Principal Investigator(s), if any	Notes
Institut des Hautes Études Scientifiques (IHES)		
Kyoto University, Yukawa Institute for Theoretical Physics		
Kyoto University, Department of Physics		
High Energy Accelerator Research Organization (KEK)	Mihoko Nojiri	
National Astronomical Observatory in Japan (NAOJ)		
Princeton University, Department of Astrophysical Sciences	David Spergel	

- If overseas satellite institutions have been established, fill in required items on the form below. If overseas satellite institutions have not been established, it is not necessary to complete the form.

2. Coauthored Papers

- List the refereed papers published in FY 2020 that were coauthored between the center's researcher(s) in domestic institution(s) (include satellite institutions) and overseas satellite institution(s). List them by overseas satellite institution in the below blocks.
- Transcribe data in same format as in Appendix 1-4. Italicize the names of authors affiliated with overseas satellite institutions.
- For reference write the Appendix 1-4 item number in parentheses after the item number in the blocks below. Let it free, if the paper is published in between Jan.-Mar. 2021 and not described in Appendix 1-4.

Overseas Satellite 1 **Berkeley** (Total: 35 papers)

No.	Author names and details
16	Big-bang nucleosynthesis with sub-GeV massive decaying particles Kawasaki, M; Kohri, K; Moroi, T; Murai, K; *Murayama, H* JOURNAL OF COSMOLOGY AND ASTROPARTICLE PHYSICS (12), 48, DEC, 2020
27	A cryogenic continuously rotating half-wave plate mechanism for the POLARBEAR-2b cosmic microwave background receiver *Hill, CA*; Kusaka, A; Ashton, P; Barton, P; *Adkins, T*; Arnold, K; Bixler, B; *Ganjam, S*; *Lee, AT*; Matsuda, F; Matsumura, T; Sakurai, Y; *Tat, R*; *Zhou, Y* REVIEW OF SCIENTIFIC INSTRUMENTS 91(12), 124503, DEC 1, 2020

65	A Measurement of the CMB E-mode Angular Power Spectrum at Subdegree Scales from 670 Square Degrees of POLARBEAR Data Adachi, S et al. (including *Cheung K; Crowley K; Goeckner-Wald N; Groh J; Jeong, O; Lee, AT; Westbrook; B, Zhou, Y*) ASTROPHYSICAL JOURNAL 904(1), 65, NOV, 2020
93	Ensemble from coarse graining: Reconstructing the interior of an evaporating black hole *Langhoff, K*; Nomura, Y PHYSICAL REVIEW D 102(8), 86021, OCT 27, 2020
149	Coarse-graining holographic states: A semiclassical flow in general spacetimes *Murdia, C*; Nomura, Y; *Rath, P* PHYSICAL REVIEW D 102(8), 86001, OCT 1, 2020
158	X-ray spectra of the Fe-L complex: II. Atomic data constraints from the EBIT experiment and X-ray grating observations of Capella Gu, LY; Shah, CT; Mao, JJ; Raassen, T; de Plaa, J; Pinto, C; Akamatsu, H; Werner, N; Simionescu, A; Mernier, F; Sawada, M; Mohanty, P; Amaro, P; *Gu, MF*; Porter, FS; Lopez-Urrutia, JRC; Kaastra, JS ASTRONOMY & ASTROPHYSICS 641, A93, SEP 15, 2020
161	Planck 2018 results: XII. Galactic astrophysics using polarized dust emission Aghanim, N et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A12, SEP 11, 2020
162	Planck 2018 results: V. CMB power spectra and likelihoods Aghanim, N et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A5, SEP 11, 2020
163	Planck 2018 results: I. Overview and the cosmological legacy of Planck Aghanim, N et al. (including *Borrill, J*; *Keskitalo, R*) ASTRONOMY & ASTROPHYSICS 641, A1, SEP 11, 2020
166	Planck 2018 results: IV. Diffuse component separation Akrami, Y et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A4, SEP 11, 2020
167	Planck 2018 results: XI. Polarized dust foregrounds Akrami, Y et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A11, SEP 11, 2020
168	Planck 2018 results: IX. Constraints on primordial non-Gaussianity Akrami, Y et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A9, SEP 11, 2020
169	Planck 2018 results: VII. Isotropy and statistics of the CMB Akrami, Y et al. (including *Borrill, J*) ASTRONOMY & ASTROPHYSICS 641, A7, SEP 11, 2020
203	The Quijote Simulations Villaescusa-Navarro, F et al. (including *Hahn, C; Feng, Y; Castorina, E*) ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES 250(1), 2, SEP, 2020
226	REVIEW OF PARTICLE PHYSICS Zyla, PA et al. (including *Klein, SR*) PROGRESS OF THEORETICAL AND EXPERIMENTAL PHYSICS 2020(8), 083C01, AUG, 2020
253	Foreground mismodeling and the point source explanation of the Fermi Galactic Center excess Buschmann, M; *Rodd, NL*; Safdi, BR; Chang, LJ; Mishra-Sharma, S; Lisanti, M; Macias, O PHYSICAL REVIEW D 102(2), 23023, JUL 16, 2020
259	Simultaneous observations of the blazar PKS 2155-304 from ultra-violet to TeV energies Abdalla, H et al. (including *Zoglauer, A*) ASTRONOMY & ASTROPHYSICS 639, A42, JUL 7, 2020

274	A Measurement of the Degree-scale CMB B-mode Angular Power Spectrum with POLARBEAR Adachi, S et al. (including *Beckman, S; Cheung, K; Chinone, Y; Crowley, K; Goeckner-Wald, N; Groh, J; Hill, CA; Jeong, O; Mangu, A; Westbrook, B; Zhou, Y*) ASTROPHYSICAL JOURNAL 897(1), 55, JUL, 2020
312	A predictive mirror twin Higgs with small Z(2) breaking *Harigaya, K*; *McGehee, R*; Murayama, H; *Schutz, K* JOURNAL OF HIGH ENERGY PHYSICS (5), 155, MAY 28, 2020
320	Theia: an advanced optical neutrino detector Askins, M et al. (including *Askins, M; Callaghan, EJ; Caravaca, J; Gann, GDO; Smiley, M; Zsoldos, S*) EUROPEAN PHYSICAL JOURNAL C 80(5), 416, MAY 13, 2020
338	Deployment of Polarbear-2A Kaneko, D et al. (including *Beckman, S; Cheung, K; Chinone, Y; Crowley, K; Groh, J; Hill, CA; Jeong, O; Lee, AT; Mangu, A; Zhou, Y*) JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.1137-1147, MAY, 2020
356	Baryogenesis from a dark first-order phase transition *Hall, E*; Konstandin, T; *McGehee, R*; Murayama, H; Servant, G JOURNAL OF HIGH ENERGY PHYSICS (4), 42, APR 7, 2020
368	Measurement of the Cosmic Microwave Background Polarization Lensing Power Spectrum from Two Years of POLARBEAR Data Faundez, MA et al. (including *Beckman, S; Cheung, K; Goeckner-Wald, N; Hill, CA; Jeong, O; Lee, AT; Mangu, A; Zhou, Y*) ASTROPHYSICAL JOURNAL 893(1), 85, APR, 2020
375	Internal Delensing of Cosmic Microwave Background Polarization B-Modes with the POLARBEAR Experiment Adachi, S et al. (including *Ali, A; Cheung, K; Chinone, Y; Crowley, K; Goeckner-Wald, N; Hill, CA; Lee, AT; Mangu, A; Zhou, Y*) PHYSICAL REVIEW LETTERS 124(13), 131301, APR 1, 2020
390	Effect of Stray Impedance in Frequency-Division Multiplexed Readout of TES Sensors in POLARBEAR-2b Elleflot, T et al. (including *Barron, D; Crowley, KT; Groh, J; Hill, C; Jeong, O; Lee, AT; Raum, C; Westbrook, B*) JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.840-848, MAY, 2020
422	Irradiation Tests of Superconducting Detectors and Comparison with Simulations Minami, Y; Akiba, Y; *Beckman, S*; Hazumil, M; Kuo, C; Kurinsky, NA; Kutsuma, H; *Lee, AT*; Mima, S; *Raum, CR*; *Sasse, T*; Stever, SL; Suzuki, A; *Westbrook, B* JOURNAL OF LOW TEMPERATURE PHYSICS 199(1-2), pp.118-129, APR, 2020
456	Design of a Testbed for the Study of System Interference in Space CMB Polarimetry Ghigna, T; Matsumura, T; Hazumi, M; Stever, SL; Sakurai, Y; Katayama, N; Suzuki, A; Westbrook, B; *Lee, AT* JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.622-630, MAY, 2020
463	Updated Design of the CMB Polarization Experiment Satellite LiteBIRD Sugai, H et al. (including *Beckman, S; Borrill, J; Chinone, Y; Cukierman, A; Curtis, D; Hill, C; Lee, AT; Linder, E; Raum, C; Taylor, E; Westbrook, B*) JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.1107-1117, MAY, 2020
515	First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform Abi, B et al. (including *Kohn, S; Luk KB; Madigan, P; Nagu, S; Singh, J*) JOURNAL OF INSTRUMENTATION 15(12), P12004, DEC, 2020
519	Neutrino interaction classification with a convolutional neural network in the DUNE far detector Abi, B et al. (including *Kohn, S; Luk KB; Madigan, P*) PHYSICAL REVIEW D 102(9), 92003, NOV 9, 2020

524	Long-baseline neutrino oscillation physics potential of the DUNE experiment: DUNE Collaboration Abi, B et al. (including *Kohn, S; Luk KB; Madigan, P*) EUROPEAN PHYSICAL JOURNAL C 80(10), 978, OCT 22, 2020
530	The cross correlation of the ABS and ACT maps Li, Z et al. (including *Crowley, KT*) JOURNAL OF COSMOLOGY AND ASTROPARTICLE PHYSICS (9), 10, SEP, 2020
557	Small Aperture Telescopes for the Simons Observatory Ali, AM et al. (including *Ali, A; Ashton, P; Chinone, Y; Corbett, L; Crowley, KT; Lee, AT; Ludlam, M; Mangu, A; Raum, C; Sasse, T; Westbrook B*) JOURNAL OF LOW TEMPERATURE PHYSICS 200(5-6), pp.461-471, SEP, 2020
561	Development of Space-Optimized TES Bolometer Arrays for LiteBIRD Jaehnig, GC; Arnold, K; Austermann, J; Becker, D; Duff, S; Halverson, NW; Hazumi, M; Hilton, G; Hubmayr, J; *Lee, AT*; Link, M; Suzuki, A; Vissers, M; Walker, S; *Westbrook, B* JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.646-653, MAY, 2020
562	Simons Observatory Microwave SQUID Multiplexing Readout: Cryogenic RF Amplifier and Coaxial Chain Design Rao, MS et al. (including *Ali, A; Ashton, P; Lee, AT; Ludlam, M; Mangu, A; Raum, C; Sasse, T; Thornton, R; Westbrook B*) JOURNAL OF LOW TEMPERATURE PHYSICS 199(3-4), pp.807-816, MAY, 2020

3. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2020. Enter by institution and length of exchange.
- Write the number of principal investigator visits in the top of each space and the number of other researchers in the bottom.

Overseas Satellite 1: Berkeley

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2020	0	0	0	0	0
	0	0	0	0	0

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2020	0	0	2	1	3
	0	0	0	0	0

Appendix 4-2 FY 2020 Visit Records of Researchers from Abroad

* If researchers have visited/ stayed at the Center, provide information on them in the below table.
* Enter the host institution name and the center name in the footer.

Total: 10

	Name	Age	Affiliation		Academic degree, specialty	Record of research activities (Awards record, etc.)	Time, duration	Summary of activities during stay at center (e.g., participation as principal investigator; short-term stay for joint research; participation in symposium)
			Position title, department, organization	Country				
1	Alexander Kusenko	55	Professor, Department of Physics & Astronomy, UCLA Senior Scientist, Kavli IPMU, U. of Tokyo	U.S.A.	Ph.D.	Simons Fellowsc(2021) Fellow of American Physical Society(2008) Outstanding Referee of American Physical Society (2012)	2020/10/23-12/23	Stay for joint research
2	Jason Lott Evans	42	Professor, Shanghai Jiao Tong U	China	Ph.D.		2020/3/2-12/27	Stay for joint research
3	Tsutomu Yanagida	72	T. D. Lee Professor , Tsung-Dao Lee Institute, Shanghai Jiao Tong University	China	Ph.D. in physics	The Particle Physics Medal (2020) Helmholtz International Fellow Award (2014) Totsuka Youji Prize (2012) Hertz Lecture at DESY Hamburg (2011) Humboldt Prize (2003) Nishina Memorial Prize (1992) Yukawa Memorial Prize (1989)	2020/1/31-11/20	Stay for joint research
4	Richard Driessnack Eager	37	Research Fellow, Korea Institute for Advanced Study	Republic of Korea	Ph.D.		2020/6/24-8/31	Stay for joint research
5	William Ross Goodchild Donovan	38	Assistant Professor, Tsinghua U, Beijing	China	Ph.D.		2020/2/10-6/9	Stay for joint research and attend an international workshop as one of the invited speakers

	Name	Age	Affiliation		Academic degree, specialty	Record of research activities (Awards record, etc.)	Time, duration	Summary of activities during stay at center (e.g., participation as principal investigator; short-term stay for joint research; participation in symposium)
			Position title, department, organization	Country				
6	Yuichiro Nakai		Associate Professor, School of Physics and Astronomy, Shanghai Jiaotong University	China	Ph.D.		2021/2/1-4	Stay for joint research
7	Hajime Fukuda		Postdoctoral Researcher, Lawrence Berkeley National Laboratory	U.S.A.	Ph.D.		2020/8/19-9/9 2021/3/14-4/30	Stay for joint research
8	Motoo Suzuki		Postdoctoral Researcher, Tsung-Dao Lee Institute, Shanghai Jiao Tong University	China	Ph.D.		2020/2/25-6/30 2021/2/1-4	Stay for joint research
9	Ryota Tomaru		Postdoctoral Researcher, Department of Physics, University of Durham	U.K.	Ph.D.		2020/10/1-11/30	Stay for joint research
10	Junyao Li	27	Graduate Student, U Science and Technology China	China	Master's degree		2019/9/20-2021/9/19	Stay for joint research

Appendix4-3 Postdoctoral Positions through Open International Solicitations

* In the column of number of applications and number of selection, put the total number (upper), the number and percentage of overseas researchers in the < > brackets (lower).

Fiscal year	number of applications	number of selection
FY 2007	481	1
	< 372, 77%>	< 0, 0%>
FY 2008	527	22
	<452 , 86%>	< 16, 73%>
FY 2009	726	20
	< 679, 93%>	<16 , 80%>
FY 2010	794	14
	< 751, 95%>	< 10, 71%>
FY 2011	811	15
	< 738, 91%>	< 14, 93%>
FY 2012	664	16
	< 615, 93%>	< 15, 94%>
FY 2013	661	19
	< 607, 92%>	< 11, 58%>
FY 2014	747	11
	< 692, 93%>	< 7, 64%>
FY 2015	610	21
	< 556, 91%>	< 13, 62%>
FY 2016	595	15
	< 535, 90%>	<10 , 67%>
FY 2017	657	20
	< 591, 90%>	< 17, 85%>
FY 2018	728	12
	< 633, 87%>	< 10, 83%>
FY 2019	670	15
	< 625, 93%>	< 13, 87%>
FY 2020	584	14
	< 544, 93%>	< 10, 71%>

Appendix 4-4 Status of Employment of Postdoctoral Researchers

Enter the information below during the period from the start of the center through the end of FY 2020.

- For each person, fill in the spaces to the right. More spaces may be added.
- Leave "Position as of April 2021" blank if unknown.
- Enter the host institution name and the center name in the footer.

Japanese Postdocs

Employment period	Position before employed at WPI center		Next position after WPI center		Position as of April 2021*	
	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located
2008/04/01-2008/06/30	Researcher, KEK	Japan	Assistant Professor, Tohoku University	Japan	Researcher, Shimane University	Japan
2008/04/01-2008/09/30	JSPS Fellow (oversea), McGill University	Canada	Senior Research Associate, Durham University	UK	Associate Professor, Kyushu University	Japan
2008/04/16-2008/10/31	Researcher, RIMS, Kyoto University	Japan	Assistant Professor, Kavli IPMU	Japan	Associate Professor, Middle East Technical University	Turkey
2008/02/01-2008/10/31	JSPS Fellow (oversea), IHÉS	France	Assistant Professor, Kyushu University	Japan	Professor, Fukuoka University	Japan
2008/04/16-2009/03/06	JSPS Fellow, The University of Tokyo	Japan	Visiting Scholar, Technische Universitat München	Germany	Senior Scientist, MPI for Gravitational Physics	Germany
2008/04/01-2009/09/30	JSPS Fellow, Graduate School of Mathematical Sciences, The University of Tokyo	Japan	Assistant Professor, Kobe University	Japan	Associate Professor, Yokohama National University	Japan
2009/04/01-2010/03/31	PhD Student, The University of Tokyo	Japan	Project Researcher, Max-Planck Inst. For Physics	Germany	company	
2009/04/01-2011/03/31	PhD Student, Kyoto University	Japan	Postdoc, YITP, Kyoto University	Japan	Assistant Professor, Nagoya University	Japan
2010/04/01-2011/11/30	JSPS Fellow, Kavli IPMU	Japan	Assistant Professor, NAOJ	Japan	Associate Professor, Tohoku University	Japan

2010/08/16- 2012/03/31	Postdoc, Perimeter Institute	Canada	Associate Professor (Hakubi), Kyoto University	Japan	Associate Professor, Kyushu University	Japan
2009/01/01- 2012/03/31	Postdoc, University of Tsukuba	Japan	Fellow Researcher, Kyoto Sangyo University	Japan	Associate Professor, Shikoku Gakuin University	Japan
2010/01/01- 2013/03/31	Fellow, European Southern Observatory	Germany	Project Assistant Professor, NAOJ	Japan	Associate Professor, NAOJ	Japan
2013/04/01- 2013/09/30	PhD Student, The University of Tokyo	Japan	Software Engineer, company	Japan	Software Engineer, company	Japan
2012/04/01- 2014/02/28	Project Researcher, The University of Tokyo	Japan	Lecturer, Tokyo University of Agriculture	Japan	Associate Professor, Tokyo University of Agriculture and Tech	Japan
2008/09/01- 2014/03/31	Postdoc, Hokkaido University	Japan	Assistant Professor, NAOJ	Japan	Postdoc, NAOJ	Japan
2010/05/01- 2014/03/31	Researcher, Ehime University	Japan	Researcher, ICRR, The University of Tokyo	Japan	Postdoc, University of Hyogo	Japan
2010/09/01- 2014/04/30	Postdoc, Tohoku University	Japan	Project Lecturer, Nagoya University	Japan	Lecturer, Nagoya University	Japan
2013/09/01- 2015/02/28	Postdoc, Academia Sinica	Taiwan	Assistant Professor, Hiroshima University	Japan	Associate Professor, Hiroshima University	Japan
2013/04/01- 2015/04/30	Postdoc, UC Berkeley	USA	Assistant Professor, KEK	Japan	Assistant Professor, The University of Tokyo, RESCEU	Japan
2015/07/01- 2016/03/31	Researcher, KEK	Japan	Researcher, AIST	Japan	Tenure track Research Scientist, AIST	Japan
2011/09/01- 2016/03/31	Senior Research Fellow, CALTECH	USA	Associate Professor, Rikkyo University	Japan	Associate Professor, Rikkyo University	Japan
2013/04/01- 2016/03/31	JSPS Fellow, UC Berkeley	USA	Postdoc, Max-Planck Inst. For Physics	Germany	Assistant Professor, Missouri University of Science and Technology	USA
2014/11/01- 2016/03/31	PhD Student, Tohoku University	Japan	JSPS Fellow, Kavli IPMU	Japan	Assistant Professor, NAOJ	Japan
2014/04/01- 2016/03/31	PhD Student, Tohoku University	Japan	Assistant Professor, Osaka University	Japan	Assistant Professor, ICRR, The University of Tokyo	Japan

2016/04/01- 2016/09/30	PhD Student, Tohoku University	Japan	Postdoc, NAOJ	Japan	Assistant Professor, National Institute of Technology, Ichinoseki College	Japan
2013/09/01- 2016/09/30	PhD Student, University of Minnesota	USA	Postdoc, McGill University	USA	Postdoc, McGill University	Canada
2014/01/01- 2016/12/31	Research Fellow, Ewha Womans University	South Korea	Associate Research Fellow, Academia Sinica	Taiwan	Associate Research Fellow, Academia Sinica	Taiwan
2013/04/01- 2017/03/31	PhD Student, The University of Tokyo	Japan	Postdoc, Institute for Advanced Study	USA	Associate Professor, Osaka University	Japan
2014/06/01- 2017/06/15	PhD Student, Kyoto University	Japan	Postdoc, CUHK	HK	Assistant Professor, ShanghaiTech University	China
2015/04/01- 2018/03/31	PhD Student, Nagoya University	Japan	Postdoc, ISM	Japan	Assistant Professor, ISM	Japan
2015/08/01- 2018/03/31	Postdoc, IAS	USA	Assistant Professor, Kyushu University	Japan	Associate Professor, Tohoku University	Japan
2015/08/01- 2018/10/31	Research support staff, Kavli IPMU	Japan	Lecturer, Keio University	Japan	Lecturer, Keio University	Japan
2015/09/01- 2019/01/31	JSPS Fellow, Kavli IPMU	Japan	Assistant Professor, Tohoku University	Japan	Assistant Professor, NAOJ, Hawaii	USA
2015/04/01- 2019/03/31	PhD Student, Graduate School of Mathematical Sciences, The University of Tokyo	Japan	Lecturer, Osaka University	Japan	Associate Professor, Josai University	Japan
2016/04/01- 2019/03/31	Lady Davis Fellow, Hebrew University of Jerusalem	Israel	Researcher, NAOJ	Japan	Researcher, NAOJ	Japan
2018/10/01- 2019/03/31	JSPS Fellow, Kyoto University	Japan	Researcher, Company	Japan	Researcher, Company	Japan
2014/10/01- 2019/03/31	Postdoc, King's College London	UK	Associate Professor, Nagoya University	Japan	Project Assistant Professor, Osaka University	Japan
2019/04/01- 2019/09/30	JSPS Fellow, The University of Tokyo	Japan	Postdoc, NCTS	Taiwan	Postdoc, NCTS	Taiwan

2017/10/01-2020/03/31	PhD Student, Graduate School of Mathematical Sciences, The University of Tokyo	Japan	Assistant Professor, Osaka University	Japan	Assistant Professor, Osaka University	Japan
2017/04/01-2020/03/31	Postdoc, Nara Women's University	Japan	Housewife business	Japan	Housewife business	Japan
2017/04/16-2020/03/31	Assistant Professor, Nagoya University	Japan	Assistant Professor, Kyoto Sangyo University	Japan	Assistant Professor, Kyoto Sangyo University	Japan
2016/04/01-2020/03/31	Lecturer, Bunkyo University	Japan	Postdoc, Chiba University	Japan	Postdoc, Chiba University	Japan
2016/10/01-2020/03/31	PhD Student, Yale University	USA	JSPS Fellow, Nagoya University	Japan	JSPS Fellow, Nagoya University	Japan
2016/04/01-2020/03/31	Research Assistant, Aoyama Gakuin University	Japan	Researcher, Tohoku University	Japan	Researcher, Tohoku University	Japan
2016/08/01-2020/07/31	PhD Student, ICEPP, The University of Tokyo	Japan	Postdoc, KEK	Japan	Postdoc, KEK	Japan
2016/01/16-2020/08/31	JSPS Fellow, IoA, The University of Tokyo	Japan	Postdoc, ASIAA	Taiwan	Postdoc, ASIAA	Taiwan
2020/06/01-2020/09/30	Postdoc, Laboratoire de l'accél érateur linéaire	France	Assistant Professor, NAOJ	Japan	Assistant Professor, NAOJ	Japan
2020/08/16-2020/10/06	Postdoc, Kyoto University	Japan	Postdoc, Université de Paris, Institut de mathé matiques de Jussieu – Paris Rive Gauche	France	Assistant Professor, Kyoto University	Japan
2020/05/16-2020/12/15	PhD Student, The University of Tokyo	Japan	Postdoc,	Canada	Postdoc, TRIUMF	Canada
2020/11/01-2021/01/31	Research Fellow, IBS	South Korea	Assistant Professor, University of Warsaw	Poland	Assistant Professor, University of Warsaw	Poland
2020/10/01-2021/03/31	JSPS Fellow, Kavli IPMU	Japan	Member (JSPS Fellow), IAS	USA	Member (JSPS Fellow), IAS	USA
2018/04/01-2021/03/31	PhD Student, Kyoto University	Japan	Lecturer, Waseda University	Japan	Lecturer, Waseda University	Japan

2021/01/01- 2021/03/31	Postdoc, KEK	Japan	Visiting Associate Professor, Iwate Prefectural University	Japan	Associate Professor (Visiting), Iwate Prefectural University	Japan
2020/10/16- 2021/03/31	Assistant Researcher, Kyoto University	Japan	Postdoc, RESCUE, The University of Tokyo	Japan	Postdoc, RESCUE, The University of Tokyo	Japan

Overseas Postdocs

Employment period	Position before employed at WPI center		Next position after WPI center		Position as of April 2021*		Nationality
	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	Position title, organization	Country where the organization is located	
2008/09/01- 2009/10/04	PhD Student, State University of NY	USA	Staff Research Member, Inst.for Defense Analysis	USA	Senior Professional, Johns Hopkins University	USA	USA
2009/04/16- 2009/12/31	Postdoc, University of Chicago	USA	Omidyar Fellow, Santa Fe Institute	USA	Assistant Professor, Carnegie Mellon University	USA	USA
2009/05/16- 2010/01/18	PhD Student, Kapteyn Inst., University of Groningen	Netherlands	Postdoc, Canadian Inst for Theoretical Astrophysics	Canada	Assistant Professor, U Amsterdam	Netherlands	India
2008/09/19- 2010/03/01	JSPS Fellow, KEK	Japan	Staff, Massachusetts General Hospital	USA	Associate Professor, Harvard University	USA	Germany
2009/05/01- 2010/03/31	PhD Student, University of Toronto	Canada	Associate Researcher, Chinese Academy of Science	China	Associate Professor, Chinese Academy of Sciences	China	China
2009/09/01- 2010/07/15	Visiting Fellow, HCRI	India	Assistant Professor, NISER	India	Associate Professor, NISER	India	India
2009/10/01- 2010/08/15	Dickson Instructor, University of Chicago	USA	Assistant Professor, Iowa State University	USA	Associate Professor, Iowa State University	USA	India
2009/09/01- 2010/08/31	Assistant Professor, University of South California	USA	Adjunct Professor, Santa Monica College	USA	Data Engineer Consultant, Company	USA	USA
2009/08/01- 2010/09/30	PhD Student, LMU München	Germany	Simons Postdoc Fellow, UC Berkeley	USA	Postdoc, UNIL, University of Lausanne	France	Germany
2009/04/03- 2010/09/30	Postdoc, CPPM	France	Senior Researcher, IFIC	Spain	Senior Researcher, NIMS	Japan	France

2008/10/16- 2010/09/30	Postdoc, Princeton University	USA	Assistant Research Fellow, ASIAA	Taiwan	Associate Research Fellow, ASIAA	Taiwan	Taiwan
2008/08/08- 2010/12/15	Research Assistant, University of Durham	UK	Assistant Professor, Arizona State University	USA	Associate Professor, Arizona State University	USA	USA
2008/11/01- 2011/02/21	Research Fellow, Seoul National University	South Korea	Assistant Professor, Chonnam National University	South Korea	Professor, Yonsei U Observatory	South Korea	South Korea
2008/09/01- 2011/05/31	PhD Student, University of Wisconsin	USA	Research Professor, Zhejiang University	China	Professor, Zhejiang University	China	China
2008/10/01- 2011/06/30	JSPS Fellow, The University of Tokyo	Japan	Assistant Professor, McGill University	Canada	Associate Professor, McGill University	Canada	France
2008/11/01- 2011/06/30	PhD Student, University College London	UK	Postdoc Fellow, CUHK	HK	Unknown		China
2011/01/01- 2011/07/15	Postdoc, IHES	France	Assistant Professor, CUHK	HK	Associate Professor, CUHK	HK	China
2008/05/01- 2011/08/14	PhD Student, Michigan State Uni	USA	Postdoc, Argonne National Lab	USA	Professor, NTNU	Taiwan	Taiwan
2010/02/01- 2011/08/14	Postdoc, Seoul National University	South Korea	Postdoc, University of Florida	USA	Associate Professor (Senior Researcher) , Seoul National University	South Korea	South Korea
2008/08/16- 2011/08/15	PhD Student, Harvard Uni	USA	Postdoc, Max Planck	Germany	Professor, Chinese Academy of Sciences	China	China
2008/09/01- 2011/08/31	Postdoc, Wayne State Uni	USA	Research Fellow, LMU Mü nchen	Germany	Professor, Fudan University	China	Italia
2008/09/01- 2011/08/31	PhD Student, University of Chicago	USA	Postdoc, SISSA	Italy	Professor, Chinese Academy of Sciences	China	China
2008/10/01- 2011/09/30	Postdoc, University of Neuchatel	Switzerland	CERN Fellow, CERN	Switzerland	Staff Researcher, INFN	Italy	Italy
2008/10/01- 2011/09/30	Postdoc, University of Amsterdam	Netherlands	CERN Fellow, CERN	Switzerland	Professor, University of Bern	Switzerland	Germany
2008/10/16- 2011/10/15	JSPS Fellow, Tokyo Institute of Technology	Japan	Engineer, Bloomberg LP	UK	Senior Engineer, Bloomberg	UK	UK

2009/05/01- 2012/04/30	PhD Student, Steklov Math Institute	Russia	Researcher, Moscow State University	Russia	Associate Professor, HSE, National Research University	Russia	Russia
2008/05/01- 2012/06/30	Researcher, Tohoku University	Japan	Assistant Professor, Kavli IPMU	Japan	Professor, NRNU MEPhl	Russia	Australia
2011/08/01- 2012/07/31	PhD Student, CUHK	HK	BP Fellow, Harvard University	USA	Assistant Professor, Boston University	USA	China
2009/09/01- 2012/08/31	Scientist, Max Planck Institute	Germany	Postdoc, Inst. Math de Jussieu	France	Assistant Professor, Universidad de Los Andes	Columbia	Russia
2009/09/01- 2012/08/31	Fellow, CERN	Switzerland	Professor, USTC	China	Professor, USTC	China	China
2010/04/01- 2012/08/31	Assistant Professor, Vienna University of Technology	Austria	Assistant Professor, Vienna University of Technology	Australia	Lecturer, University of Melbourne	Australia	Austria
2009/06/01- 2012/08/31	PhD Student, University of Pennsylvania	USA	Humboldt Fellow, Max Planck Institute	Germany	Data Scientist, Company	Germany	Hong Kong, China
2011/07/01- 2012/08/31	Research Assistant, University of Illinois	USA	Assistant Professor, Stony Brook University	USA	Professor, SUNY, Stony Brook	USA	Germany
2009/09/01- 2012/08/31	Assistant, UC San Diego	USA	Postdoc, University of Copenhagen	Denmark	Software Executive, Company	USA	USA
2009/09/16- 2012/09/15	PhD Student, University of Michigan	USA	Research Associate, University of Minnesota	USA	Associate Professor, Shanghai Jiao Tong University	China	USA
2010/09/01- 2012/11/15	Instructor, Harvard University	USA	Assistant Professor, University of Tsukuba	Japan	Associate Professor, University of Tsukuba	Japan	USA
2010/08/01- 2012/12/31	Assistant, University of Southern California	USA	Lecturer, University of New South Wales	Australia	Lecturer, UNSW	Australia	Romania
2011/09/16- 2013/01/31	Fellow, Lawrence Berkeley Lab	USA	Assistant Professor, Kavli IPMU	Japan	Assistant Professor, UC Santa Cruz	USA	France
2010/07/01- 2013/06/30	PhD Student, UC Berkeley	USA	Research Staff, Institute for Defense Analyses	USA	Head of AI, Company	USA	USA
2013/04/01- 2013/07/31	PhD Student, The University of Tokyo	Japan	Postdoc Researcher, University of Chile	Chile	Research Fellow, University of Turku	Finland	Indonesia

2010/09/01- 2013/08/31	PhD Student, Harvard University	USA	Postdoc, CALTECH	USA	Associate Professor, University of Copenhagen	Denmark	USA
2010/09/01- 2013/09/30	Research Scientist, Boston University	USA	Research Scientist, University of Oxford	UK	Data Scientist, Company	USA	Canada
2010/09/16- 2013/09/30	PhD Student, University of Minnesota	USA	Research Fellow, University of Nottingham	UK	Research Fellow, University of Portsmouth	UK	Turkey
2012/09/01- 2013/10/31	Postdoc, McGill University	Canada	S.Hawking Fellowship, University of Cambridge	UK	Associate Professor, HKUST	HK	China
2012/09/01- 2014/02/28	KICP Fellow, Kavli Institute, University of Chicago	USA	Assistant Professor, Kavli IPMU	Japan	Associate Professor, IUCAA	India	India
2011/05/01- 2014/06/30	JSPS Fellow, School of Science, Kyoto University	Japan	Project Researcher, NAOJ	Japan	Assistant Professor, Saitama University	Japan	Germany
2011/08/01- 2014/07/31	Research Assistant, National Center for Theoretical Science	Taiwan	Unknown		Postdoc, Ohio State University	USA	Taiwan
2011/04/16- 2014/07/31	Fellows, Swiss National Science Foundation	Swiss	Postdoc, Ludwig-Maximilians University	Germany	Company	Germany	Germany
2011/08/16- 2014/08/15	PhD Student, USTC	China	Postdoc, YITP, Kyoto University	Japan	Postdoc, Jagiellonian University	Poland	China
2009/10/01- 2014/08/21	Postdoc, Max Planck	Germany	Assistant Professor, Kavli IPMU	Japan	Associate Professor, USD	USA	China
2011/09/01- 2014/08/31	PhD Student, Tata Institute	India	Postdoc, Durham University	UK	Assistant Professor, IIT	India	India
2011/09/01- 2014/08/31	Postdoc, Tata Institute	India	Assistant Professor, Indian Institute of Science	India	Assistant Professor, Centre for High Energy Physics (CHEP), IISc	India	India
2011/09/01- 2014/08/31	Research Fellow, Korea Ins. Of Advanced Study	South Korea	IBS Fellow, IBS, POSTECH	South Korea	Professor, SYSU	China	China
2011/09/01- 2014/08/31	Postdoc, CALTECH	USA	Associate Professor, San Diego State Univ.	USA	Professor/ Director, San Diego State University	USA	USA

2013/06/01- 2014/08/31	PhD Student, University of Michigan	USA	Postdoc, Stanford University	USA	Assistant Professor, University of Oregon	USA	China
2011/09/16- 2014/09/15	PhD Student, UC Santa Barbara	USA	Postdoc, McGill University	Canada	Unknown		USA
2011/09/16- 2014/09/15	PhD Student, UC Santa Cruz	USA	Postdoc, Vanderbilt University	USA	Lecturer, University of Pennsylvania	USA	USA
2010/10/01- 2014/09/30	PhD Student, University of Chile	Chile	Scientific Researcher, CONICET/NSTRC	Argentina	Scientific Researcher, CONICET	Argentina	Argentina
2010/10/01- 2014/09/30	Postdoc, University of Chile	Chile	Scientific Researcher, CONICET/NSTRC	Argentina	Scientific Researcher, CONICET	Argentina	Argentina
2013/10/01- 2014/09/30	Postdoc, Euro Org for Nuclear Research	Switzerland	Adjunct Professor, APCTP/POSTECH	South Korea	Assistant Professor, SEOULTECH	South Korea	South Korea
2012/10/01- 2014/09/30	PhD Student, UC Berkeley	USA	Postdoc, Imperial College London	UK	Assistant Professor, University of Massachusetts, Boston	USA	USA
2011/10/01- 2014/09/30	PhD Student, UC Berkeley	USA	Postdoc, FSM Paris	France	Data Scientist, Company	Germany	Romania
2011/10/01- 2014/12/31	Visiting Assist. Professor, Duke University	USA	Assistant Professor, YITP, Kyoto University	Japan	Associate Professor, Duke Kunshan University	China	UK
2012/08/16- 2015/05/15	PhD Student, Yale University	USA	Assistant Professor, Kyoto University	Japan	Assistant Professor, HKUST	HK	Canada
2012/09/01- 2015/05/31	PhD Student, Princeton University	USA	Data Science Fellow, Company	USA	Senior Data Scientist, Company	USA	USA
2012/08/16- 2015/08/15	PhD Student, University of Pennsylvania	USA	Postdoc, Pacific Northwest Nat Lab	USA	AI Data Scientist, Company	USA	USA
2012/07/16- 2015/09/15	PhD Student, UC Santa Barbara	USA	Postdoc, IAS	USA	Assistant Professor, Tsinghua U, Beijing	China	Chile
2013/09/16- 2015/09/17	PhD Student, Stanford University	USA	Postdoc, UC Berkeley	USA	Applied Researcher, Company	USA	USA
2012/09/01- 2015/09/20	PhD Student, UC Berkeley	USA	Postdoc, Fudan University	China	Company	Japan	USA
2012/09/08- 2015/09/30	Postdoc, University of Crete	Greece	Postdoc Associate, Stony Brook University	USA	Lecturer, Julius Maximilian University of Würzburg	Germany	Germany

2012/10/01- 2015/09/30	PhD Student, HCRI	India	Postdoc Associate, University of Pittsburgh	USA	Assistant Professor, Indian Association for the Cultivation of Science	India	India
2012/10/16- 2015/10/15	Postdoc, Carnegie Mellon University Qatar	Qatar	Postdoc, Melbourne University	Australia	Permanent Staff Researcher, INAF Padova	Italy	Italy
2012/11/01- 2015/10/31	PhD Student, DESY	Germany	Postdoc, Max-Planck Inst. For Physics	Germany	Research Fellow, CERN	Switzerland	Germany
2012/11/01- 2015/11/30	Postdoc, Technion, Israel Inst of Tech	Israel	Reader, Tata Institute of Fund Res	India	Reader (tenure-track faculty), TIFR	India	India
2013/01/16- 2016/01/15	Visiting Assist. Professor, Duke University	USA	Assistant Professor, Clark University	USA	Assistant Professor, Clark University	USA	USA
2014/04/16- 2016/02/29	Postdoc, IIS, Bangalore	India	Reader-Faculty, Inst of Physics, Bhubaneswar	India	Reader Faculty, Institute of Physics, Bhubaneswar	India	India
2013/04/01- 2016/04/30	Postdoc, ICRR	Japan	Assistant Professor, ICRR, The University of Tokyo	Japan	Assistant Professor, ICRR, The University of Tokyo	Japan	Spain
2015/09/07- 2016/07/31	Assistant Professor, Ohio State University	USA	Associate Professor, Aarhus University	Denmark	Associate Professor, Aarhus University	Denmark	Iran
2013/09/01- 2016/08/31	PhD Student, University of Chicago	USA	Postdoc, UC Riverside	USA	Postdoc, UC Riverside	USA	China
2013/10/01- 2016/09/30	Postdoc, KIAA, Peking University	China	Postdoc, NAOJ	Japan	Company	Germany	Germany
2013/10/01- 2016/09/30	Junior Scientist, NCBJ	Poland	Senior Postdoc, NCTS	Taiwan	Research Fellow, National Tsing Hua University	Taiwan	Taiwan
2013/09/01- 2017/01/15	PhD Student, MIT	USA	Postdoc, OIST	Japan	Lecturer, Mahidol University	Thailand	Thailand
2013/11/01- 2017/01/31	Postdoc, CRM	Canada	Associate Professor, Moscow Inst of Physics & Tech	Russia	Associate Professor, MIPT	Russia	Russia
2014/08/01- 2017/02/14	PhD Student, Nanjing University	China	Postdoc, UC Santa Cruz	USA	Associate Research Scholar, Princeton University	USA	China
2016/08/01- 2017/03/31	PhD Student, CUHK	HK	Newton Int'l Fellow, University of Oxford	UK	Postdoc, The University of Tokyo, Kavli IPMU	Japan	China

2014/10/01- 2017/03/31	Research Fellow, KIA	South Korea	Postdoc, Seoul National University	South Korea	Assistant Professor, Seoul Natl. University	South Korea	South Korea
2014/05/01- 2017/04/30	Postdoc, Kyoto University	Japan	Assistant Professor, The University of Tokyo, ICRR	Japan	Assistant Professor, The University of Tokyo, ICRR	Japan	France
2014/03/16- 2017/07/10	Lecturer, Chulalongkorn University	Thailand	Lecturer, Chulalongkorn University	Thailand	Lecturer, Chulalongkorn University	Thailand	Thailand
2014/10/16- 2017/08/13	PhD Student, University of Edinburgh	UK	Postdoc Associate, University of Arizona	USA	Associate Professor, Xiamen University	Malaysia	Sri Lanka
2014/10/01- 2017/09/30	PhD Student, UC Santa Cruz	USA	Data Scientist, Company	USA	Machine Learning Engineer, Company	USA	USA
2013/08/01- 2017/12/31	Postdoc, Max Planck Institute	Germany	Principal Investigator, Company	Japan	Principal Investigator, Company	Japan	Australia
2015/11/01- 2018/03/15	Fellow, CERN	Switzerland	Associate Professor, Sun Yat-sen University	China	Associate Professor, Sun Yat-sen University	China	China
2014/11/01- 2018/05/31	Research Assistant, University of Edinburgh	UK	Assistant Professor, Yau Math Sciences Center, Tsinghua University	China	Assistant Professor, Tsinghua University, Beijing	China	UK
2014/11/16- 2018/06/30	Postdoc, University of Chicago	USA	Data Scientist, IUCAA	India	Data Scientist, IUCAA	India	India
2015/04/01- 2018/08/19	PhD Student, Tohoku University	Japan	Research Assistant, Tohoku University	Japan	Assistant Professor, Tsinghua University, Beijing	China	China
2016/07/01- 2018/08/31	Postdoc, Durham University	UK	Associate Professor, Shanghai Jiao Tong University	China	Associate Professor, Shanghai Jiao Tong University	China	China
2015/09/01- 2018/08/31	PhD Student, UC Santa Barbara	USA	Postdoc, UCLA	USA	NOVA Fellow, Leiden University	Netherlands	Italy
2015/09/01- 2018/08/31	Postdoc, Princeton University	USA	Postdoc, University of Parma	Italy	Postdoc, University of Parma	Italy	Israel
2017/10/01- 2018/09/05	PhD Student, UCLA	USA	Data Scientist, Company	USA	Senior Data Scientist, Company	USA	USA

2016/10/01- 2018/09/30	Postdoc, University of Pennsylvania	USA	Postdoc, Liverpool John Moores University	UK	Postdoc, Liverpool John Moores University	UK	Australia
2015/08/01- 2018/09/30	PhD Student, Brown University	USA	Postdoc, Max Planck Institute	Germany	Research Fellow, University of Warwick	UK	Greece
2014/04/01- 2018/09/30	Postdoc, RIKEN	Japan	Researcher, The Open University of Japan	Japan	Team Leader (Software Development, Company	Russia	Russia
2017/10/01- 2018/10/11	PhD Student, King's College London	UK	Researcher, Company	UK	Researcher, Company	UK	UK
2016/04/01- 2019/01/21	JSPS Fellow, The University of Tokyo	Japan	Project Researcher, MSRI	USA	Young Investigator, Fudan University	China	China
2015/09/16- 2019/03/31	Postdoc, APCTP	South Korea	Research Fellow, KIAS	South Korea	Associate Professor, SYSU	China	China
2016/11/01- 2019/04/30	Research Associate, Imperial College London	UK	company	France	company	France	France
2016/05/01- 2019/06/21	PhD Student, University of Paris - Sud XI	France	Postdoc, University of South Dakota	USA	Postdoc, University of Alabama	USA	Ukraine
2016/11/01- 2019/08/15	PhD Student, Leiden University	Netherlands	Data Scientist, company	Germany	Data Scientist, company	Germany	Germany
2016/09/01- 2019/08/31	PhD Student, Duke University	USA	ML Researcher, company	Germany	ML Researcher, Company	Germany	Italy
2016/09/01- 2019/08/31	PhD Student, University of Melbourne	Australia	Postdoc, University of Melbourne	Australia	Postdoc, University of Melbourne	Australia	Australia
2018/09/16- 2019/08/31	Postdoc Prize Fellow, Caltech	USA	Postdoc, Princeton University	USA	Postdoc, Princeton University	USA	Switzerland
2015/09/01- 2019/08/31	PhD Student, Seoul National University	South Korea	Postdoc, University of Nebraska-Lincoln	USA	Postdoc, University of Nebraska-Lincoln	USA	South Korea
2015/09/01- 2019/08/31	PhD Student, UNC Chapel Hill	USA	Postdoc, Haverford College	USA	Postdoc, Haverford College	USA	USA
2016/08/01- 2019/08/31	Postdoc, National Tsing Hua University	Taiwan	Postdoc, Yonsei University	South Korea	Postdoc, Yonsei University	South Korea	Taiwan

2017/06/01- 2019/08/31	Postdoc, Durham University	UK	Associate Researcher, Shanghai Jiao Tong University	China	Associate Researcher, Shanghai Jiao Tong University	China	China
2016/09/01- 2019/09/10	PhD Student, Indian Inst. of Science	India	Research Fellow, Trinity College Dublin	Ireland	Research Fellow, Trinity College Dublin	Ireland	India
2016/04/01- 2019/09/29	Postdoc, UC Berkeley	USA	Flatiron Research Fellow, Flatiron Inst, Simons Foundation	USA	Flatiron Research Fellow, Flatiron Institute, Simons Foundation	USA	China
2017/10/16- 2019/09/30	Postdoc, Max Planck Institute	Germany	Associate Professor, Shanghai Jiao Tong University	China	Associate Professor, Shanghai Jiao Tong University	China	China
2015/08/01- 2019/09/30	PhD Student, CUHK	Hong Kong, China	Postdoc, Caltech	USA	Postdoc, Caltech	USA	China
2015/10/16- 2019/10/15	PhD Student, LMU, Munich	Germany	Postdoc Researcher, RIKEN	Japan	Postdoc Researcher, RIKEN	Japan	Austria
2016/10/01- 2019/10/31	PhD Student, Technion, Israel Inst of Tech	Israel	Postdoc, University of Milano - Bicocca	Japan	Postdoc, University of Milano - Bicocca	Italy	Israel
2016/11/01- 2019/11/30	Assistant Professor, University of Western Ontario	Canada	Assistant Professor, Università di Pisa	Italy	Assistant Professor, Università di Pisa	Italy	Italy
2018/10/01- 2019/12/31	Postdoc, CERN	Switzerland	Assistant Professor, Durham University	UK	Assistant Professor, Durham University	UK	Spain
2017/09/01- 2019/12/31	Research Associate, Kyoto University	Japan	Assistant Professor, CNRS	France	Assistant Professor, CNRS	France	France
2018/09/01- 2020/01/19	Visiting Assistant Professor, University of Massachusetts	USA	Lecturer, University of Queensland	Australia	Lecturer, University of Queensland	Australia	Hungary
2016/09/01- 2020/02/29	Postdoc, John Hopkins University	USA	Postdoc, UC Santa Cruz	USA	Assistant Professor, National Taiwan University	Taiwan	Taiwan
2017/03/01- 2020/02/29	Hodge Fellow, IHES	France	Associate Professor, Osaka University	Japan	Unknown		UK
2019/02/01- 2020/03/31	PhD Student, Univ. Paris-Sud/Paris-Sadav	Japan	Assistant Professor, Okayama University	Japan	Assistant Professor, Okayama University	Japan	USA

2017/09/01- 2020/08/31	PhD Student, University of Illinois	USA	Special Postdoc, RIKEN	Japan	Special Postdoc, RIKEN	Japan	Taiwan
2017/10/16- 2020/10/15	PhD Student, University of Sydney	Australia	Senior Research Fellow, IBS-CTPU	South Korea	Senior Research Fellow, IBS-CTPU	South Korea	Australia
2018/04/01- 2020/10/24	Research Assistant Professor, Kyoto University	Japan	Associate Professor, Chinese Academy of Sciences	China	Associate Professor, Chinese Academy of Sciences	China	China
2019/08/01- 2020/10/31	Postdoc, University of Mainz	Germany	Assistant Professor, The University of Tokyo, Kavli IPMU	Japan	Assistant Professor, The University of Tokyo, Kavli IPMU	Japan	Australia
2018/09/01- 2021/01/04	Visiting Assistant Professor, University of Massachusetts	USA	Lecturer, University of Glasgow	UK	Lecturer, University of Glasgow	UK	USA
2020/01/16- 2021/02/28	Postdoc, CITA - University of Victoria	Canada	Assistant Professor, University of Barcelona	Spain	Assistant Professor, University of Barcelona	Spain	France
2018/12/01- 2021/03/31	Lab Demonstrator, University of Queen's Land	Australia	Unknown		Unknown		Australia
2020/10/09- 2021/03/31	Postdoc, University of Cambridge	UK	Research Fellow, Flatiron Institute, Simons Foundation	USA	Research Fellow, Flatiron Institute, Simons Foundation	USA	UK
2020/11/12- 2021/03/31	PhD Student, Peking University	China	Postdoc, University of Hawaii	USA	Postdoc, University of Hawaii	USA	China
2019/07/15- 2021/03/31	PhD Student, UC San Diego	USA	Assistant Professor, JAXA	Japan	Assistant Professor, JAXA	Japan	USA

Appendix4-5 List of the Cooperative Research Agreements with Overseas Institutions

*Prepare the information below during the period from the beginning of the Center through March 2021.

1. Name of an Agreement: AGREEMENT FOR THE CREATION OF AN INTERNATIONAL RESEARCH LABORATORY, Cosmology and Elementary Particle Physics International Laboratory - CEPPIL
   Dates of an Agreement: 31 March, 2021
   Counterpart of an Agreement: Centre National de la Recherche Scientifique (CNRS)
   Summary of an Agreement: This agreement aims to promote academic research and collaborative activities in areas of mutual interest. In this context, the creation of the international research laboratory CEPPIL between UTokyo and IN2P3-CNRS will perfectly coincide with the start of new research programs in Japan and around the world, with a very great potential for first-class discoveries. Strengthening existing collaborations for fundamental research in physics, and developing new common research areas will be the objective of this program. The CEPPIL should help strengthen the partnership over a long period of time.
   In search of new discoveries, physicists explore what the universe is made of and what are its fundamental laws at the smallest and largest scales. The scientific fields concerned by CEPPIL are elementary particle physics, cosmology, astro-particles and astrophysics. This new laboratory will promote joint research projects between the Institute for Cosmic Ray Research (ICRR), the Kavli Institute for Physics and Mathematics of the Universe (Kavli IPMU) under the UTokyo Institute of Advanced Studies (UTIAS), International Center for Elementary Particles Physics (ICEPP), and School of Science on one side, and on the date of signature ten laboratories operated by IN2P3 on the other. More than fifty physicists from these different institutions or laboratories in France and Japan will participate in CEPPIL's activities.

2. Name of an Agreement: Global Fellowships (IF), Co-operation Agreement, Hyper-KOD - The Hyper-Kamiokande Outer Detector - Project No. 892264
   Dates of an Agreement: 3 March, 2021
   Counterpart of an Agreement: Kings College London (KCL)
   Summary of an Agreement: The purpose of this Agreement is to regulate the cooperation between the Parties regarding the Research Project. King's College London has been successful in obtaining a "Marie Curie International Outgoing Fellowship" Grant Agreement 892264 – Hyper-KOD with the European Commission, as part of the Horizon 2020 Framework Programme, for a project called "The Hyper-Kamiokande Outer Detector".IPMU and KCL have agreed the research training activities under the Project which will further the instructional and research objectives of the Parties in a manner consistent with their status as educational institutions. The fellowship within the Project provides the successful holder.

3. Name of an Agreement: MEMORANDUM OF UNDERSTANDING
   Dates of an Agreement : 18 October, 2019
   Counterpart of an Agreement: The UNIVERISITY OF BONN
   Summary of an Agreement: This MoU aims to implement exchanges and other activities in areas of academic research of mutual interest in philosophical problems from scientific point of views.

4. Name of an Agreement: MEMORANDUM OF UNDERSTANDING
   Dates of an Agreement: 1 October, 2018
   Counterpart of an Agreement: Walter Burke Institute for Theoretical Physics, The California Institute of Technology (CALTECH)
   Summary of an Agreement: This MoU aims to implement exchanges and other activities in areas of academic research of mutual interest in theoretical physics, in particular on elementary particles, quantum field theory, and string theory.

5. Name of an Agreement: Non-Proprietary User Agreement between Fermi Research Alliance, LLC and Kavli Institute for the Physics and Mathematics of the Universe
   Dates of an Agreement: 30 November, 2017

Counterpart of an Agreement: Fermi Research Alliance
Summary of an Agreement: This agreement aims to provide opportunities IPMU researchers (participants) to participate in Hadron Production Measurements and ipmlement experiments at fermilab (FNAL) started in 2018.

6. Name of an Agreement: Memorandum of Understanding Regarding IPMU-ISSP-JHU collaborative program in Physics and Astronomy
Dates of an Agreement: 11 December,2018
Counterpart of an Agreement: Department of Physics and Astronomy, The Johns Hopkins University (JHU) and The Institute for Solid State Physics, The University of Tokyo (ISSP)
Summary of an Agreement: Under the recognition on a joint interest in particle physics, astrophysics, and condensed matter physics, complementary scientific expertise, and the importance of providing an international perspective to students and postdocs, three institutions establishes the IPMU-ISSP-JHU collaborative program in Physics and Astronomy for implementing the periodic workshop, the students and postdoc exchange as well as the researchers exchange.

7. Name of an Agreement: AGREEMENT FOR THE CREATION OF THE LABORATOIRE INTERNATIONAL ASSOCIE (LIA)(International Joint Laboratory) "Kavli IPMU-IN2P3 on cosmology"
Dates of an Agreement: 27 October, 2017
Counterpart of an Agreement: Centre National de la Recherche Scientifique (CNRS)
Summary of an Agreement: This Agreement intends to strengthen the ties of the two Institutes around specific projects of common interest by forming a distributed "virtual" laboratory named "Kavli IPMU-IN2P3 for Cosmology". It funds for researcher exchange, an annual common workshop held alternatively in the two laboratories and possibly support for postdoctoral positions associated with the common projects.

8. Name of an Agreement: Agreement for Cooperation
Dates of an Agreement: 20 July, 2017
Counterpart of an Agreement: Mainz Institute for Theoretical Physics at Johannes Gutenberg University Mainz(MITP)
Summary of an Agreement: The purpose of this agreement is to encourage scientific exchange visits and collaborations between researchers at Kavli IPMU and MITP in order to promote progress in all research areas of common interest and to build academic ties between the two institutions.

9. Name of an Agreement: MEMORANDUM OF UNDERSTANDING
Dates of an Agreement: 4 May, 2017
Counterpart of an Agreement: The Kavli Foundation and Kavli Institute for Astronomy and Astrophysics at Peking University, China (KIAA)
Summary of an Agreement: This MOU aims to support excellent research in astrophysics by early-career researchers, advance promising early-career researchers and promote enhanced opportunities for diverse career pathways, promote collaborations and share of resources between KIAA and Kavli IPMU as well as strength the scientific output and international visibility of KIAA and Kavli IPMU.

10. Name of an Agreement: Memorandum of Understanding
Dates of an Agreement: 24 October, 2016
Counterpart of an Agreement: Department of Physics, University of Oxford
Summary of an Agreement: The purpose of this MOU is to provide the fellowships which are intended to enable doctoral students studying for D.Phil. research degrees in Astrophysics or Particle Physics at the University of Oxford to be supervised by faculty members of Kavli IPMU and to provide the opportunity for the students to conduct research in collaboration with Kavli IPMU researchers.

11. Name of an Agreement: MEMORANDUM OF UNDERSTANDING, Concerning the Collaboration on the SUBARU MEASUREMENT OF IMAGES AND REDSHIFTS PROJECT
Dates of an Agreement: 28 July, 2016

Counterpart of an Agreement: The Academia Sinica Institute of Astronomy and Astrophysics (ASIAA)
Summary of an Agreement: The purpose of this MOU is to pursue a collaboration in the development of an extremely wide field camera, the HyperSuprime Cam(HSC), and a wide field multi-object spectrograph, the Prime Focus Spectrograph (PES), for the Subaru Telescope, and in conducting wide field sky surveys with the HSC and PES instruments. The combination of imaging and spectroscopic data acquired by these surveys, known as the Subaru Measurement of Images and Redshifts (SuMIRe) project, would yield unprecedented constrains on the properties of Dark Energy, and on the formation and evolution of distant galaxies.

12. Name of an Agreement: SLOAN DIGITAL SKY SURVEY IV, MEMORANDUM OF UNDERSTANDING
Dates of an Agreement: 17 FEB, 2014
Counterpart of an Agreement: The Astrophysical Research Consortium
Summary of an Agreement: he Sloan Digital Sky Survey (SDSS) has been in operation since 1998, in three prior phases (termed SDSS, SDSS-II, SDSS-III). It is operated by the Astrophysical Research Consortium (ARC) and uses a dedicated 2.5-m telescope with associated imaging and spectroscopic instrumentation at Apache Point Observatory, in Sunspot.
The hardware and software systems of SDSS will be unmatched by any other facility for large-scale survey observations for several years to come. The combination of continuing significant scientific impact, the ability to make contributions to diverse fields of astrophysics, and the effectiveness of current and future operations provides the basis to continue for a new phase called SDSS-IV.

13. Name of an Agreement: THE INTERMEDIATE PALOMAR TRANSIENT FACTORY, A COLLABPRATIVE AGREEMENT (iPTF CA)
Dates of an Agreement: 23 DEC, 2013
Counterpart of an Agreement: The Intermediate Palomar Transient Factory (iPTF)
Summary of an Agreement: Following on from PTF (The Palomar Transient Factory)'s success, this Collaborative Agreement (CA) codifies the Consortium known as The Intermediate Palomar Transient Factory (iPTF). iPTF will be a follow-on survey to PTF that will inherit many of the same assets (wide-filed MOSAIC camera and associated software etc.), but will build upon PTF's success by employing new survey strategies to search for and study transient phenomena poorly measured by PTF.
* The governing mechanism for the iPTF Consortium is the iPTF Board (the Board). The Board is composed of one representative from each Principal partner institution, plus the Caltech/COO Director in an ex offiio voting capanity.

14. Name of an Agreement: Memorandum of Understanding
Dates of an Agreement: 15 SEP, 2013
Counterpart of an Agreement: Steklov mathematical Institute, Russian Academy of Sciences
Summary of an Agreement: Kavli IPMU and Steklov Mathematical Institute are linked by common academic interests and seek to develop collaborations and exchanges in fields of shared interests and expertise.
- The principles of Innovation and Collaborations for the advancement of teaching and research in mathematical sciences.

15. Name of an Agreement: Memorandum of Understanding
Dates of an Agreement: 29 MAY, 2013
Counterpart of an Agreement: Tsinghua university Mathematical Sciences Center
Summary of an Agreement:
To encourage the development of the following types of activities In the "2011 Project" Proposal from MSC:
- Visits and exchanges of students, faculty, and scholars in specific areas of education, research and outreach.
- Organize and hold joint conferences, symposia, or other scientific meetings on subjects of mutual interest.
- Develop joint research programs and collaborations.

- Exchange of academic information and materials.
- Other exchange and cooperation programs to which both parties agree.

16. Name of an Agreement: SLOAN DIGITAL SKY SURVEY AS3 ("After SDSS-III"), MEMORANDUM OF UNDERSTANDING
    Dates of an Agreement: 25 MAY, 2013
    Counterpart of an Agreement: The Astrophysical Research Consortium
    Summary of an Agreement: The Sloan Digital Sky Survey (SDSS) is a project observationally studying a large area of sky to measure large-scale structure, properties of galaxies, the structure of the Milky Way, and stellar astrophysics. The SDSS was succeeded by the SDSS-III project which extends to 30 June 2014.

17. Name of an Agreement: The assembly work of the silicon vertex detector (SVD) layers used in the Belle II experiment
    Dates of an Agreement: 10 MAY, 2013
    Counterpart of an Agreement: The Tata Institute of Fundamental Research
    Summary of an Agreement: Kavli IPMU and the Tata Institute of Fundamental Research conduct the collaborative research.

18. Name of an Agreement: Memorandum of Understanding Between Kavli IPMU And TRIUMF, Concerning Collaboration to Facilitate Joint Appointment
    Dates of an Agreement: OCT, 2012
    Counterpart of an Agreement: TRIUMF. The Governors of The University of Alberta, the University of British Columbia, Carleton University, Simon Fraser University, the Governing Council of the University of Toronto and the University of Victoria and such other universities who may become full member universities established pursuant to a contract governed by the laws of the Province of British Columbia operating a Joint Venture known as TRIUMF.
    Summary of an Agreement: To document the terms governing this joint appointment and to ensure the necessary management elements to facilitate cooperation and the successful exchange of the identified employee.

19. Name of an Agreement: Memorandum of Understanding among institutions of the Prime Focus Spectrograph Collaboration
    Dates of an Agreement: 11 AUG, 2012
    Counterpart of an Agreement: Universidade de São Paulo,California Institute of Technology, JetPropulsion Laboratory,Princeton University, Johns Hopkins University, Laboratoire d'Astrophysique de Marseille, Academia Sinica Institute of Astronomy and Astrophysics
    Summary of an Agreement: The PFS project aims to survey a large volume of the Universe at an unprecedented depth. It will use thousands of optical fibers each of which can be robotically controlled with hundred milliarcseconds accuracy pointing at a particular galaxy or star of interest. It will be mounted on the Subaru telescope in Hawaii that has a wide field of view. By contributing to the construction of PFS, the collaboration members expect to share observing time on the Subaru telescope, in full partnership with the Japanese astronomical community, under the framework of a Subaru Strategic Program. The contribution and commitment of each institution or consortium of institutions to the project are described.

20. Name of an Agreement: AGREEMENT BETWEEN THE SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI (SISSA) AND THE INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE (IPMU)
    Dates of an Agreement: 24 FEB, 2012
    Counterpart of an Agreement: The Scuola Internazionale Superiore di Studi Avanzati (SISSA)
    Summary of an Agreement: SISSA and IPMU recognize the value of educational, cultural, and scientific exchanges between international research institutions, and have determined that sufficient interest exists to establish a formal relationship to encourage the exchange of faculty, researchers, and graduate students.

21. Name of an Agreement: AGREEMENT ON ACADEMIC EXCHANGE BETWEEN THE UNIVERSITY OF TOKYO AND PRINCETON UNIVERSITY
    Dates of an Agreement: 21 DEC, 2010
    Counterpart of an Agreement: Princeton University
    Summary of an Agreement: Implement exchanges and other activities in areas of academic research of mutual interest through the following.
    (1) Exchange of faculty and administrative staff and researchers.
    (2) Exchange of students.
    (3) Conducting collaborative research.
    (4) Holding joint lectures and symposia.
    (5) Exchange of academic information and materials.

22. Name of an Agreement: SEVENTH FRAMEWORK PROGRAMME Marie Curie Actions People, International Research Staff Exchange Scheme
    Dates of an Agreement: 15 SEP, 2010
    Counterpart of an Agreement: Unification of Fundamental Forces and Applications (UNIFY)
    Summary of an Agreement: One objective is to gain new insights on the quantum mechanical description of the gravitational interaction, an outstanding fundamental problem in theoretical physics, of crucial importance to our understanding of the Universe and of the forces between its basic constituents. The other main objective is to explore recent developments in String Theory and Quantum Gravity in the fields of Cosmology, Black Hole Physics and Gauge Theory. The forthcoming years will bring unprecedented experimental discoveries in these fields of research and are sure to call for new explanations and to shape our attempts to construct an unifying theory of all interactions. UNIFY will achieve its goals by setting a challenging exchange programme that involves world leading universities and institutes (FCUP, HU, Saclay, PI, YITP, IPMU). UNIFY institutions will organize a number of thematic work programmes to push our present knowledge of the law's of nature to its very limit. UNIFY includes in its exchange programme a strong dimension on the training of the next generation of theoretical physicists, as to establish long lasting collaborations between its partners.

23. Name of an Agreement: AGREEMENT ON ACADEMIC EXCHANGE BETWEEN THE UNIVERSITY OF TOKYO AND THE UNIVERSITY OF CALIFORNIA, BERKELEY
    Dates of an Agreement: 17 DEC, 2009
    Counterpart of an Agreement: The University of California, Berkeley
    Summary of an Agreement: Implement exchanges and other activities in areas of academic research of mutual interest through the following.
    (1) Exchange of faculty and administrative staff and researchers.
    (2) Exchange of students.
    (3) Conducting collaborative research.
    (4) Holding joint lectures and symposia.
    (5) Exchange of academic information and materials.

24. Name of an Agreement: Memorandum of Understanding between The University of Tokyo, Institute for Physics and Mathematics of the Universe
    Dates of an Agreement: 24 JUN, 2009
    Counterpart of an Agreement: National Taiwan University, Leung Center for Cosmology and Particle Astrophysics (LeCosPA)
    Summary of an Agreement: Collaborate on the research topics relating to cosmology and particle astrophysics.
    (1) Measurements and analysis of microwave background and related phenomena,
    (2) Theory and observation of dark energy and dark matter,
    (3) String cosmology,
    (4) Large scale structure formation and evolution,
    (5) Ultra-high energy cosmic rays and neutrinos and the cosmic accelerator that produces them,
    (6) Gemma ray bursts.

25. Name of an Agreement: Agreement of Cooperation between Deutsches Elektronen Synchrotron (DESY) and the Institute for the Physics and Mathematics of the Universe (IPMU), University of Tokyo
    Dates of an Agreement: 24 JUN, 2009
    Counterpart of an Agreement: Deutsches Elektronen Synchrotron (DESY)
    Summary of an Agreement:
    - DESY offers 2-year postdoctoral positions in the frame of its annual fellowship programme.
    - DESY, after consultation and only in agreement with IPMU, may offer to a postdoc, who is supposed to work in one of the above mentioned field of common interests, an option of extending the appointment for the another 1-2 years (thus making it into a 3-4 years appointment) with the extra 1-2 years being spent at the IPMU in Tokyo.
    - The extra 1-2 years can be chosen by the postdoc him/herself in agreement with the DESY and IPMU theory groups. The stay at IPMU can start after the first year at DESY, with the option to return to DESY to complete the 2 year fellowship.
    - During the stay at IPMU the postdoc remains employed at DESY. The salary is paid directly to the postdoc by IPMU instead of DESY during the 1-2 years.
    - DESY and IPMU will intensify the already existing collaboration by increasing the exchange of staff, postdocs and graduate students.

26. Name of an Agreement: Memorandum of understanding between Garching/Munich Cluster of Excellence on "The Origin and Structure of the Universe" and Institute for the Physics and Mathematics of the Universe, Tokyo
    Dates of an Agreement: 25 FEB, 2009
    Counterpart of an Agreement: Garching/Munich Cluster of Excellence on "The Origin and Structure of the Universe"
    Summary of an Agreement: Garching Excellence Cluster and IPMU acknowledge the existence of common principles and goals that make it desirable for the two parties to cooperate in scientific collaboration and education.
    - Explore the creation of a strong collaboration on these questions related to the formation and evolution of the Universe, the innermost structure of matter, space and time and the nature of the fundamental forces.
    - Explore prospects and possibilities to participate in projects of the other party.
    - Organize international conferences, workshops, and schools.
    - Exchange personnel and organize visit, including the possibility of joint appointment.

27. Name of an Agreement: SLOAN DIGITAL SKY SURVEY III MEMORANDUM OF UNDERSTANDING BETWEEN The University of Tokyo and The Astrophysical Research Consortium
    Dates of an Agreement: 2 FEB, 2009
    Counterpart of an Agreement: The Astrophysical Research Consortium
    Summary of an Agreement: The Sloan Digital Sky Survey (SDSS) is a project observationally studying a large area of sky motivated primarily by extragalactic problems including large-scale structure, properties of galaxies, and other topics. The SDSS was operated by the Astrophysical Research Consortium (ARC) to June 2005, and was succeeded by the SDSS-II project to 30 June 2008. The two SDSS projects included a Japanese team, which included a number of members from the University of Tokyo. The SDSS-III is a new project that succeeds the SDSS and SDSS-II with new scientific product obtained by the earlier SDSS projects. The continuing significant scientific impact together with the ability to make contributions to diverse fields of astrophysics justifies the SDSS-III.

Appendix4-6 Holding International Research Meetings

* Indicate up to twenty of most representative international research conferences or symposiums held from the start of the center through March 2021 and give the number of participants using the table below.

Date	Meeting title and Place held	Number of participants
2020/11/30 -12/3	CMB systematics and calibration focus workshop (Online)	From domestic institutions: 38 From overseas institutions: 190
2020/9/21-24	Beauty 2020 (Online)	From domestic institutions: 14 From overseas institutions: 332
2020/7/6 -8/14	McKay correspondence, mutation and related topics (Online)	From domestic institutions: 14 From overseas institutions: 40
2020/1/13-22	14th Kavli Asian Winter School on Strings, Particles and Cosmology (Sakura Hall, Tohoku Univ., Japan)	From domestic institutions: 36 From overseas institutions: 70
2020/1/14-17	East Asia Core Doctoral Forum in Mathematics 2020 (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 24 From overseas institutions: 36
2019/3/25-29 -8/14	Extremely Big Eyes on the Early Universe (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 34 From overseas institutions: 52
2018/9/18-22	IGM2018: Revealing Cosmology and Reionization History with the Intergalactic Medium (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 36 From overseas institutions: 74
2017/10/16-18	Kavli IPMU 10th anniversary symposium (Kavli IPMU & Kashiwanoha Conference Hall, Japan)	From domestic institutions: 171 From overseas institutions: 17
2017/11/27 -12/1	9th PFS general collaboration meeting (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 57 From overseas institutions: 79
2016/5/30 -6/1	PHYSTAT-nu Workshop on Statistical Issues in Experimental Neutrino Physics (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 21 From overseas institutions: 68
2015/12/10-16	B mode from Space (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 59 From overseas institutions: 71
2014/11/17-21	Galaxies and Cosmology in Light of Strong Lensing (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 18 From overseas institutions: 48
2014/2/10-14	Primitive forms and related subjects (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 40 From overseas institutions: 41

Date	Meeting title and Place held	Number of participants
2013/1/27-28	4th Open Meeting for the Hyper-Kamiokande Project (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 40 From overseas institutions: 64
2012/8/13-16	PFS 3rd General Collaboration Meeting (Kavli IPMU, The University of Tokyo, Japan)	From domestic institutions: 17 From overseas institutions: 51
2012/8/13-16	IAU Symposium 279: Death of Massive Stars: Supernovae and Gamma-ray Bursts (Hotel Nikko Senhime Monogatari, Tochigi, Japan)	From domestic institutions: 59 From overseas institutions: 100
2010/9/27 -10/1	Horiba International Conference on Cosmology and Particle astrophysics (Ichijo Hall, Hongo Campus, The University of Tokyo, Japan)	From domestic institutions: 135 From overseas institutions: 159
2010/6/28 -7/2	CLJ2010: from Massive Galaxy Formation to Dark Energy (Media Hall, Kashiwa Campus, The University of Tokyo, Japan)	From domestic institutions: 53 From overseas institutions: 107
2009/6/22-26	IPMU International Conference Dark Energy: Lighting up the Darkness! (Media Hall, Kashiwa Campus, The University of Tokyo, Japan)	From domestic institutions: 79 From overseas institutions: 55
2008/3/11-12	IPMU Opening Symposium (Media Hall, Kashiwa Campus, The University of Tokyo, Japan)	From domestic institutions: 119 From overseas institutions: 18

Appendix 5 List of Achievements of Center's Outreach Activities between FY 2007 – 2020

* Using the table below, show the achievements of the Center's outreach activities from FY2007 through FY2020 (number of activities, times held).

*If there are any rows on activities the center didn't implement, delete that (those) row(s). If you have any activities other than the items stated below, fill in the space between parentheses after "Others" on the bottom with the name of those activities and state the numbers of activities and times held in the space on the right. A row of "Others" can be added, if needed.

Activities	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020
	10	30	50	46	66	77	75	74	55	70	70	112	96	59
PR brochure, pamphlet	1	5	5	6	6	7	6	7	10	11	16	17	10	2
Lectures, seminars for the general public	0	4	10	6	11	13	12	8	10	10	14	53	36	14
Teaching, experiments, training for elementary, secondary and high school students	0	0	2	1	8	7	6	8	3	3	3	11	11	4
Science cafe	0	5	3	0	4	3	3	5	5	6	7	4	9	3
Open house	0	1	2	2	1	1	1	1	1	1	1	1	1	1
Participating, exhibiting in events	0	0	2	1	2	3	4	4	3	3	4	3	3	2
Press releases	4	9	17	20	25	33	33	31	16	25	21	21	20	27
Publications of the popular science books	5	6	9	10	9	10	10	10	7	11	4	2	6	6

Appendix 5 List of Media Coverage of Projects Carried out between FY 2007 – 2020

* Select main items of press releases, media coverage, and reports for FY 2007-2020 (especially by overseas media)

1) Japan

No.	Date	Type of the media (e.g., newspaper, magazine, television)	Description
1	21/02/2021, 29/02/2021, 29/03/2021	NHK General News (TV), NHK WEB (website), NHK World (website), Tokyo Shimbun (newspaper), Asahi Kids Newspaper (newspaper)	"Study finds Betelgeuse supernova explosion could be 100,000 years away" * Media coverage of press release by Ken'ichi Nomoto and Chiaki Kobayashi et al., released on Feb 4, regarding how unikely it is Betelgeuse will explode in the near future
2	29/01/2021, 01/02/2021	Nikkei Shimbun (newspaper, website)	"R&D Digital Transformation, Making Use of Virtual Space and Secret Strategy to Get Results" * This article features comments by Hirosi Ooguri, and introduces how the Kavli IPMU has been using virtual space to support research activities during the COVID-19 pandemic
3	19/10/2020	Asahi Shimbun (newspaper, website)	"Capture Dark Matter: Searching for Hints of the Milky Way Galaxy Caretaker" * This article features comments by Hitoshi Murayama and Shigetaka Moriyama. Article focuses on press release by Kai Martens and Shigetaka Moriyama et al. about XENON1T dark matter experiment recording excess events
4	19/12/2019	Mainichi Shimbun, Mainichi jp (newspaper, website)	"Voices: Hiromi Yokoyama - University of Tokyo Professor - Working towards equality in women's activities" * This article features news about October 17 paper publication "Parental gender attitudes associated with Japanese girls' reduced university participation" by Hiromi Yokoyama and Yuko Ikkatai et al
5	19/04/2019	NHK General (TV)	"Don't Sleep Through Life! About Baseball's First Pitch and What Is Gravity" * Hirosi Ooguri gave an expert explanation about gravity to the general audience
6	15/10/2018, 16/10/2018, 19/10/2018	Asahi Shimbun, Nikkei Shimbun, Chunichi Shimbum, Yahoo! News, 47NEWS, MSN Japan etc (newspaper, website)	"Ooguri becomes University of Tokyo Kavli IPMU Director", "Kavli IPMU welcomes Hirosi Ooguri as second director" * These articles featured news about the change in directorship at the Kavli IPMU
7	25/09/2018	Gendai Shiso (magazine)	"Yasunori Nomura and Markus Gabriel in Universe X World" * This article published the talks from June 10, 2018, Kavli IPMU public event "Universe X World", including Yasunori Nomura and philosopher Markus Gabriel
8	30/08/2018	NHK-BS Premium (TV)	Cosmic Front NEXT "Using the newest observational data to uncover dark matter" * This show introduced research using the Hyper Suprime-Cam, and featured interviews with Masahiro Takada, Masamune Oguri, and Hironao Miyatake
9	08/08/2018	Nikkei Sangyo Shimbun (newspaper)	"Start Up Innovation Science = Using Space Imaging technology to discover cancer" * This article featured an interview with Tadayuki Takahashi
10	27/04/2018	Nikkei Shimbun (newspaper)	"Science Agora: Nagoya University Associate Professor Yukari Ito talks about the spark between mathematics and physics" * This article featured an interview with Yukari Ito
11	26/03/2018	Newton (magazine)	"Episode 2: Mathematics in a Curved World. The curious geometry that opened the way to the theory of general relativity" * Commentary by Toshitake Kohno
12	20/08/2017	NHK Educational (TV)	"Heart of Time: Yogachara. Episode 5: Science of Yogachara" * Guest appearance by Hirosi Ooguri. A conversation with Rikkyo University Emeritus Professor Koitsu Yokoyama at Kavli IPMU.
13	06/01/2017	NHK General (TV)	NHK documentary "Hitoshi Murayama's Great Adventures in the Universe: Where are we going?" * Hitoshi Murayama features as show guide
14	25/11/2016	Nikkei Science (magazine)	"Unraveling Holography entanglement entropy and the Ryu-Takayanagi formula" * Hirosi Ooguri and Tadashi Takayanagi provides expertise in this article
15	25/06/2016	Newton (magazine)	"Einstein's theory stands true even in the depths of the Universe" * Media coverage of press release by Teppei Okumura and Chiaki Hikage et al., released May 11
16	26/05/2016, 28/05/2016	Mainichi Shimbun (newspaper), Mainichi Shimbun (website), Asahi Shimbun (website)	"Black hole interferes with star formation", "Hot gas winds interfere with star formation", "AKIRA's hot gas explains mechanism behind how star formation stops" * Media coverage of press release by Edmond Cheung and Kevin Bundy, released May 26
17	11/05/2016	Nikkei Shimbun (newspaper)	"Opening the door to a Global Age - Kavli IPMU drives world-leading astronomical observation" * This story introduces the Sumire Project's Hyper Supreme-Cam (HSC) and Prime Focus Spectrograph (PFS). Includes comments from Hitoshi Murayama, Masahiro Takada, Naoyuki Tamura.
18	25/08/2015	Nikkei Science (magazine)	"SIMPs, not WIMPs" * Interview with Hitoshi Murayama "Capturing dark matter" * Interview with Yoichiro Suzuki "What Professor Nambu achieved" * written by Hirosi Ooguri
19	02/07/2015	NHK-BS Premium (TV)	Cosmic Front: How the oldest black hole ever detected was born * Features Naoki Yoshida and Kavli IPMU
20	15/05/2014	NHK-BS Premium (TV)	Cosmic Front: Supernova 1987A * Features Ken'ichi Nomoto and Kavli IPMU
21	30/04/2014	Asahi Shimbun (newspaper, website)	University of Tokyo wins battle with US university in solving gravitational lens mystery surrounding supernova * Article on Robert Quimby et al. research, result of April 25 press release "Cosmic illusion revealed: Gravitational lens magnifies supernova"
22	10/12/2013	Newton Special Edition (magazine)	Expanding Universe, Extra Dimension * Supervised by Shinji Mukohyama
23	09/10/2013, 13/10/2013	Mainichi/Sankei/Asahi/Yomiuri Shimbun (newspaper)	Nobel Prize in Physics: Higgs Particle * Article features comments by Hitoshi Murayama
24	06/06/2013	NHK-BS Premium (TV)	Cosmic Front: Mystery in A.D.775 * Features appearance by Marcus Werner
25	10/05/2012	Mainichi/Asahi/Sankei/Nikkei/Yomiuri Shimbun (newspaper)	Hitoshi Murayama and Mr. Fred Kavli visited Japanese Prime Minister, Yoshihiko Noda.
26	09/02/2012	NHK General (TV)	Bakumon Gakumon: Take us to the edge of the Universe! * Features Hitoshi Murayama and Kavli IPMU
27	09/10/2011	TV Asahi (TV)	Miracles in the Earth: Genius in Japan - Addressing deep mystery of the Universe * Features Hitoshi Murayama, Masahiro Takada, and Kavli IPMU
28	20/04/2010	Mainichi (newspaper)	Frontier: Scientists that changed the world. Hitoshi Murayama. From conversation to new theories
29	07/2009	Science (magazine)	Feature: What language is the universe written in – IPMU's challenge * Features Hitoshi Murayama, Naoshi Sugiyama, Katsuhiko Sato, Kunio Inoue, Hirosi Ooguri, Alexey Bondal, Simeon Hellerman, Masahiro Takada, Mark Vagins, Mihoko Nojiri, Yukinobu Toda
30	28/01/2008	Yomiuri (newspaper)	Hitoshi Murayama appointed director of University of Tokyo space research institute to round up top minds in the world

2) Overseas

No.	Date	Type of the media (e.g., newspaper, magazine, television)	Description
1	29/12/2020 - 05/01/2021	Sci-News.com, SPACE DAILY, Research Channel, 中国资源新闻网, Gizmodo Australia,Engineering Newsなど (website)	"Primordial black holes and the search for dark matter from the multiverse" (media coverage of December 24 press release by Volodymyr Takhistov, Alexander Kusenko, Masahiro Takada, Misao Sasaki, Sunao Sugiyama et al.)
2	11/11/2020 - 15/11/2021	Sci-News.com, Science Daily, Environmental News Network, The Union Journal, astronews, Nachrichten Weltなど (website)	"History of temperature changes in the Universe revealed—First measurement using the Sunyaev-Zeldovich effect" (media coverage of November 10 press release by Eiichiro Komatsu, Ryu Makiya, Brice Ménard et al.)
3	28/08/2020 - 29/08/2020	Sci-News.com, Science Daily, SPACE DAILY, West Hawaii Today, Astronomy Nowなど (website)	"Rare encounters between cosmic heavyweights" (media coverage of August 27 press release by John Silverman, graduate student Shenli Tang et al.)
4	18/06/2020 - 20/06/2020, 24/06/2020 - 25/06/2020	Phys.org, SPACE DAILY, TechNews 科技新報, New Atlas, Huffington Post Greeceなど	"Observation of Excess Events in the XENON1T Dark Matter Experiment" (media coverage of June 17 press release by Kai Martens, Shigetaka Moriyama, and the XENON group)
5	02/03/2020, 09/03/2020	Phys.org, daily geek show (website)	"Researchers find string theory link in a class of complex numbers" (news about March 2 press release by Taizan Watari and Satoshi Kondo, who was also Project Researcher and Project Assistant Professor at Kavli IPMU between 2008 and 2014)
6	01/02/2020	NOTICES OF THE AMS (magazine, website)	"Mathematics People -Ooguri Awarded Medal of Honor of Japan" (article about Hirosi Ooguri receiving the Medal of Honor with Purple Ribbon)
7	19/12/2019	Asia Research News (magazine)	"On the hunt for primordial black holes" (story about April 2 research paper publication "Subaru Telescope helps determine that dark matter is not made up of tiny primordial black holes" by Masahiro Takada and graduate student Hiroko Niikura et al.)
8	26/07/2019, 29/07/2019, 31/07/2019	Medical Xpress, News Medical, Physics World (website)	"Under development medical camera could help cut time and cost of procedures" (news about July 24 research paper publication by Tadayuki Takahashi and Shin'ichiro Takeda)
9	18/06/2019	SNMMI TV (website)	"National Cancer Center, Japan" video of research results, created by the Society of Nuclear Medicine & Molecular Imaging, USA. (video features Japan's National Cancer Center and work by Kavli IPMU researchers to adapt gamma-ray imaging technology to medical research, and includes an appearance by Miho Katsuragawa"
10	27/02/2019	Nature News (website)	"Gigantic Japanese detector prepares to catch neutrinos from supernovae" (this article features Mark Vagins, and his team's work on the SK-Gd project)
11	26/09/2018, 27/09/2018	Science Daily, SciTech Europa, Health Medicine Network, International Business Times etc (website)	"Hyper Suprime-Cam survey maps dark matter in the universe" (these articles feature research results from "Hyper Suprime-Cam Survey reveals detailed dark matter map of the universe", published on September 26, 2018, featuring Chiaki Hikage)
12	24/05/2018, 25/05/2018	PASADENA NOW, Scienmag, Presse Box etc (website)	"Caltech String Theorist Wins Hamburg Prize", "Hirosi Ooguri has been awarded the 2018 Hamburg Prize for Theoretical Physics" (these articles mention Hirosi Ooguri's achievement in receiving the Hamburg Prize. Also published on Kavli IPMU website)
13	06/10/2017	International Business Times, Science Newsline and others (website)	"Supernova Explosions Of Some White Dwarf Stars Triggered By Excessive Helium" (media coverage of October 5 press release by Mamoru Doi and including Ken'ichi Nomoto, Naoki Yasuda, and Nao Suzuki)
14	23/05/2017	Scientific American (magazine)	"The Quantum Multiverse" (written by Kavli IPMU Yasunori Nomura)
15	19/02/2017, 21/03/2017	UNESCO Creative Cities Network, culture360 (website)	" 'Datum' by Norimichi Hirakawa: a glimpse of 2017 Sapporo International Art Festival", "Wrocł aw | Everything and Nothing exhibition" * Article introducing group talk "Media Art: Art and Science" at the 2017 Sapporo International Art Festival featuring Kavli IPMU Artist in Residence Norimichi Hirakawa
16	26/05/2016, 27/05/2016	Phys.org, Nature Publishing, International Business Times UK, and others (website)	"Supermassive Black Holes in 'Red Geyser' Galaxies Cause Galactic Warming", "Red geysers: How supermassive black holes turn galaxies into featureless wastelands by Hannah Osborne" (media coverage of May 26 press release by Edmond Cheung and Kevin Bundy)
17	11/05/2016, 12/05/2016	Phys.org, Science Daily, Astronomy Now, Science Newsline (website)	"New test by deepest galaxy map finds Einstein's theory stands true", "Daily, New test by deepest galaxy map finds Einstein's theory stands true", "Now, Deepest 3-D galaxy map suggests Einstein's theory stands true by Astronomy Now" (media coverage of May 11 press release by Teppei Okumura and Chiaki Hikage et al.)
18	11/09/2015	Yahoo! News (US/Canada), AP, International Business Times and others (website), Fox29 WFLX TV, KFMB-TV CBS-8, KAUZ-TV: NewsChannel 6 Now (TV)	"Takaaki Kajita, Yoichiro Suzuki receive 2016 Breaththrough Prize in Fundamental Physics" (media coverages of Takaaki Kajita and Yoichiro Suzuki receiving 2016 Breakthrough Prize in Fundamental Physics)
19	27/05/2015- 29/05/2015	SPACE DAILY, Health Medicine Network, Press-News.org, Phys.org, News, Nanotechnology Now, Science Newsline, Scientific Computing (website)	"How Spacetime is built by Quantum Entanglement: New Insight into Unification of General Relativity and Quantum Mechanics" (media coverage of May 27 press release by Hirosi Ooguri et al.)
20	11/09/2014	Yahoo! News (UK&IRELAND), ScienceDaily, Phys.org (website)	"Nasa's Hubble: Bright Blue Star Discovered Reveals Missing Piece of Supernova Puzzle" (media coverage of September 11 press release by Gastón Folatelli and Melina Bersten et al.)
21	25/04/2014	BBC News, PHYS.ORG, NATIONAL GEOGRAPHIC, New Scientist, 新華網. Science Newsline (website)	"Cosmic illusion revealed: Gravitational lens magnifies supernova" (media coverage of April 25 press release by Robert Quimby et al.)
22	31/07/2013- 03/08/2013	CNET, BruDirect, Telegraph, SPACE.com, Gizmag, SEPAMAS, Pijama Surf, RIA (website)	"A New View on the Origin of Dark Matter and Dark Energy - Image of M31 Heralds the Dawn of HSC" (media coverage of July 31 press release about making the HSC First Light image open to the public)
23	13/06/2013, 14/06/2013	Pacific News, Newtalk, Business Standard, Economic Times, Youth Daily News (website)	"Cosmic giants shed new light on dark matter" (media coverage of June 13 press release by Masahiro Takada et al.)
24	03/08/2012	Hindustantimes, redOrbit, Mail Online, Phys.org (website)	"Clumpy Structure of Supernova Explosions -- A Subaru view of supernova explosion mechanism" (media coverage of August 3 press release by Masaomi Tanaka, Keiichi Maeda, Ken'ichi Nomoto et al.)
25	09/02/2012	Astrocast.tv, NonotechNow, Newwise, spaceREF, Science Insider, Nature News, Phys.org, Physics World (website)	"New Kavli Institute Announced at The University of Tokyo" (media coverage of Kavli IPMU announcement, released February 8)
26	11/11/2011	Space.com, Clarksville Online, La Canada Flintridge Patch (website)	"First Stars Heavy But Not Monstrous - Researchers recreate Universe's first star - " (media coverage of November 11 press release by Naoki Yoshida et al.)
27	20/05/2010	ABC Science (website)	"An Unusual Supernova May Be a Missing Link in Stellar Evolution Research - Keiichi Maeda - " (media coverage of May 20 press release by Keiichi Maeda and Ken'ichi Nomoto et al.)
28	09/11/2009	Physics Today (website)	"Hirosi Ooguri wins Nishina Memorial Prize" (article about Hirosi Ooguri receiving the Nishina Memorial Prize)
29	28/06/2008	KBS News (TV)	SUSY 09 in South Korea, Hitoshi Murayama talked about CERN
30	14/01/2008	Fermilab Today (website)	"Hitoshi Murayama named IPMU founding director" (article about Hitoshi Murayama being named founding director of IPMU)

Appendix 5b Outreach Activities and Their Results

List up to three of the Center's outreach activities carried out during the period between FY 2017 and 2020 that have contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program, and describe its concrete contents and effect in narrative style. (Where possible, indicate the results in concrete numbers.)

Examples:
- As a result of using a new OO press-release method, a OO% increase in media coverage was obtained over the previous year.
- By holding seminars for the public that include people from industry, requests for joint research were received from companies.
- We changed our public relations media. As a resulting of using OO to disseminate information, a OO% increase in inquiries from researchers was obtained over the previous year.
- As a result of vigorously carrying out OO outreach activity, ¥OO in external funding was acquired.

Enter a list of your outreach activities in Attachment 5a.

Example 1: Study on lumpiness of matter in the Universe named Most Discussed paper
In September 2018, an international team led by Project Assistant Professor Chiaki Hikage released the paper, "Cosmology from cosmic shear power spectra with Subaru Hyper Suprime-Cam first-year data", which was promoted domestically through a press conference, and internationally using the Kavli IPMU's media list and news services such as EurekAlert!, AlphaGalileo, and Asia Research News. About 46 news articles mentioning the Kavli IPMU were published in Japan and overseas. The paper was published in the Publications of the Astronomical Society of Japan (PASJ), where it was selected as the Most Discussed paper of 2019 thanks to its influence online, including social media and news websites. Thus, this paper was not only an achievement academically, but also gave the institute itself extra exposure to audiences within and outside of Japan.

Example 2: Kavli IPMU AIR exhibition and driving the fusion between science and art
Since 2015, the Kavli IPMU has hosted the Artist in Residence Program (AIR), creating a new opportunity to showcase the social and creative value of fundamental research. To date, the program has had several achievements, including a two-week exhibition in 2018 hosted by Kavli IPMU, which featured work by three past AIR residents, which attracted 400 visitors. An art piece titled "datum", inspired during the residence and developed by 2016 AIR resident and media artist Norimichi Hirakawa, was awarded second prize in the Art Category at the Japan Media Arts Festival, and later on became part of the public collection at the Art Gallery of New South Wales in Australia. 2015 AIR resident Yasuo Nomura was named a Japan Agency for Cultural Affairs Overseas Study for Upcoming Artists, and has been residing in New York since 2020, where he continues to develop his work, and has hosted his own exhibition. These examples show Kavli IPMU AIR is a recognized driver for new creations in science and art. The institute has also received invitations from several conferences to speak about AIR, exposing the institute to diverse audiences. In June 2021, the Kavli IPMU will co-host "Fundamentals Bazaar", an open meet up for researchers and artists, together with JACST (Japan Association of Communication for Science and Technology), which is made up of communication specialists from 130 universities and institutes. The program has also secured 1 million JPY of funding. Such achievements highlight how the Kavli IPMU has been able to lead the fusion between science and art in Japan, on the same scale as existing programs hosted by institutions such as CERN or MIT.

Example 3: Kavli IPMU Monoshiri Newspaper
Monoshiri Newspaper became a new feature of the Kavli IPMU following the institute's 10th anniversary in 2017. The two-sided wall newspaper is filled with pictures and stories surrounding specific research fields. The newspaper is currently uploaded to the Kavli IPMU website, and is distributed to Super Science High School-certified schools and preparatory schools across Japan. It has grown in popularity over the years, with 607 schools receiving the first edition in September 2017, to now more than 700 schools receiving the most recent 11th edition. The institute continues to receive requests from teachers asking for a copy to be sent to their own school. In May 2020, the Kavli IPMU hosted an event, "Kavli IPMU Monoshiri Newspaper Online Talk Series". Four researchers who had appeared in the newspapers took part as teachers, and talked about their research and day-to-day activities. About 1895 people tuned into the event, of which just under half identified themselves as students, including undergraduate and graduate students. The event also attracted people from outside the Tokyo area, providing the opportunity to introduce the institute to a wider audience.

Appendix6-1 Host Institution's Commitment (Fund, Personnel)

1. Contributions from host institution

(1) Fund, Personnel

* Regarding "Fund" entry, describe with reference to the items in the Progress Report (Jisseki-hokoku-sho) based on Article 12 of the Grant Guidelines (Kofu-yoko).

* Don't include competitive funding obtained by researchers (used as research project funding)

(FY 2007-2020)

<Fund> **(million yen)**

Fiscal Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Personnel	94	258	235	278	229	257	271	297	353	366	374	677	763	708
Faculty members	68	150	160	201	229	257	271	296	352	362	372	603	633	614
Full-time	0	0	10	10	10	24	33	49	94	108	123	356	379	376
Concurrent	68	150	150	191	219	233	238	247	258	254	249	247	254	238
Postdocs	0	0	0	0	0	0	0	0	0	0	0	52	107	67
RA etc.	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Research support staffs	0	0	0	0	0	0	0	1	1	4	2	22	23	26
Administrative staffs	26	108	75	77	0	0	0	0	0	0	0	0	0	0
Full-time	26	108	75	77	0	0	0	0	0	0	0	0	0	0
Concurrent	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Project activities	3	18	113	7	23	8	42	185	70	133	131	275	213	400
Travel	1	1	2	6	1	1	1	1	1	2	2	25	55	5
Equipment	0	0	7	0	3	0	0	0	9	19	19	93	56	157
Research projects	290	536	646	503	675	675	560	584	1084	700	391	453	437	230
Total	388	813	1003	794	931	941	874	1067	1517	1220	917	1523	1524	1500

<Personnel> **(person)**

Fiscal Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Personnel	16	38	42	52	44	48	49	54	61	59	56	94	111	92
Faculty members	10	28	31	41	44	48	49	52	59	56	54	76	76	71
Full-time	0	0	1	1	1	3	3	5	9	11	10	33	31	30
Concurrent	10	28	30	40	43	45	46	47	50	45	44	43	45	41
Postdocs	0	0	0	0	0	0	0	0	0	0	0	14	31	15
RA etc.	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Research support staffs	0	0	0	0	0	0	0	2	2	3	2	4	4	5
Administrative staffs	6	10	11	11	0	0	0	0	0	0	0	0	0	0
Full-time	6	10	11	11	0	0	0	0	0	0	0	0	0	0
Concurrent	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix6-1 Host Institution's Commitment

1. Contributions from host institution

(2) Provision of land and/or building(s), lab space, etc.

The university provides land free at the Kashiwa-Campus for the Kavli IPMU building. It is approximately 1,600 m^2. Also at the Kashiwa-Campus second complex building, three rooms are free for researchers, post doctors and students. It is about 645 m^2 in total.

2. System under which the center's director is able to make substantive personnel and budget allocation decisions

From the beginning, UTokyo developed an innovative scheme to allow the positioning of the Kavli IPMU as an organization directly under the Office of President working in an organic linkage with existing university organizations. In January 2011, UTokyo established the UTIAS and the Kavli IPMU was accepted as its first member institute. Under this scheme, Director of the Kavli IPMU has decision-making power in the operation of the Institute, including the recruitment of researchers. Director can have strong leadership in various decision makings, the Kavli IPMU has the Steering Committee and the Finance Committee for the final assurance/check on personnel and budget, respectively.

3. Support for the center director in coordinating with other departments at host institution when recruiting researchers, while giving reasonable regard to the educational and research activities of those departments

In order to ensure that education and research activities of the University faculties and institutions from which the researchers are gathered for the Kavli IPMU, the Administration Bureau provided any necessary financial support, such as for personnel expenses of substitute teaching staff, to the concerned university departments and divisions. This allows such departments and divisions to take measurements including securing substitute teaching staff, expecting further improvement in the mobility of researchers within the University. The affiliate member system has been working as well. The researchers at other departments of the University can be assigned as affiliate members, and the Kavli IPMU supports their traveling expenses. Also, cross appointment system between the Kavli IPMU and the other departments is working well.

4. Revamping host institution's internal systems to allow introducing of new management methods

(e.g., English-language environment, merit-based pay, cross appointment, top-down decision making unfettered by conventional modes of operation)

As described above, UTokyo has developed an innovative scheme to allow the positioning of the Kavli IPMU within UTIAS. Under this scheme, the Kavli IPMU has taken charge of the operation of the organization, including the recruitment of researchers. New special regulations were also established designating the Kavli IPMU as a special zone in which participating researchers and support staff members are allowed a limited exemption from some restrictions under the work rules that are generally applied within the university. Those measures are; English bilingual staff can be easily hired, recruit prominent researchers from all over the world based by paying internationally competitive salary, possible joint appointments between the Kavli IPMU and the foreign universities, and so on.

5. Utilities and other infrastructure support provided by host institution

(*In addition to those listed in the item 1. "Contributions from host institution")

UTokyo places great importance on the development of an environment to permit excellent researchers

from overseas to steadily concentrate on their research activities. Priority allocation of the residences at the opened facility has already been made for researchers invited to the Kavli IPMU from overseas. Top priority has been given to the appropriation of land for a research building for the Kavli IPMU and its financing. In 2011, the University built a fancy five-story 'fusion building' for the Kavli IPMU. It is a spiral configuration without any concrete definition of each story. All the researchers, staff moved from an inconvenient pre-have house to this comfortable new building. Also at the Kashiwa-Campus second complex building, three rooms are free for researchers, post doctors and students. It is about 645 m^2.

6. Support for other types of assistance

With the aim of supporting the establishment of an internationally competitive center through the program, UTokyo has set up a committee headed by the board member in charge of the program. The committee, in addition to ensuring university-wide support for the Kavli IPMU, has been worked in close cooperation with the Global COE (Centers of Excellence) Program, the Leading Graduate School Program, and other schemes, as part of its role to produce maximum synergy. In 2020, the Excellent Graduate School program was approved by the government, and the ForPM course commenced together with the Faculty of Science. By this scheme, several new Kavli IPMU faculty are accepted to approach and teach graduate students in the Faculty of Science, officially. The administrative functions of the Administrative Bureau were reorganized in 2007 to intensively support the Kavli IPMU, among other organizations. With these schemes, the University has provided the maximum possible consistent support for the promotion of the Kavli IPMU concept. In 2021, UTokyo secured the full budget requested by the Kavli IPMU to sustain it as a permanent institute of the University. The whole activities of the Kavli IPMU match President's Vision 2020 scheme to pull up the international visibility of UTokyo. Based on the long reliability between UTokyo and the Kavli Foundation, US$10 million additional endowment for the Kavli IPMU was boosted up by the energetic efforts of the university executives. The Kavli Foundation was received Todai Shokumon Award for its long and significant contribution to the Kavli IPMU.

Appendix6-2 The Host Institution's Mid-term Plan

* Excerpt the places in the host institution's "Mid-term objectives" and/or "Mid-term plan" that clearly show the positioning of the WPI center within its organization.

The First Term (April 1, 2004 – March 31, 2010)

- Objectives on Enhancing the Systems for Research
  Actively promote the establishment and development of a core research facility.
- Measures to Achieve the Objectives on Enhancing the Systems for Research
  - Specific measures on the development of research facilities to function as centers for nationwide and worldwide collaboration
  - Based on institutes, national common use facilities, and university common facilities for education and research, develop centers for national and international research collaboration in the university.
  - At the world's top level research center, the "Institute for the Physics and Mathematics of the Universe", intensively develop organizations to investigate the origin and evolution of the universe through the collaboration of mathematics, physics and astronomy.

The Second Term (April 1, 2010 – March 31, 2016)

- Objectives on Internationalization
  Contribute to society through internationalizing education and research, strengthening the presence of Japan in the world, and creating relationships for international cooperation.
- Measures to Achieve the Other Objectives
  Measures to Achieve the Objectives on Internationalization
  - In order to advance internationalization even more, constantly revise the mid- and long-term strategy for enhancing internationalization and develop and utilize the organization for realizing the objectives.
  - Specifically, promote international research collaboration in the field of advanced astronomical scientific research, as well as develop the environment for education by inviting world-class researchers.

The Third Term (April 1, 2016 – March 31, 2022)

- Objectives on Contents and Outcome of Education
  Foster the intelligence professionals who can be active for human society enthusiastically through the degree courses in the graduate school.
- Measures to Achieve on Contents and Outcome of Education
  As for the progressive start to realize the objective, establish the "international excellent graduate school" to gather young excellent people from all over the world under the fascinating system of the world top level research initiative.

- Objectives on Level and Outcome of Research
  Carry out the world top level research which can open the new horizon of intelligence in advance.
- Measures to Achieve on Level and Outcome of Research
  Intensive investment should be accelerated on those highly appreciated institutes from over the world such as the UTIAS.

World Premier International Research Center Initiative (WPI)
Progress Plan (For Final Evaluation)

Host Institution	The University of Tokyo	Host Institution Head	Makoto Gonokami
Research Center	Kavli Institute for the Physics and Mathematics of the Universe		
Center Director	Hirosi Ooguri	Administrative Director	Tomiyoshi Haruyama

Write your report **within 6 pages**.
* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.

1. Mid- to Long-term Research Objectives and Strategies Based on the Center's Results during Funded Period

Describe new challenges in the Center's research objectives and plans after the funding period ends. If major adjustments will be made in the Center's operation, such as newly set research themes/objectives or a change in the director, describe the strategic background to the adjustments.

The mission of the Kavli IPMU is to discover fundamental laws of nature and to use them to address the questions about the Universe; how it was born, how it evolved, and what the future will be. Our long-term objectives are to solve these problems by integrated efforts of mathematicians, physicists and astronomers. Immediately after H. Ooguri became the Director in the fall of 2018, he initiated the Long Term Strategic Planning Exercise of the Kavli IPMU. It identified the following three areas as the institutional priorities in experimental physics and observational astronomy:

- CMB Projects
- Kamioka Projects
- Survey Astronomy Projects.

Each of these projects involves multiple faculty members of the Kavli IPMU, and a large fraction of our resources will be invested in them. All these projects are consistent with Kavli IPMU's mission. Cosmology and neutrino physics are making significant progress and there are also opportunities for synergies among these projects. We expect that these investments will bear fruits over the next five to ten years, and it is important to ensure their successes. In addition to these priority areas, we will also support projects conducted by single PI's as well as theoretical research.

1.1 CMB Projects

The Kavli IPMU is participating in POLARBEAR/Simons Array and the Simons Observatory. We are playing a major role in the Simons Observatory upgrade. The experiences we have gained in this project are important for us to take the leadership in the Japanese project, LiteBIRD.

ISAS (the science division of JAXA) has approved the launch of the LiteBIRD satellite, currently scheduled in November 2029. The Kavli IPMU is a lead institution for its Master Plan 2020 proposal to the Science Council of Japan and is expected to contribute to the project with development of polarization modulators and hosing of the data analysis center.

Currently, there are three faculty members working on CMB projects. Assuming that LiteBIRD will receive a final approval by JAXA and is fully funded both for the polarization modulator development and the data analysis center, in a steady state of the project, we plan to keep the current size of faculty on CMB projects.

1.2 Kamioka Projects

The Kavli IPMU is involved in several projects at the Kamioka Observatory.

SK-Gd: This project is a fulfillment of the idea of Kavli IPMU PI M. Vagins and his collaborator J. Beacom. Since 2020, the gadolinium is being added Super-Kamiokande, and the sensitivity is expected to increase substantially in the coming years. It will make it possible to detect signals of supernova relic neutrinos and of anti-neutrino spectrum from nuclear reactors.

T2K: Full physics operation started in 2010, with the best constraint on δ_{CP} by summer 2017. T2K is expected to become an important partner of the Hyper-Kamiokande project described below. A couple of our faculty members are involved in this project.

Hyper-Kamiokande: The construction has started and is in steady progress despite the COVID-19 pandemic.

1.3 Survey Astronomy

Hyper Suprime-Cam (HSC) and Prime Focus Spectrograph (PFS) are flagship projects of the Kavli IPMU. Currently, there are 5 full-time faculty members, 7 affiliates, 10 postdocs, 5 students working on them. The Kavli IPMU has played critical roles in funding and leadership of these projects. HSC has already had great success with its early science results, in particular with the weak lensing survey, and more results are expected with full data set. PFS will play a complementary role with highly multiplexed, deep, wide redshift survey. The instruments are being assembled in Hawaii.

To make the most of HSC and PFS, close collaborations with other survey projects worldwide are essential. Rubin Observatory (LSST) will be the main survey project for the coming decade. It is a natural synergistic extension of HSC and PFS, and there are opportunities to make an impact with our experience with these projects. Coordinating with NAOJ, we are negotiating with the Rubin Observatory on in-kind contributions to the project, which will include providing substantial computer time for data analysis. WFIRST is expected to be launched in October 2025. Subaru is supposed to contribute 100 nights. Data analysis support, in particular interface to data is going to be important.

1.4. Single PI Projects

There are several projects conducted by single PI's. Scientifically, they are all excellent projects and we will continue to encourage such activities:

Belle II: This is a major national project following the successful Belle experiment, which verified the theory of Kobayashi and Maskawa, leading to their Nobel Prizes. The Kavli IPMU group successfully completed the semiconductor detector production and delivery in 2018, and the experiment started in March 2019. Subsequently, our group has made a successful transition to data analysis.

XENON-nT: The Kavli IPMU is making an impact on the project with its contribution of the gadolinium technology from Kamioka, eliminating the need for the problematic liquid scintillator.

Medical Applications of Gamma-Ray Imaging: It is important to explore opportunities like this one to make our basic science research useful to the society. Currently, the project is funded by grants for T. Takahashi, with a laboratory at the National Cancer Center. It provides opportunities for us to make societal impacts.

1.5. Theoretical Research

Project-style research is not suited to theoretical studies. Nevertheless, there are a few important topics about which we expect to make significant contributions.

Mathematics and Theoretical Physics: Collaborations between our mathematicians and theoretical physicists have been very successful and have yielded many noteworthy results until today. We will maintain such interactions. Our challenge in the coming decade is to expand the frontiers in algebraic geometry toward other areas in mathematics and theoretical physics.

One of the important issues is to study the categorical aspects of quantum field theories (QFT). A few years ago, the concept of perverse schobers was proposed by a Kavli IPMU researcher (M. Kapranov), which are categorical analogs of perverse sheaves. The work up to now indicates that perverse schobers provide, among other things, a mathematical framework for the study of 2 dimensional QFT in the infrared limit (the Algebra of the Infrared of Gaiotto-Moore-Witten) as well as for induction-restriction formalism of Representation Theory. Developing a solid mathematical foundation of this theory is a challenge.

Another related issue is the study of moduli spaces of coherent sheaves on algebraic varieties. Those sheaves also appear in supersymmetric gauge theories in theoretical physics. Many quantum field theoretic quantities, such as partition functions, correlation functions, are expressed as integrals over moduli spaces. Even more, finer objects, such as Hilbert spaces in quantum physics, could be related to moduli spaces. Thus, studies from the mathematical side will give tools to compute physical quantities. On the other hand, research in physics will provide different ways to look at moduli spaces, and lead to the existence of structures that are unexpected in mathematical studies. We hope that our planned studies on moduli spaces may give new insights into other fields of mathematics, such as representation theory, number theory, and so on.

Astrophysics, Cosmology and Particle Physics: In the areas of astrophysics and particle physics, there is an important unsolved issue, i.e., the nature of dark matter and dark energy.

With the planned world-leading projects mentioned above at hand, our challenges are to develop an efficient analysis method that can deal with the big data delivered by those projects. The planned surveys are aimed at collecting images of billions of galaxies and stars. Data to be delivered by those surveys typically exceed tens of petabytes. Real-time analysis of the sheer volume of data is a real challenge. It necessitates us to develop efficient data analysis methods using machine learning. The expected scientific outputs and the potential of unexpected discovery heavily rely on how well astronomical/cosmological information can be extracted from the large data set. We will make a concerted effort with astronomers, physicists, mathematicians, and computer scientists to develop such a method to develop a "machine" that automates data analysis and scientific discovery from the large observational programs.

As for theory, diverse studies on dark matter have been performed at the Kavli IPMU for various candidates ranging from ultralight to macroscopic ones. For example, Primordial Black Holes (PBH) as a macroscopic candidate, Electro-Weakly Interacting Massive Particle (EWIMP) as a heavy particle candidate, Weakly Interacting Massive Particle (WIMP) as a typical particle candidate, sterile neutrino as a non-thermal light candidate, Strongly Interacting Massive Particle (SIMP) as a thermal light candidate, dark photon as a very light particle candidate, axion as an ultralight (wave-like) candidate. Through these studies, we proposed concrete models, found new mechanisms on dark matter processes, suggested experimental methods to test the candidates, and contributed to dark matter search projects by showing the nature of each candidate. We will keep developing such theoretical models, in particular, through various international and interdisciplinary collaborations with other fields, i.e. astrophysical observations (HSC, PFS) for pBH/EWIMP/WIMP/SIMP, TeV gamma-ray observations (CTA) for EWIMP/WIMP, MeV gamma-ray observations (COSI) for WIMP/sterile neutrino/SIMP, underground experiments (XENON) for EWIMP/WIMP, chemical synthesis (new direct dark matter detection) for SIMP/dark photon, and precision physics (Atomic clock, GW) for axion, hadron collider experiments (HL-LHC) for EWIMP/WIMP, lepton collider experiments (Belle II, ILC) for WIMP, SIMP, and so on.

Quantum Information Theory: The Kavli IPMU is a member of the Trans-Scale Quantum Science Institute, a crosscutting research platform for quantum science including cosmology, particle physics, condensed matter physics, quantum information and mathematics at the University of Tokyo. Theoretical physicists at the Kavli IPMU are involved in applications of ideas and techniques of quantum information theory to advance our understanding of quantum gravity. We are also expecting that insight gained in quantum gravity theory can be useful in quantum computers and quantum cryptography. In addition to faculty members working in this area, we are supporting research activities at the interface of quantum information and quantum gravity with postdocs appointments and conferences.

2. Management System of the Research Organization

2-1. Describe the Center's Research Organizational Management System that will Execute the Research Strategy and Plan Described above.

- In Appendix 1-1, list the PIs who will ensure that the Center's project is sustained and advanced after the funding period ends.
- In Appendix 1-2, enter the number of Center personnel (researchers, research-support staff, and administrative staff) in FY 2022
- In Appendix 2, diagram the Center's organizational management system.

To secure success in the above research objectives, human resources are essential. We will maintain our high standard in recruiting new faculty members and hiring postdocs from all over the world. In 2021, the Kavli IPMU has launched the diversity initiative to promote the diversity and inclusion in our institute and spread successful practices within the University of Tokyo and throughout Japan.

A few PIs are assigned to each of the main objectives 1.1, 1.2 and 1.3, so that the scopes of research will be as wide and deep as possible. To further enhance international collaborations, the Kavli IPMU is taking part in collaborative agreements with IN2P3/CNRS, France, in the areas of CMB, neutrino physics and survey astronomy, together with ICRR, University of Tokyo. For the single PI projects as well as theoretical projects, each PI or faculty member will tackle their respective objectives. To encourage mutual interactions and multidisciplinary collaborations, we will keep our tradition of daily teatime at 3 pm.

Currently, some of our PIs are faculty members of the Kavli IPMU and others are associated with other institutions. The job descriptions in comparison to those of tenured faculty members (full and associate professors) have not been well-defined. We are currently reviewing both the PI system and the faculty system and will come up with a coherent personnel system and document them.

Similarly, we are also working on a personnel manual that describes rules governing faculty recruiting and promotions. Documenting these rules is important to ensure that everyone is treated fairly and consistently. This is particularly important in promoting the diversity and inclusion and in attracting talented researchers from all over the world.

Our supporting and administrative staffs are also among the most efficient in the world. We will maintain their high quality by properly assigning their duties and clearly defining their responsibilities.

Currently, the Kavli IPMU is managed with the strong leadership of the Director, and the steering committee chaired by the Director is its decision-making body on important matters such as faculty hiring and promotion. This top-down management structure allows timely decisions on recruitments, retentions, and resource allocations. The organization remains flat with no "departments" within the institute, and the directorate is always open to new initiatives from the individual faculty members. We intend to maintain this administrative structure in coming years.

2-2. Initiatives and Plans that will Impel System Reforms

- Describe the Center's action plan that embodies the basic policies of the University Reform Plan, and the Center's plan and strategies that lead to host institution reforms either directly or via ripple effects (also to other institutions, if applicable). Describe also the Center's strategies for fostering and securing the next generation of researchers (e.g., introduction of tenure tracks), and the system reform for enhancing the Center's organizational management, such as the implementation/verification PDCA system.
- Describe your plan for sustaining and enhancing the WPI brand.

The Kavli IPMU has been successful in implementing system reforms. They include:

- establishing the environment to concentrate the research
- split appointments with institutes outside Japan
- merit-based salary system
- global standard for the hiring system
- "nenpo" system

The successful reforms of the system and organization within the Kavli IPMU should not stay confined within our Institute. Already, many of our accomplishments are taken up by the University administration. We take the role of an evangelist to make these reforms permeate the system to boost the overall competitiveness of research in Japan. One of the examples we have achieved to spread these reforms can be seen in the Administrative Director's contribution to Tokushima University on the program established by the Cabinet Office project "Promotion of Regional Industries and Universities". He gave a lecture to the President and board members of Tokushima University on the detailed successful experience of the WPI program at the Kavli IPMU. He has been assigned as a member of the External Evaluation Committee of the newly established laboratory at the university.

As an important aspect of fostering and securing the next generation of researchers, recently we have established a new tenure track system. A tenure track assistant professor is hired for the initial seven years, and through the process of mid-term review and the following final review, the candidate can be a tenured associate professor. Also, we are planning to form a standing committee to search for talented young researchers, especially for female and minority researchers. We defined the Kavli IPMU code of conduct to guarantee the diversity initiative research environment and it was developed to the University's code of conduct later.

Regarding the education of young people including undergraduate students, a successful program between Oxford University and the Kavli IPMU since 2015 has been producing a couple of PhDs every year. So far, we have accepted nine students, and five have defended their Ph.D. theses. In addition to that, the excellent graduate student program WISE is accepted by MEXT and the faculty members in Kavli IPMU can officially approach to foster students.

The Kavli IPMU is now recognized as the one of the prominent WPI institutes from over the world. We are obliged to keep this WPI brand even after the WPI full support is terminated. So, what is the WPI brand? We recall the four missions of the WPI: science, fusion, globalization and system reform. For science and fusion, we will enter the fruitful season of the world top class projects soon and high visibility can be achieved through those results. We will make further effort to keep the present world top level researchers stay inside the institute by guaranteeing the excellent research environment as it is. Fortunately, we have been keeping around 50% fraction of foreign researchers for many years. This implies that our institute is comfortable for many foreign researchers to accomplish their advanced research. This is the results of system reform done under the strong motivation as the WPI institute for 14 years. We will always conscious of what we have done and how to challenge for the next step to reach a much higher level.

3. Plan for Promoting the International Circulation of World's Best Brains

Describe your policy and concrete plan for promoting the international circulation of the world's best brains, which is an important function of the WPI Academy.

Our program to keep requiring our postdocs to spend at least a month up to three months per year visiting institutions abroad has been done successfully for a long time. By this young researchers' activities, the name of Kavli IPMU spread all over the world in this decade and a half. Also we invited many world-top researchers as well as young researchers with high potential. In addition, we established named visiting professorships and fellowships. These efforts have been the key to achieve our international composition with almost half of the researchers being non-Japanese nationals. Every year, about half of 800-1000 visiting researchers are from abroad. The international solicitation for postdoc plays the key and important role for the young excellent brain circulation. About 700 applicants annually compete for about 12 Kavli IPMU postdoc positions. The short-listed candidates are excellent, and about 30 % of full number of offers are normally accepted. After three years postdoc research, about a half of "graduate" postdoc normally found tenure, or tenure-track faculty positions at universities, research organizations. After leaving the institution, many active researchers are assigned as affiliate members of the Kavli IPMU. We support traveling and staying accommodations to make it easy to visit us. New collaborative research between inside researcher and affiliate member is expected to be commenced in such occasion.

4. Center's Position within Host Institution and Measures to Provide It with Resources

Describe the Center's future plans with regard to the following points after the funding period ends.

4-1. From a Mid- to Long-term Perspective, the Position of the Center within the Organization of the Host Institution

Describe where the Center will be placed within the host institution's overall organizational strategy under the leadership of the institution's head.

- In Appendix 3, diagram the Center's position within the organization of the host institution, and describe that positioning using excerpts from the institution's mid- to long-term plan. If the plan has not been established yet, describe the consideration being given to the Center's positioning.

The University of Tokyo recognizes that the Kavli IPMU is the flagship of the University, and the successive Presidents of the University have expressed their commitment to the Kavli IPMU at many WPI occasions, such as meetings of the Program Committee, Site visits, and follow-up visits.

In March 2021, UTIAS (University of Tokyo Institute for Advanced Studies) approved that Kavli IPMU to stay continued as a research organization within UTIAS. The criteria of these qualifications are: the institute should be evaluated as an excellent international research initiative, world top-level researches are active there, enough running budget is secured, and enough globalization of research environment has been achieved.

In April 2021, new President T. Fujii pointed out three important strategies in his inaugural message. Those are: conversation in person, diversity and inclusion, and visible and centripetal UTokyo.
In his address,
"Diversity and inclusion are fundamental not only in the creation of academic knowledge, but also to human resource development, university management and partnerships with society…. In addition, we will gather outstanding people with diverse backgrounds from around the world as faculty, staff and students, and create a place where they can thrive".
"By realizing a digital campus that promotes digital innovation throughout education, research and administration, we aim to improve the quality of faculty and staff members' time and work, and make UTokyo a place of learning where people from around the world will want to come and join".

The President is now preparing the institution's mid-to-long-term plan which will match with the Fourth Term Mid-term Target.

4-2. Host Institution's Action Plan for Sustaining and Advancing the Center as a World Premier International Research Center (e.g., Positioning, Financial Resources)

- In Appendix4, describe the host institution's resource allocation plans for the Center, including the allocation of posts (in both its research and administrative divisions).

In March 2021, the University of Tokyo approved our proposal to place the university funding for the Kavli IPMU in the core expenses category, at about 1 billion yen per year. Being part of the core expenses

category means that the funding is permanent. The Kavli IPMU is also keeping its status as a research organization inside UTIAS guaranteed its special managing system. These actions reflect University's commitment to sustain the Kavli IPMU as a permanent institute, both in terms of finances and administrative arrangements.

The Kavli IPMU has already secured 26 permanent positions for the core of faculty to guarantee excellent activities of the Kavli IPMU as it is. Most positions are assigned to core faculty. The University secured also 9 UTokyo permanent administrative staff. In addition, the university has decided that termed administrative staff should be hired as permanent positions including bilingual staff. It means that the many supporting staff for the foreign researchers can stay in the Kavli IPMU. The loan for the main building has already completed and three rooms at the second complex building are free for us. UTIAS is an outstanding support system allowing the Kavli IPMU to operate as an incubator of systems reform within the University.

In 2020, the Kavli Foundation decided to increase the Kavli IPMU endowment by $10 million, guaranteeing a stable source of discretionary research funding. The Kavli Foundation has also committed to provide matching fund up to $2 million to help fund raising of UTokyo for more support for the Kavli IPMU. These actions reflect the trust and appreciation of the Kavli Foundation on the Kavli IPMU regarding its high level of research activities and the stewardship of the endowment.

The grant from Hamamatsu Photonics has been renewed for 5 years from 2019 to 2023.

The University of Tokyo is committed to maintain the excellent research environment for the Kavli IPMU to function as a world premier leading institute.

Appendix 1-1 List of Principal Investigators (for Progress Plan)

* If the number of principal investigators exceeds 10, add rows as appropriate.
* Give age as of 1 April 2022
* For investigators who cannot participate in the center project from FY 2022, indicate the time that their participation will start in the "Notes" column.
* Enter the host institution name and the center name in the footer.

	Name	Age	Current affiliation (position title, organization, department)	Academic degree and current specialties	Effort(%)*	Notes (Enter "new" or "ongoing")
1	Hirosi Ooguri	60	Director Kavli IPMU, UTIAS, The Univ. of Tokyo Director and Fred Kavli Professor Walter Burke Institute for Theoretical Physics California Institute of Technology	Ph.D. Theoretical Physics (Mathematical Physics)	50	ongoing
2	Hiroaki Aihara	66	Deputy Director Kavli IPMU, UTIAS, The Univ. of Tokyo Executive Director and Vice President The Univ. of Tokyo	Ph.D. Experimental Physics (High Energy Physics)	30	ongoing
3	Alexey Bondal	60	Professor Steklov Mathematical Institute Project Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	40	ongoing
4	Kentaro Hori	56	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Theoretical Physics (String Theory)	80	ongoing
5	Kunio Inoue	56	Professor, Director Research Center for Neutrino Science, Tohoku University	Ph.D. Experimental Physics (Neutrino Physics)	45	ongoing
6	Takaaki Kajita	63	Director, Professor ICRR, The Univ. of Tokyo	Ph.D. Experimental Physics (Neutrino Physics)	10	ongoing
7	Mikhail Kapranov	59	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	100	ongoing

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

	Name	Age	Current affiliation (position title, organization, department)	Academic degree and current specialties	Effort(%)*	Notes (Enter "new" or "ongoing")
8	Stavros Katsanevas	68	Professor, Université Paris Denis Diderot Director, European Gravitational Observatory	Ph.D. Astroparticle Physics	10	ongoing
9	Masahiro Kawasaki	61	Professor ICRR, The Univ. of Tokyo	Ph.D. Theoretical Physics (Cosmology)	40	ongoing
10	Young-Kee Kim	59	Louis Block Distinguished Service Professor Dept. of Physics, University of Chicago	Ph.D. Physics	10	ongoing
11	Toshiyuki Kobayashi	59	Professor Graduate School of Mathematical Sciences, The Univ. of Tokyo	Ph.D. Mathematics	30	ongoing
12	Toshitake Kohno	66	Professor School of Interdisciplinary Mathematical Sciences Meiji University	Ph.D. Mathematics	40	ongoing
13	Eiichiro Komatsu	47	Director Dept. of Physical Cosmology, Max Planck Institute for Astrophysics	Ph.D. Theoretical Physics (Cosmology)	20	ongoing
14	Kai Uwe Martens	58	Associate Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Experimental Neutrino Physics, Dark Matter Direct Detection	80	ongoing
15	Shigeki Matsumoto	49	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Theoretical Physics (Cosmology)	80	ongoing
16	Shigetaka Moriyama	52	Professor Kamioka Observatory, Institute for Cosmic Ray Research, The Univ. of Tokyo	Ph.D. Experimental Physics (Neutrino Physics)	20	ongoing

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

	Name	Age	Current affiliation (position title, organization, department)	Academic degree and current specialties	Effort(%)*	Notes (Enter "new" or "ongoing")
17	Hitoshi Murayama	58	MacAdams Professor of Physics and Center for Japanese Studies, University of California, Berkeley Professor, Principal investigator Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Particle theory, Cosmology	20	ongoing
18	Masayuki Nakahata	62	Professor Kamioka Observatory, Institute for Cosmic Ray Research, The Univ. of Tokyo	Ph.D. Astroparticle physics	40	ongoing
19	Hiraku Nakajima	60	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	35	ongoing
20	Mihoko Nojiri	59	Professor Institute of Particle and Nuclear Studies , High Energy Accelerator Research Organization	Ph.D. Theoretical Physics (Particle Theory)	20	ongoing
21	Yasunori Nomura	48	Director, Berkeley Center for Theoretical Physics, Univ. of California, Berkeley Professor, Dept. of Physics, Univ. of California, Berkeley Senior Faculty Scientist, Physics Division, Lawrence Berkeley National Laboratory	Ph. D. Theoretical Physics (Particle Theory)	15	ongoing
22	David Spergel	61	Emeritus Professor Department of Astrophysical Sciences, Princeton University Director, Center for Computational Astrophysics, Flatiron Institute	Ph.D. Cosmology	40	ongoing
23	Naoshi Sugiyama	60	Vice President Director Professor Graduate School of Science Nagoya University	Ph.D. Cosmology	30	ongoing

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

	Name	Age	Current affiliation (position title, organization, department)	Academic degree and current specialties	Effort(%)*	Notes (Enter "new" or "ongoing")
24	Masahiro Takada	48	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Astronomy	80	ongoing
25	Tadayuki Takahashi	62	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Experimental Physics	80	ongoing
26	Yukinobu Toda	42	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. Mathematics	80	ongoing
27	Mark Robert Vagins	56	Professor Kavli IPMU, UTIAS, The Univ. of Tokyo	Ph.D. High Energy Physics	80	ongoing
28	Naoki Yoshida	48	Project Professor, PI Kavli IPMU, UTIAS, The Univ. of Tokyo Professor Department of Physics, The Univ. of Tokyo	Ph.D. Cosmology	40	ongoing

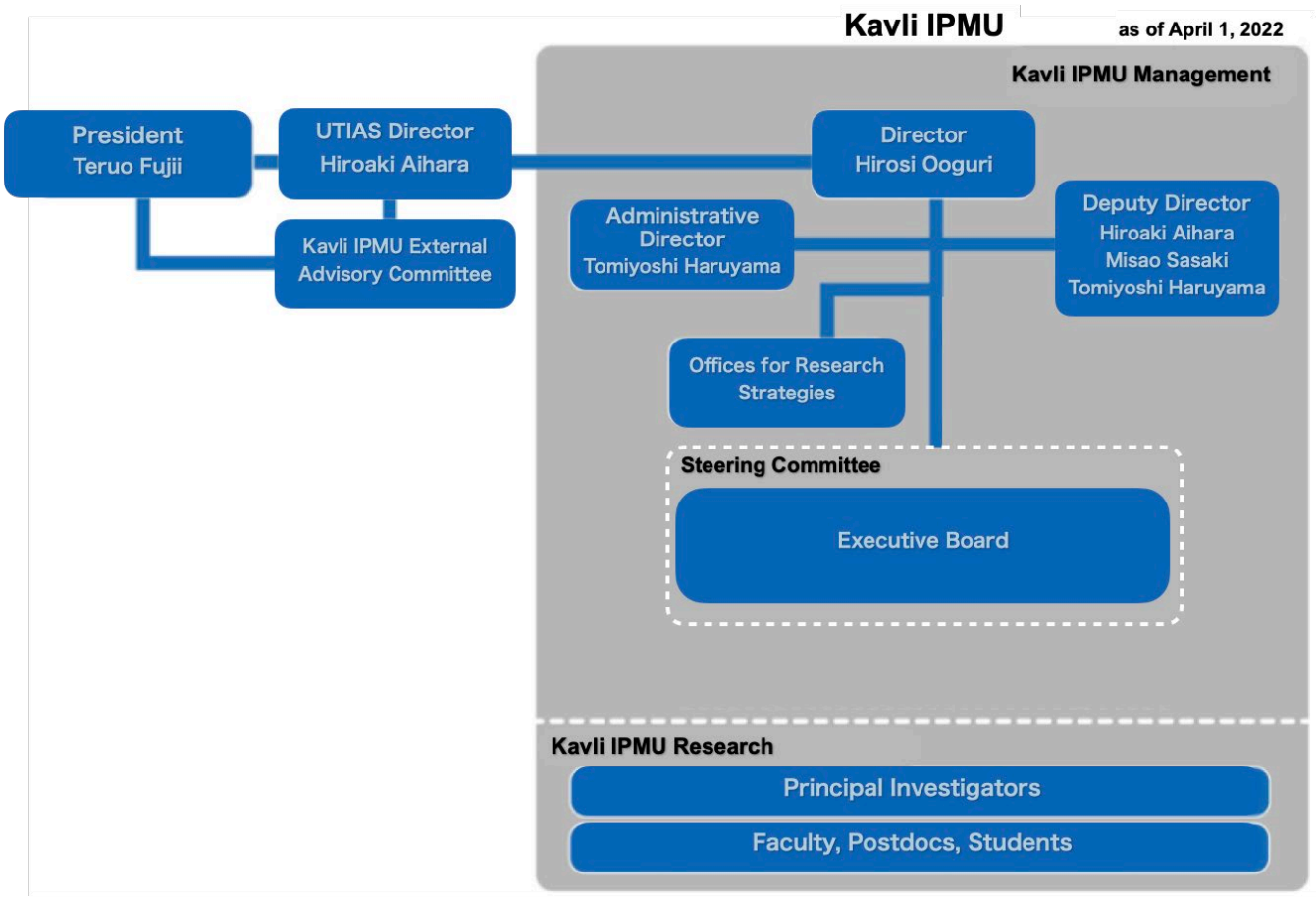
*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

Number of Center Personnel

			FY2022	
			Number of persons	%
Researchers			220	
	Overseas researchers		113	51
	Female researchers		26	12
	Principal investigators (PIs)		28	
		Overseas PIs	7	25
		Female PIs	2	7
	Other researchers		142	
		Overseas researchers	71	50
		Female researchers	14	10
	Postdocs		50	
		Overseas Postdocs	35	70
		Female Postdocs	10	20
Research support staffs			27	
Administrative staffs			9	
TOTAL			256	

Appendix 2　Diagram of Center Management System

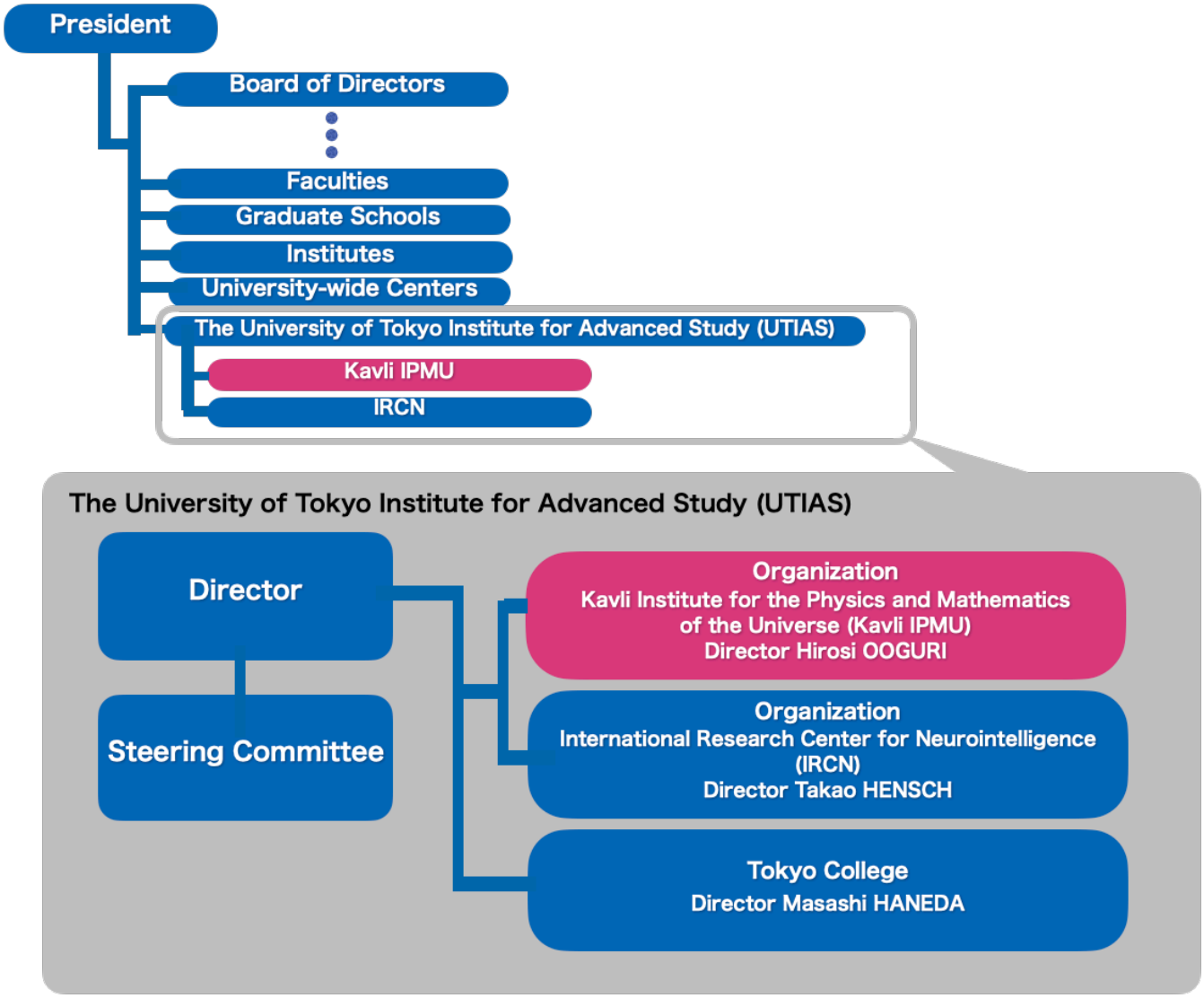
- Diagram management system after the funding period ends in an easily understood manner.
- If you are planning to change your organization management system and/or its position within the host institution in or after FY 2022 compared to their description in Appendix 3-1 of Activities report, show the changes in the diagram. Especially describe any important changes being planned in such as the center director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).



Appendix 3 Position of the Center within Host Institution

* Diagram the Center's position within the organization of the host institution, and describe that positioning using excerpts from the institution's mid- to long-term plan. If the plan has not been established yet, describe the consideration being given to the Center's positioning.

In March 2021, UTIAS (University of Tokyo Institute for Advanced Studies) approved that the Kavli IPMU will keep stay in UTIAS as the qualified research organization. The new President T. Fujii is now preparing the institution's mid-to long-term plan which will match to the Fourth Mid-term Target which will start in April 2022 for another 6 years.



Appendix 4. Resource Allocation Plan for Sustaining and Advancing the WPI Center

Annual Plans (FY 2022 – FY 2026)					
<Fund >					**(million Yen)**
Fiscal Year	**2022**	**2023**	**2024**	**2025**	**2026**
- Funding from host institution	1,582	1,582	1,582	1,582	1,582
(details)					
Personnel	1,276	1,276	1,276	1,276	1,276
Project activities	202	202	202	202	202
Travel	64	64	64	64	64
Equipment	15	15	15	15	15
Other research projects	20	20	20	20	20
Costs of Satellites	5	5	5	5	5
- Funding from external sources	300	300	300	300	300
Total	1882	1882	1882	1882	1882
<Personnel> **					**(person)**
Fiscal Year	**2022**	**2023**	**2024**	**2025**	**2026**
Total number of Personnel	158(158)	158(158)	158(158)	158(158)	158(158)
- PIs	18(18)	18(18)	18(18)	18(18)	18(18)
Full-time	12	12	12	12	12
Concurrent	6	6	6	6	6
- Other researchers	64(64)	64(64)	64(64)	64(64)	64(64)
- Postdocs	40(40)	40(40)	40(40)	40(40)	40(40)
- Research support staffs	27(27)	27(27)	27(27)	27(27)	27(27)
RAs etc.	0(0)	0(0)	0(0)	0(0)	0(0)
- Administrative staffs	9(9)	9(9)	9(9)	9(9)	9(9)

- Use yen (¥) when writing monetary amounts. If an exchange rate is used to calculate the yen amount, give the rate.
- When entering amounts, round down numbers to the first decimal.
- When funding is stated in a range between two amounts, explain the reason for the lower and upper amounts and fluctuations between them.

** When the host institution covers the expense, enter the amount in parentheses.

In this table, numbers in personnel are UTokyo employed person only. Affiliates in foreign and other institutes are not included.

< Measures to be implemented from FY 2022>

– Strategy and action plan for allocating personnel (posts) , space, and others measures required for the Centers' Progress.

The Kavli IPMU has already secured 26 permanent positions for the core of faculty to guarantee excellent activities of the Kavli IPMU as it is. Most positions are assigned to core faculty. The University secured also 9 UTokyo permanent administrative staff. In addition, by the university's decision, termed administrative staff are getting permanent status. It means that the many supporting staff for the foreign researchers can stay in the Kavli IPMU. The loan for the main building has already completed and three rooms at the second complex building are free for us. It is essential to acquire external funding to keep and strengthen the challenging research activities of the Kavli IPMU after the extension terminates. Before ending the WPI support, UTokyo took an action to the Kavli Foundation to boost the endowment. Additional $10M endowment increase was successfully achieved. In addition, Hamamatsu Photonics donation has been renewed for 5 years from 2019 to 2023. The University will continuously guarantee to maintain good research environment to achieve scientific output as the world premier leading institute. Established system reform, such as joint appointment, tenure-track position, global brain circulation and so on, will be promoted further for Kavli IPMU and the related University faculty.