World Premier International Research Center Initiative (WPI)
FY 2018 WPI Project Progress Report

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

Common instructions:
* Unless otherwise specified, prepare this report based on the current (31 March 2019) situation of your WPI center.
* So as to execute this fiscal year's follow-up review on the "last" center project plan, prepare this report based on it.
* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.
* Prepare this report within 10-20 pages (excluding the appendices, and including Summary of State of WPI Center Project Progress (within 2 pages)).

Summary of State of WPI Center Project Progress (write within **2 pages**)

H. Ooguri succeeded H. Murayama as the second Director of Kavli IPMU on Oct 15, 2018.

Research Highlights

This is our second report from the 5-year extension period of the WPI funding, for which we have added 9 new challenges. Here let us first summarize research highlights in accordance with their relevance to the 4 new challenges directly related to research.

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

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. In 2018, they developed the "Dark Emulator" that outputs statistical quantities and spatial clustering of galaxies needed for cosmological parameter inference with weak gravitational lensing observation. The emulator is based on modern statistical techniques, such as Gaussian process and principle component analysis, as well as a large simulation database. It has already been used in several publications by the HSC collaboration. They have also developed a deep-learning method based on generative adversarial networks to reduce the noise in gravitational lensing measurements.

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

An agreement (2017-2020) has been made between the Kavli IPMU and ISAS/JAXA to transfer hard X-ray and gamma-ray imaging technology to nuclear medicine and to set up a new laboratory at the Kavli IPMU for detector R&D. We also established an agreement between the Kavli IPMU and National Cancer Center and have started in-vivo imaging experiments of small animals using a variety of radio-isotopes. For this research, JSPS Kakenhi (Grant-in-Aid for Scientific Research on Innovative Areas, PI. T. Takahashi) has been granted.

(3) Discover new major framework for geometric thinking in mathematics and physics with the derived and non-commutative geometry, such as to unify various types of dualities:

Our mathematicians have made substantial progress in using derived and non-commutative geometry as a new major framework for geometric thinking in mathematics and physics. Y. Toda has developed new concepts of d-critical (i.e., derived critical) loci and flips. This has allowed him to extend several fundamental results of birational geometry, such as wall-crossing equivalences, to a broad class of derived moduli spaces important in physics. One of the tools to study wall-crossing has been the cohomological Hall algebra (COHA), but its precise definition was restricted to quiver-like situations. M. Kapranov, jointly with E. Vasserot, defined and studied COHA for algebraic surfaces, based on ideas of derived geometry. F. Sala, with M. Porta, gave a direct definition of the K-theoretical version using derived moduli spaces. The work of W. Donovan and T. Kuwagaki extended the homological mirror symmetry, originally an equivalence of derived categories, to a certain class of perverse schobers. The latter are natural systems of derived categories analogous to perverse sheaves, introduced earlier by M. Kapranov and V. Schechtman.

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

・The Hyper Suprime-Cam team has measured how cosmic structures including dark matter have evolved as a function of cosmic time using gravitational lensing effects, and determined the parameter of clumpiness of the Universe today with the world's highest-level precision. The construction of the Prime Focus Spectrograph instrument is well underway to start science operation in 2022. All 2550 fiber positioners "Cobra", as well as all science-grade detectors, have been delivered to Hawaii and the team is now carrying out various tests, including image quality and thermal performance.

・XMASS-I detector has been completed, and the xenon has been safely recovered. Seven papers were submitted and five published in 2018. Machine learning has been used for event classification to discriminate events from the detector's inner surface contaminating data sets. The Kavli IPMU is leading the Japanese participation in the XENON1T detector's impending upgrade to XENONnT.

・T2K released new oscillation results at a KEK colloquium in January 2019. These results disfavor CP conservation at the 95% confidence level. Oxford/Kavli IPMU graduate student T. Vladisavljevic has completed his thesis work to update the T2K flux calculation with replica target data collected by the

NA61/SHINE experiment. With his work, the uncertainty on the T2K flux calculation has been reduced from 10% to 5%.

・CMB experiments have been actively led by the Kavli IPMU team. POLARBEAR2 reached to the first light in December 2018. Simons Observatory finished the design review and is now in fabrication phase. LiteBIRD finished Pre-phaseA2 and is in process of down-selection with its outcome in 2019.
・Belle II completed detector construction, where the Kavli IPMU team successfully produced outermost layer devices of SVD, and started data taking in March 2019.

Scientific research progress

During the calendar year (CY) 2018, 403 papers were published (519 when including WPI-related). Over the past 5 years, we have consistently produced a large number of scientific papers: 165 (380) in CY2013, 315 (452) in CY2014, 349 (466) in CY2015, 353 (450) in CY2016, and 306 (392) in CY2017. Among the WPI papers published in CY2018, the rate of highly cited “top 1% of papers” is 37 (7.1%) based on the Web of Science by Clarivate Analytics. The impact factor for all of our refereed papers published from the institute’s inception to Dec 2018 are as follows: the average number of citations per paper is 29.6; 169 papers have over 100 citations and 517 over 50 citations in which review papers are excluded. The fraction of CY2018 papers with international collaboration reached 81%. Kavli IPMU members also received 16 valuable prizes/awards and honorary titles during FY2018.

Interdisciplinary studies

Among 216 seminars and colloquia in FY2018, interdisciplinary ones were as follows: 83 math-string (MS) seminars and 103 astronomy-particle physics-experimental physics-cosmology (APEC) seminars. T. Takahashi, a new PI in the Kavli IPMU, is a leading astro-particle physicist developing hard X-ray and gamma ray detectors in satellite and rocket experiments. He started a new collaboration with JAXA/ISAS and Keio University School of Medicine to apply his detector technology to biomedical research. H. Ooguri’s paper on de Sitter swampland conjecture has made a large impact on cosmology and became the most cited paper in high energy theory in 2018.

Globalization

The ratio of non-Japanese members among all of researchers at the Kavli IPMU is 49%. During FY2018, we had 1025 (1261) visitors (the numbers in the parentheses count multiple visits), 560 (632) of which were international. We hosted 21 conferences and workshops, where 436 were from foreign institutions among 994 participants. We have also provided leadership opportunities for non-Japanese members also. For example, K. Martens has been appointed as the new Director of our Kamioka Branch. This has been made possible thanks to bilingual administrative staffs. A joint proposal “Higher algebraic structures and their concrete” between the Kavli IPMU and Hamburg University for student exchanging program is being prepared. The Kavli IPMU has signed three new research agreements with the Johns Hopkins University together with the Institute for Solid State Physics, Okinawa Institute of Science and Technology Graduate University and the National Cancer Center Japan together with the Institute of Physical and Chemical Research.

Organizational Reform

Our successful system reforms have now spread across the University. For example, the number of cross-appointments in UTokyo has become more than 90. In FY 2018, Prof. Y. Ito was cross-appointed between Nagoya University and M. Hartz was promoted to Associate Professor with cross-appointment between TRIUMF. Our system reforms have also spread to other research institutions, and there have been new cross-appointments between Kyoto University and MPI, and between KEK and Osaka University. Kavli IPMU administrative staff members developed a smartphone app and were awarded the Special Prize for Business Transformation from the UTokyo President. This is our sixth award, following 2008, 2013, 2015, 2016 and 2017. Administrative staff in other departments have started to emulate us, and to develop similar smartphone apps. Regarding ‘taking out walls between departments’, H. Yokoyama has been appointed as a research leader of Science Communication of UTokyo Bioethics Collaborative Research Organization, which was founded as a collaborative research organization made up of the multiple UTokyo departments.

Efforts to Secure the Center’s Future Development over the Mid- to Long-term

New Director H. Ooguri started a long term strategic planning exercise for the next 10 years, building on our achievements over the last 12 years. We have renewed leadership positions: H. Yokoyama is the first female member of our Steering Committee, K. Martens is the new Director of our Kamioka Branch, and A. Kusaka (cross-appointment between UTokyo and Lawrence Berkeley National Lab) is the new Director of our Berkeley Satellite.

Others

Former Director H. Murayama became a University Professor of the University of Tokyo and the Hamamatsu Professor of the Kavli IPMU. E. Komatsu organized a career event for prospective postdocs in physics. We also co-hosted a science career event for female students studying physics. N. Hirakawa, 2016 Artist in Residence at Kavli IPMU, was awarded the Excellence Award in the Japan Media Arts Festival organized by the Agency of Cultural Affairs for his art work inspired by his stay at the Kavli IPMU. This year’s Journalist in Residence, Bruno Martin, a reporter for the major Spanish newspaper El País, wrote a feature-length article for the paper about the Gadolinium project of the Super-Kamiokande detector. E. Komatsu, was a scientific advisor for a planetarium movie, “HORIZON”. Ooguri’s science movie “The Man from the 9 Dimensions,” has been translated into Spanish and German. H. Murayama and H. Ooguri have appeared in NHK TV programs.

* Describe clearly and concisely the progress being made by the WPI center project from the viewpoints below.
- In addressing the below-listed 1-6 viewpoints, place emphasis on the following:
  (1) Whether research is being carried out at a top world-level (including whether research advances are being made by fusing fields).
  (2) Whether a proactive effort continues to be made to establish itself as a "truly" world premier international research center.
  (3) Whether a steadfast effort is being made to secure the center's future development over the mid- to long-term.

H. Ooguri, Fred Kavli Chair in Theoretical Physics and Mathematics and the Founding Director of the Walter Burke Institute for Theoretical Physics at the California Institute of Technology (Caltech), became the new Director of Kavli IPMU on Oct 15, 2018. H. Ooguri is a world-renowned scientist both in physics and mathematics, and is a recipient of the inaugural Leonard Eisenbud Prize for Mathematics and Physics, awarded by the American Mathematical Society. In 2018, he also received the Hamburg Prize in Theoretical Physics. He has extensive leadership experiences as the Founding Director of the Walter Burke Institute for Theoretical Physics at Caltech and the President of the Aspen Center for Physics. He initiated a long-term strategic planning exercise for the next 10 years, building on our achievements and current scientific activities.

This is our second report from the 5-year extension period of the WPI funding. In addition to the five major questions that we proposed to address in our original plan 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 framework for geometric thinking in mathematics and physics with the derived and non-commutative 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 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.

1. Advancing Research of the Highest Global Level

* Among the research results achieved by the center, concretely describe those that are at the world's highest level. In Appendix 1, list the center's research papers published in 2018.
* Regarding the criteria used when evaluating the world level of center, note any updated results using your previous evaluation criteria and methods or any improvements you have made to those criteria and methods.

The Kavli IPMU aims at establishing a multi-disciplinary research institute with the unifying goal of understanding five fundamental questions about the Universe: how it started, 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 from the synergistic perspectives of physics, mathematics, experimental physics, and astronomy. Below we describe the research progress in 2018 related to each question.

How did the Universe start?

Early universe and dark energy: C. Han, S. Pi, and M. Sasaki discovered that if the quintessence field that explains dark energy of the universe is coupled to the Higgs potential, the Higgs-driven vacuum instability that would contradict inflation in the early universe can be saved. Interestingly enough,

the coupling that saves the instability supports the Swampland Conjecture recently proposed by H. Ooguri and C. Vafa.

Primordial black holes and gravitational waves: R.G. Cai, S. Pi, and M. Sasaki showed that if primordial black holes, which are produced from large curvature perturbations from inflation, are the dark matter of the universe, the induced gravitational waves from those curvature perturbations will be detected by the future space gravitational wave observatory LISA, no matter how large or small the non-Gaussianity of the curvature perturbation is. Conversely, the non-detection of such gravitational waves will place a robust, stringent constraint on the primordial black hole scenario.

The international team, led by graduate student H. Niikura, M. Takada, and N. Yasuda, carried out a microlensing search of stars in the Andromeda galaxy (M31) due to primordial black holes (PBHs) using the 2 min dense Subaru/Hyper Suprime-Cam (HSC) data over a period of 7 hour-long observation (one Subaru night) [Nature Astronomy, in press 2019]. PBHs could be formed in the early universe as initially claimed by S. Hawking, and are a viable candidate of dark matter. Thanks to the 8.2m wide field-of-view and 8.2m aperture of HSC/Subaru, the team was able to simultaneously monitor about 90 million stars in M31 and detect more than 15000 candidates of variable stars. If PBHs make up all dark matter that exist in between Subaru (Earth) and M31, the team expected about 1000 microlensing events in the HSC M31 data. However, they found only one possible microlensing candidate. In other words, the team obtained the world-record, most stringent upper bound on the abundance of PBHs in the mass range, $M_{PBH}=[10^{-11},10^{-6}]M_{sun}$; PBHs can contribute no more than 0.1 per cent of all dark matter mass.

CMB experiments (POLARBEAR2, Simons Observatory, LiteBIRD): 4 faculties, 6 postdocs, and 7 students are actively leading the POLARBEAR2, Simons Observatory, and LiteBIRD. POLARBEAR2 has deployed at the Atacama Desert in Chile and reached to the first light in December 2018. One of the responsibilities at the Kavli IPMU is to develop a relative gain calibration hardware. It is in progress of being integrated to the rest of the telescope in Chile. The commissioning phase continues and the team is pushing hard to reach the nominal CMB observational mode this year. Collaboration of POLARBEAR2 with Subaru Hyper-Suprime Cam (HSC) is on-going and a scientific paper has been submitted. The team working on Simons Observatory has gone the design review. After the successful review, it is now in the fabrication phase and various parts of the optics tube for Small Aperture Telescope are arriving to be tested. The Kavli IPMU is in charge of the cryogenic assembly test and millimeter wave optical characterization. LiteBIRD finished the Japan Aerospace Exploration Agency's (JAXA) Institute of Space and Astronautical Science (ISAS) Pre-phaseA2. The Kavli IPMU was in charge of developing the polarization modulator and calibration. After the extensive development, the modulator has reached the technological readiness level of 4 by the end of the phase, and we passed the review successfully. LiteBIRD is in the process of the down-selection, and we shall know the outcome of the selection in 2019 [(4) of 9 challenges].

What is the Universe made of?

Particle phenomenology: Particle phenomenological researches at FY2018 reflected more diversity than previous years. For instance, S. Matsumoto, S. Shirai and M. Takeuchi proposed new strategies to search for dark matter at a hadron collider such as LHC and FCC-hh (JHEP1806, 049, 2018 and JHEP1903, 076, 2019), which make use of the precision measurement of lepton production cross sections. T. Melia proposed novel strategies (e.g. leveraging gravitational wave detectors) for the direct detection of 'blobs' of dark matter (PRD98, 15020, 2018) within a variety of existing and upcoming experiments, such as liquid xenon and solid-state dark matter detectors, gravitational wave detectors (LIGO, atomic interferometers) and spin precession set-ups (CASPEr). N. Barrie proposed a new non-thermal Leptogenesis mechanism that takes place during the reheating epoch, utilizing an analogue to the well-known forced pendulum (PLB785, 184, 2018). The model successfully reproduces the observed baryon asymmetry, while simultaneously providing an origin for neutrino masses via the seesaw mechanism. S. Ge proposed with T. Yanagida and A. Kusenko an improved version of anarchy models assisted by residual $S^R_3 \times S^L_3$ symmetries (PLB781, 699, 2018), and studied the dimension-8 gluonic Quartic Gauge Coupling (QGC) operators for the first time (PRL121, 041801, 2018) with J. Ellis.

The early Universe was filled with a hot plasma of the Standard Model particles. The thermodynamic quantities, such as energy, entropy and pressure, of the Standard Model gas played a crucial role in the evolution of the Universe. The Standard Model particles were never free particles, but either strongly or weakly interacting with each other. Moreover, there were QCD and electroweak phase transitions in the early Universe. These features provide non-trivial corrections to the thermal properties of the Standard Model. K. Saikawa and S. Shirai revisited the thermodynamics of the Standard Model, based on the latest non-perturbative lattice calculations on the QCD and electroweak phase transition and the results of the perturbative estimations (JCAP 1805, 035). They updated thermodynamic properties of the Standard Model in the early Universe and estimated its uncertainties. They studied the impact of their result on the spectrum of primordial gravitational waves. In this estimation, they have also included several non-thermal effects overlooked in the literature. They found these corrections affect the spectrum by O(1-10)%, compared to previous studies. The thermodynamics of the Standard Model affects the estimation of all the cosmological quantities in the early Universe, such as dark matter and baryon abundance. They found the impact of the present corrections are much greater than the current experimental uncertainties. Their result has been adopted for the analysis by the Planck Collaboration.

XMASS: Data taking with the XMASS-I detector was successfully completed at 09:00 JST on February 20, 2019 after accumulating a total of 1639 days of good data with full waveform information. A campaign where the XMASS collaboration spiked the liquid xenon in the detector with ^{222}Rn to collect high statistics of tagged beta decays in its decay chain concluded their use of the XMASS-I detector. The xenon has since been removed from the detector and put into secure storage, and detector operation with its associated shifts was terminated. During FY2018 two technical papers were published: One on the scintillation decay time constant from nuclear recoils in liquid xenon in the Journal of Instrumentation, and one on the XMASS-I low radioactivity photomultiplier tubes in Nuclear Instruments and Methods A. On the data analysis side, a significant number of papers came to fruition in FY2018, starting with an updated annual modulation analysis using 2.7 years of data published in Physical Review D. An update of their 2-neutrino double electron capture results appeared in the journal PTEP. Their hidden photon and axion-like particle dark matter limits were published in Physics Letters B, as was their search for dark matter in the fiducial volume at the center of the XMASS-I target mass, which yielded the most stringent upper limit for the spin-independent WIMP-nucleon cross section from a single-phase liquid xenon detector to date. A search for sub-GeV dark matter by annual modulation is under review at the same journal, and one for WIMP inelastic scattering on ^{129}Xe at Astroparticle Physics. Further analysis will continue to optimally exploit the accumulated XMASS-I data [(4) of 9 challenges].

XENONnT: XENONnT is designed to detect possible WIMP Dark Matter interactions with the xenon nuclei in the target mass down to cross sections of a few times 10^{-48} cm^2 for a 50 GeV/c^2 WIMP. FY2018 was a big year for the Japanese groups in the XENON collaboration. At the September collaboration meeting in Coimbra, Portugal, the collaboration accepted their proposal to use Kamioka's EGADS technology to implement the neutron veto surrounding the cryostat that will contain XENONnT's liquid xenon time projection chamber. This neutron veto is a vital new component in the detector upgrade from XENON1T to XENONnT, and their technology will allow them to build it without using a liquid scintillator. The Laboratori Nazionali del Gran Sasso in Italy, where its predecessor XENON1T stopped taking data in December 2018 so that the collaboration could start the upgrade to XENONnT, has warmly embraced this effort to build an efficient neutron veto without liquid scintillator. From FY2019 Kavli IPMU's K. Martens is the PI on a four-year JSPS Kiban A grant to implement the Kavli IPMU (M. Vagins)/Kamioka (SK-Gd&EGADS) technology at XENONnT. During Japan's "probation period" in the collaboration, from being admitted in December 2017 through the end of 2018, K. Martens was Japan's sole representative on the XENON collaboration board; since January of this year he is joined there by representatives also of the other Japanese institutions working together on XENONnT. The Japanese contribution to XENONnT hardware does not stop with the neutron veto. XMASS experience in liquid xenon purification is also brought to bear at XENONnT, where Kavli IPMU affiliate member M. Yamashita from ICRR, UTokyo, is convener for the liquid purification effort in the experiment. Kavli IPMU PI S. Moriyama holds another JSPS Kiban A grant for our purification effort at ICRR. Through this solid, Kamioka based cooperation within UTokyo between the Kavli IPMU and ICRR on XENONnT and the Kyodo-Riyo based inclusion of our old XMASS colleagues at Kobe University and Nagoya University, Japan has quickly earned the

respect of the XENON collaboration and contributes to crucial components of the detector upgrade to XENONnT. [(4) of 9 challenges].

What is the fate of the Universe?

SuMIRe (HSC and PFS): SuMIRe (Subaru Measurement of Image and Redshifts) is a large-scale international survey project aiming at uncovering the origin and future of the universe led by the Kavli IPMU. A wide-field imaging camera Hyper Suprime-Cam (HSC), the new 900M-pixel digital camera for Subaru Telescope, is one of the two subprojects of SuMIRe. An international team including scientists in Japan, Taiwan and Princeton University has been carrying out a large-scale imaging survey of the sky with the Subaru HSC since 2014. The Kavli IPMU contributed to more than a half of the HSC instrument, including the wide-field corrector lens, precision mechanical control, and some of the filters, on top of leading the science team. The team, led by C. Hikage and M. Oguri, used multi-color data from the first two years over 137 sq. deg. of the sky to carry out a high-precision measurement of cosmic weak lensing power spectra [PASJ, in press 2019]. By combining the cosmic weak lensing power spectra with photometric redshifts of galaxies that give approximate distances to each galaxy, the team measured 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% precision that characterizes clumpiness of the Universe today. Compared to Planck cosmic microwave background constraints, our results prefer slightly lower value of S_8 similarly to what have been indicated by other weak lensing experiments such as Dark Energy Survey in US and Kilo-Degree Survey (KiDS) in Europe. This inconsistency might indicate new physics beyond the concordance ΛCDM model such as time-evolving dark energy. The HSC team will continue to explore a higher-precision measurement of the cosmological parameter with more HSC data as well as by combining the HSC weak lensing measurements with spectroscopic galaxy data from the Sloan Digital Sky Survey (SDSS) over the overlapping regions of the sky.

On the other hand, we also have made progress in another subproject of SuMIRe, a wide-field multi-object spectrograph, Prime Focus Spectrograph (PFS), aimed at making the spectroscopic follow-up of HSC images. This project is being led by H. Murayama as the principal investigator (PI), the science group co-leader M. Takada, and the project manager N. Tamura, all from the Kavli IPMU. It involves an interdisciplinary group that consists of physicists, astronomers, and instrumentalists from the Academia Sinica Institute for Astronomy and Astrophysics (ASIAA, Taiwan), the California Institute for Technology (Caltech), NASA Jet Propulsion Laboratory (JPL), Princeton University, Johns Hopkins University (JHU), Laboratoire d'Astrophysique de Marseille (LAM, France), Universidad São Paulo, the Laboratório Nacional de Astrofísica (LNA, Brazil), the Max Planck Institutes for Astrophysics, and for Extraterrestrial Physics, the Chinese PFS Participating Consortium, and US North-East Participating Group. The construction of the PFS instrument is well underway. All 2550 fiber positioners "Cobra" have already been delivered to the site. The team at Caltech and JPL is integrating them into "Cobra modules", each of which consists of 57 Cobras to move the fiber tips to astronomical targets on the focal plane. All science-grade detectors in optical and infrared wavelengths were also delivered. The team is now carrying out various tests such as image quality and thermal performance at LAM and JHU. Kavli IPMU scientist, Y. Moritani, is leading the coordination and detailed planning of re-integration and test of the PFS subsystems at the Subaru Telescope observatory at the summit of Mauna Kea, and subsequent on-sky commissioning observations of the integrated PFS instrument. Another Kavli IPMU scientist, K. Yabe, is meanwhile leading the development of software tools to simulate spectra of astronomical objects expected with PFS, and to simulate a 300 Subaru-night PFS survey in detail including the planned science programs. We envision that we can start science operation in early 2022, spending more than or equal to 300 nights of Subaru telescope. The combination of HSC and PFS is unique in the world and will enable us to examine the nature of dark matter and dark energy, the evolution and origin of galaxies and the assembly history of the Milky Way, Andromeda Galaxy, and the Local Group as a whole [(4) of 9 challenges].

IGM/Large-Scale Structure: The intergalactic medium (IGM) tomography group led by Kavli IPMU assistant professor K.-G. Lee continued to develop the technique on multiple fronts. On the observational side, the pioneering CLAMATO (COSMOS Lyman-Alpha Mapping And Tomography Observations) Survey on the Keck-I telescope marked a unique scientific result: the farthest

detection of cosmic voids to-date, at a mean redshift of 2.3 compared to the z~1 that was previously attained with galaxy surveys. The void size distribution in the CLAMATO data appears consistent with the expectation from excursion set models, although more detailed analysis into the void profiles and multipoles will have to await the greater statistical power of future data sets. The first public release of CLAMATO data was also published in FY2018; several external groups have already started work on various projects using this unique data set. Kavli IPMU postdoc M. Ata, who joined in June 2018, has started work on reconstructing the density field from the various galaxy surveys in COSMOS in order to provide a comparison with the CLAMATO absorption map, which will yield unique insights into the thermodynamic history of the IGM. On the theory side, B. Horowitz, a visiting NSF/JSPS Fellow from UC Berkeley, has developed a constrained reconstruction algorithm shown to provide better recovery of the cosmic web observed in IGM tomography data than previous methods. Excitingly, this method allows us to model, across the entire cosmic history, the gravitational evolution of cosmic web structures observed in high-redshift (z~2-3) in IGM tomography data. The implementation of this method would, however, have to await larger data sets that can adequately sample sufficiently large volumes without aliasing the cosmic structures. These developments help push forward the case for the IGM tomography component in the upcoming Subaru Prime Focus Spectrograph, which is being designed in large part by Kavli IPMU faculty members K.-G. Lee and J. Silverman and will cover ~100x the volume of the existing CLAMATO data.

What are its fundamental laws?

Quantum Field Theory: Y. Tachikawa continued his research on quantum field theories, mainly concerning quantum anomalies, topological phases of matter, and their relevance to string theory. In a nutshell, a topological phase of matter necessarily supports a nontrivial system on its boundary, and the inconsistency of the boundary theory (i.e. its quantum anomaly) if formulated alone is canceled by the dynamics of the bulk topological phase. This new viewpoint, found by condensed-matter theorists, allows them to study the anomalies of systems which were hitherto impossible. One such example is the content of a collaboration between Y. Tachikawa and K. Yonekura (Kyushu U), where string theory objects called 'orientifolds' were analyzed carefully. Orientifolds have been known and used in various string theory constructions for decades, but it has been known to have an uncanceled anomaly at the same time, due to its fractional charge, which is against the standard Dirac quantization condition. In this collaboration, they found two overlooked contributions, which were found to cancel the known anomaly perfectly. Y. Tachikawa also gave an invited plenary talk in the autumn meeting of the Mathematical Society of Japan, explaining the general concept of quantum field theories to mathematicians.

In two papers "Gauge Theory and Integrability I/II" in collaboration with K. Costello and E. Witten, M. Yamazaki realized integrable field lattice models from four-dimensional analog of the Chern-Simons theory introduced previously by Costello. This solved a long-standing problem which had been around since the early 1990s of explaining spectral parameters in integrable models from a suitable quantum field theory. M. Yamazaki is currently working on an extension of the story to integrable field theory in collaboration with K. Costello.

String Theory: The Swampland question asks, given an effective theory of gravity, how one can judge whether it is realized as a low energy approximation to a consistent quantum theory with ultra-violet completion such as string theory. In 2018, H. Ooguri and C. Vafa, together with their students, formulated a new Swampland conjecture, which is now called the de Sitter conjecture, on the potential energy for scalar fields in a low energy effective action. Their paper made a large impact on cosmology and particle physics model building since it excludes quasi-stable de Sitter vacua in string theory. It became the most cited paper in high energy theory in 2018, according to the Inspire data base. H. Ooguri and C. Vafa, with E. Palti and G. Shiu, published a follow-up paper, where they refined the conjecture and show how it can be derived in asymptotic limits from the distance conjecture, which Ooguri and Vafa proposed in 2006.

M. Yamazaki organized several discussions sessions on the Swampland conjecture at the Kavli IPMU, and has already written three papers on the subject, all in collaboration with particle phenomenologists and cosmologists. In the first paper "Do We Live in the Swampland?" (JHEP1812, 032, 2018), co-authored with the ex-director H. Murayama and T. Yanagida, M. Yamazaki pointed

out the problems of the original de Sitter conjecture, in local minima for the Higgs and the axions, and discussed several possible loopholes and the theoretical/phenomenological constraints on these loopholes. This paper is now regarded as one of the foundational papers on the subject. After the new “refinement” of the de Sitter conjecture was proposed, M. Yamazaki, in collaboration with S. Shirai, H. Fukuda (both in particle phenomenology) and a cosmologist R. Saito, worked out the phenomenological consequences of the refined de Sitter swampland conjecture (arXiv:1810.06532 [hep-th]). This is the very first paper on this topic, and the authors derived interesting constraints on inflationary models. More recently, M. Yamazaki co-authored a paper on electroweak quintessence axion with T. Yanagida and M. Ibe (ICRR). They motivated the scenario by several swampland conjectures, and have discussed various observational constraints on the models. The validity of such a scenario could be probed in future measurement on the values of the equation-of-state parameter w, e.g. in HSC at Subaru telescope.

On a more formal development of string theory, K. Hori studied aspects of quantum anomalies in general and reviewed relevant facts on classifying spaces for principal bundles, as a preparation for extending the result that boundary degrees of freedom in two-dimensional gauge theories form flat projective representations of the gauge group to theories involving spinors, as well as for applying it in various set-ups. He also initiated the study of boundary conditions of 2d (2,2) supersymmetric gauge theories that preserve A-type supersymmetry, as a starting point for "homological Seiberg duality for A-branes."

Mathematics: M. Kapranov, jointly with B. Hennion, computed the cohomology of the Lie algebra of regular vector fields on an affine algebraic variety (arXiv:1811.05032). This was made possible by the use of techniques of factorization algebras. The result was conjectured by B. Feigin back in the 1990s but no proof had been found before. M. Kapranov, jointly with E. Vasserot, has found another application of factorization homology to cohomological Hall algebras of surfaces (arXiv:1901.07641). They found that these algebras possess a factorization structure and used this structure to describe the graded dimension of the algebra.

T. Kobayashi developed his mathematical program on branching laws of infinite-dimensional representations. He published two long papers (one 342 pages and the other 96 pages) this year among others: constructed and established a complete classification of conformally covariant, symmetry breaking operators for differential forms on the model space with B. Speh (Lecture Notes in Mathematics, Springer, 2018), and determined with F. Kassel the three ring structures of invariant differential operators on spherical varieties with hidden symmetries. Applications include topics on a generalized Gross-Prasad conjecture in automorphic forms, and analysis on locally pseudo-Riemannian symmetric spaces. Furthermore, he initiated with M. Pevzner a new line of investigation on "holographic transforms" in branching problems (arXiv:1812.09733).

T. Kohno studied a relation between homological representations of braid groups and the monodromy representations of Knizhnik-Zamolodchikov (KZ) connections based on solutions of the KZ equation expressed by hypergeometric integrals. He also investigated the case of resonance at infinity appearing in conformal field theory. He showed that the KZ equation is represented as a differential equation satisfied by period integrals for certain algebraic varieties, and is expressed as a Gauss-Manin connection.

H. Nakajima studied partial resolutions of singularities of Coulomb branches arising from flavor symmetry with Braverman and 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 also proposed a conjecture realizing geometric Satake correspondence for general Kac-Moody Lie algebras via Coulomb branches. This conjecture was proved for affine type A.

Y. Toda introduced the notions of d-critical flops, flips, as analogues of birational transformations for d-critical schemes, and showed that moduli spaces of stable objects on Calabi-Yau 3-folds are related by d-critical flops, flips, under wall-crossing of stability conditions (arXiv:1805.00182). Moreover, he showed the existence of fully-faithful functors between derived categories of coherent sheaves on stable pair moduli spaces, which gives a link between wall-crossing of

Donaldson-Thomas invariants and D/K conjecture in birational geometry (arXiv:1805.00183).

T. Abe constructed a certain 0-cycle containing information of ramification to describe ramification theory using a homotopy theoretic point-of-view. To construct this 0-cycle, we need successive modification of a given variety, and the hardest part is to show that this modification stops. For this, we used ideas of Kedlaya, and needed a deep analysis on Zariski-Riemann space. Next year, Abe plans to make the link with ramification theory clear using this 0-cycle.

T. Milanov worked in collaboration with J. Cheng in 2018. They focused on a certain type of Kac-Wakimoto hierarchies of type D. It is known that the total descendant potential of a simple singularity of type ADE is a tau-function of the so-called principal Kac-Wakimoto hierarchy. It is also known that the solutions to the Kac-Wakimoto hierarchy of D type are parametrized by the points of an infinite Grassmanian. The goal of their first project was to find the point in the infinite Grassmanian that corresponds to the total descendant potential. They solved the problem by characterizing the wave function of the corresponding point in the Grassmanian as an eigenfunction of a certain differential operator. The paper is available on arXiv:1804.07417 (submitted to IMRN). The second project was to construct an integrable hierarchy governing the Gromov-Witten invariants of a Fano orbifold line of type D. The answer can be given both in the form of a system of Hirota bilinear equations and a system of Lax equations. The details of their work will be outlined in two papers, which will be available soon on the arXiv.

All of the mathematical works are concerned with (3) of 9 challenges.

Why do we exist?

KamLAND-Zen: Neutrinoless double beta decay is one of the clues to solve the mystery: why is our Universe made of matter? Or why does almost no antimatter exist in our Universe? KamLAND-Zen is an experiment to search for neutrinoless double beta decay in Xenon 136 and its detector is located 1000m underground in the Kamioka mine. An international team led by K. Inoue (PI of the Kavli IPMU and also Director of the Research Center for Neutrino Science, Tohoku University) including A. Kozlov holds the world best limit for the effective Majorana neutrino mass and the limit excludes most of the degenerated mass hierarchy region. The team has successfully launched new experimental phase with doubled Xenon mass of 745 kg. The newly introduced container appeared to be 10 times cleaner with respect to the previous contamination level, and the fiducial volume can be 3 to 4 times larger than the previous phase. It will surpass the previously achieved world best sensitivity in about 6 months and will cut into the inverted mass hierarchy region where theoretical predictions by Yanagida's model and another Hamaguchi's model exist [(4) of 9 challenges].

T2K: The T2K experiment probes neutrino oscillation by studying the properties of neutrinos and antineutrinos produced at the J-PARC accelerator and detected 295 km away in the Super-Kamiokande (SK) detector. The main physics objective of T2K is to compare the rate of muon neutrino to electron neutrino oscillations with the rate of muon antineutrino to electron antineutrino oscillations. Observing a difference in the oscillation rates for neutrinos and antineutrinos would be the first evidence of CP violation in the lepton sector. The Kavli IPMU has been directly involved in the analysis of T2K data to make neutrino oscillation measurements, with M. Hartz serving as co-Analysis Coordinator, and B. Quilain serving as the leader of the Japanese oscillation analysis effort. With data collected through May 2018, T2K released new oscillation results at a KEK colloquium in January 2019. These results disfavor CP conservation at the 95% confidence level. The Kavli IPMU is also contributing to improvements in the oscillation analysis. Oxford/Kavli IPMU graduate student T. Vladisavljevic has completed his thesis work to update the T2K flux calculation with replica target data collected by the NA61/SHINE experiment. With his work, the uncertainty on the T2K flux calculation has been reduced from 10% to 5%. This new flux calculation will be used in T2K oscillation and neutrino cross section measurements starting in 2019. T2K will now shift focus to upgrading the experiment for future operation. In FY2019, budget for the upgrade of the J-PARC main ring power supplies was approved, and it is expected that this upgrade will be completed in FY2021. After completion of the upgrade, it will be possible to increase the beam power by a factor of two, allowing for faster accumulation of T2K data [(4) of 9 challenges].

Belle II: 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 of particle physics. The silicon vertex detector (SVD) for the Belle II experiment has a four-layer cylindrical structure, and each of the layers is comprised of ladder-like sensor arrays called “ladders”. A team led by T. Higuchi has been responsible to the mass production of 16 ladders, which make up the outermost SVD layer. By May 24, 2018, the team had successfully finished the ladder mass-production, creating 19 ladders, which took six years to make from the first R&D. The ladders were placed into the vertex detector (VXD) with the other ladders at KEK. An integrated system test of the finished VXD with cosmic rays had successfully shown a >99% charged-track finding efficiency. The VXD was installed into the Belle II detector in November. In parallel with the ladder mass-production, the Belle II detector confirmed the first electron-positron collision with a reduced-scale VXD (BEAST) on April 26, 2018. The other “first” collision meaning the first collision with all the Belle II sub-detectors installed was confirmed on March 25, 2019. Real data taking of Belle II has just started, and the team will elucidate the new physics in the Belle II data by continuing precise measurements of the CP-violating parameters, search for a long-lived particle, and other physics activities utilizing their deep experience in the experimental apparatus [(4) of 9 challenges].

EGADS: In FY2018 the most significant activity was the complete refurbishment of the Super-Kamiokande (SK) tank in preparation of loading gadolinium (Gd) following the successful demonstration of the necessary technology in EGADS. After some 3000 people-days of effort, the longstanding water leak in the SK tank was successfully repaired, a few hundred dead PMTs that had failed since the last in-tank work in 2006 were replaced, rust spots on detector surfaces were removed, and additional Gd-related plumbing was installed. The EGADS team led by M. Vagins now expect to add the first Gd to SK during FY2019. In the already Gd-loaded EGADS, they will continue water filtration studies and a hunt for neutrinos from galactic supernova explosions [(4) of 9 challenges].

2. Generating Fused Disciplines

* Describe the content of measures taken by the Center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields. If any, describe the interdisciplinary research/fused discipline that have resulted from your efforts to generate fused disciplines. You may refer to the research results described concretely in “1. Advancing Research of the Highest Global Level.”

Cosmology 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. In 2018, they developed the “Dark Emulator” that outputs statistical quantities and spatial clustering of galaxies needed for cosmological parameter inference with weak gravitational lensing observation. The emulator is based on modern statistical techniques, such as Gaussian process and principle component analysis, as well as a large simulation database. It has already been used in several publications by the HSC collaboration. They have also developed a deep-learning method based on generative adversarial networks to reduce the noise in gravitational lensing measurements [(1) of 9 challenges].

Physics and mathematics:

H. Ooguri, with D. Harlow, proved the long standing conjecture that quantum gravity has no global symmetry. Symmetry has been an important guiding principle in discovering fundamental laws of Nature and using them to describe physical phenomena. However, it has been claimed that any mathematically consistent theory to unify quantum mechanics and general relativity cannot have exact global symmetry, which acts non-trivially on physical states. The pair gave definite proof of this conjecture in the context of the AdS/CFT correspondence. Before their paper, the main argument for it was based on the counting of black hole microstates using the Bekenstein-Hawking entropy formula. This argument, however, was limited in several ways, and in particular did not exclude discrete global symmetries. They took a new approach and proved the conjecture in full generality by making use of the recently-discovered connection between the holographic principle in quantum gravity and the theory of quantum error correction, which is expected to play an important role in realizing fault tolerant quantum computation. Their work has also allowed proof of two other related conjectures about gauge symmetries in quantum gravity. They have published two papers, one with

a full proof in 175 pages, and another announcing the proof in 5 pages. The shorter 5-page paper will appear in a future issue of Physical Review Letters.

M. Yamazaki constructed an intriguing example of supersymmetry enhancement along renormalization group flow in three dimensions. This is in collaboration with former Kavli IPMU postdoc D. Gang, who is currently a postdoctoral fellow at the Korea Institute for Advanced Study. They provided three independent arguments for supersymmetry enhancement, and one of them uses the 3d-3d correspondence, a topic M. Yamazaki initiated in his 2011 paper with a mathematician Y. Terashima. In a paper in 2016, M. Yamazaki previously pointed out the relevance of the determinant formula for the parabolic Verma modules in the study of conformal bootstrap. M. Yamazaki subsequently derived a new determinant formula and irreducibility criterion for superconformal algebras, in collaboration with former Kavli IPMU postdoc Y. Oshima. In collaboration with a Kavli IPMU postdoc K. Sen, M. Yamazaki worked out in detail the irreducibility criterion to superconformal algebras, and worked out a complete list for the possible positions of the poles in superconformal blocks for all possible operators and for all superconformal algebras. M. Yamazaki has been studying the properties of the “lens-elliptic gamma function”, a special function introduced by him, F. Benini and T. Nishioka in 2011 in connection with supersymmetric gauge theories on lens space. This year M. Yamazaki and A. Kels, a postdoc at UTokyo in Komaba campus, formulated a novel generalization of the tau-function of the discrete elliptic Painlevé equation associated with the E8 root lattice, and found a solution with the E7-invariance. The proof uses in a crucial way the previous results by A. Kels and M. Yamazaki. This paper has been accepted and will appear in mathematics journal IMRN [(3) of 9 challenges].

T. Watari, a string theorist in the Kavli IPMU, published a paper in collaboration with S. Kondo, a mathematician and a faculty member at Middle East Technical University with an affiliated member at the Kavli IPMU. It addresses a question of whether modularity of arithmetic varieties has anything to do with modular invariance observed in string theory. To be more specific, they pointed out that the Hasse-Weil L-function of an elliptic curve with complex multiplication is given by the Mellin transform of chiral correlation functions of Type II string theory with the elliptic curve as the target space. For an elliptic curve with complex multiplication of a fixed complex structure, there are infinitely many arithmetic models. Infinitely many different choices of a metric on the elliptic curve as a target space of string theory make it possible to reproduce the L-functions of the infinitely many arithmetic models [(3) of 9 challenges].

T. Melia uncovered a new example of a particular mathematical duality—Howe duality—in physics. This arose in his research that targets a deeper mathematical understanding of effective field theory (EFT), for systematic application to LHC Phenomenology. It is intimately tied to a new geometric understanding of a physical manifold (Stiefel manifold) upon which all observables have support. The physics upshot: this can recast the approach of EFT through the lens of harmonic analysis, and paves the way to a ‘power spectrum’ (a la CMB) approach to LHC data. The discovery of the Stiefel manifold also led to applications in numerical Monte Carlo methods as applied to higher-order field theory calculations (e.g. precision calculations for the LHC), work performed with P. Cox (JHEP1812, 038, 2018). T. Melia co-organized three conferences/symposiums: Beyond the BSM (Gunma, Oct 2018; focused on interface of particle physics and cosmology), Berkeley Week (Kavli IPMU, Jan 2018; particle physics and cosmology, encouraged collaborative work between members of the Kavli IPMU and UC Berkeley physics department), and Visions for table-top dark matter experiments (Kavli IPMU, Feb 2018; cross-disciplinary between atomic molecular optics and particle physics) [(3) of 9 challenges].

Medical application of gamma-ray imaging: The life-saving capability of nuclear medicine stems from its highly sensitive ability of detecting the early stages of abnormal biological activity. Radioactive-labeled compounds, the compound delivery systems and the gamma-ray detection and imaging devices make up the vital technological components of nuclear medicine. A team led by T. Takahashi established an agreement between the Kavli IPMU and ISAS/JAXA for hard X-ray and gamma-ray imaging to transfer from space technology to nuclear medicine (2017-2020), and set up a new laboratory at the Kavli IPMU for detector R&D. JSPS Kakenhi (2018-2022: Grant-in-Aid for Scientific Research on Innovative Areas, PI. T. Takahashi) has been approved. They also established an agreement between the Kavli IPMU and National Cancer Center, and have started in-vivo imaging

experiments of small animals using a variety of radio-isotopes. The team consists of five members (one from the field of medicine and one from the field of engineering) and two more members, one from physics and one from pharmaceutical sciences, will be added. They organized an international workshop to discuss interdisciplinary approach of applying cutting-edge technologies at the frontier of cancer research in March 2019 [(2) of 9 challenges].

Science and Society: H. Yokoyama, Professor in Science Communication and Public Policy, and Y. Ikkatai study gender stereotypes that contribute to fewer women in physics and mathematics by focusing on social norms, images, and cultures. In 2018, the results of their study showed that many Japanese people share some gender biases that suggest certain academic fields are suitable for women, while others are not. More specifically, many people considered pharmacy and nursing to be suitable for women, but physics and mechanical engineering were suited to men. Interestingly, this tendency was found in people who have a lower level of egalitarian attitude towards gender roles. This research has been promoted as a project of RE-designing Science, Technology and Innovation Policy, SciREX (2017-2020), supported by the Japan Science and Technology Agency (JST) [(2) of 9 challenges].

Science and Art: A. Tsuboi, a staff member at the Kavli IPMU, and T. Kohno, Kavli IPMU PI and Professor of Mathematics, organized a symposium on art and mathematics with support from JSPS grant-in-aid. In addition to A. Tsuboi and T. Kohno, Y. Nomura (painter) and N. Hirakawa (media artist), who were both Artist in Residents at the Kavli IPMU, and M. Yamazaki (a string theorist at the Kavli IPMU) presented talks in a symposium [(2) of 9 challenges].

3. Realizing an International Research Environment

* Describe what's been accomplished in the efforts to raise the center's recognition as a genuine globally visible research institute, along with innovative efforts proactively being taken in accordance with the development stage of the center, including the following points, for example:
- Efforts being developed based on the analysis of number and state of world-leading, frontline researchers (in Appendix 2); exchanges with overseas entities (in Appendix 4); number and state of visiting researchers (in Appendix 5)
- Proactive efforts to raise the level of the center's international recognition
- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

FY 2018 was the second year of the 5-year extension of the WPI support to achieve the proposed 9 challenges. To realize (5) of these challenges, we retained the best and open-minded scientists from around the world. T. Takahashi and H. Nakajima were newly appointed as Principal Investigators (PIs), and total number of PIs has become 28. Among them, the number of on-site PIs increased to 11. All of our 28 Principal Investigators (7 non-Japanese: 25%) are world-leading scientists. T. Takahashi is a leading astro-particle physicist on developing hard X-ray and gamma ray detectors in satellite and rocket experiments. He 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 conducts research as a leader in a mathematical study of gauge theories, which have their origin in mathematical physics. H. Ooguri received the 2018 Hamburg Prize for Theoretical Physics. This was the first year the prize covers all areas of theoretical physics. His paper on de Sitter swampland conjecture had a major impact on cosmology and became the most cited paper in high energy theory in 2018. H. Murayama was appointed as a University Professor of UTokyo. M. Vagins has led the EGADS project, and the refurbishment work of the SK detector was successfully completed in January 2019 to apply the concept (SK-Gd). The SK resumed data taking with pure water, and is expecting the first Gd to SK during FY 2019. M. Takada is the leader of the HSC project, where fruitful scientific results continue to come out following the publication of the Publications of the Astronomical Society of Japan, which includes 40 new studies related to HSC observation. An international team, led by his group, ruled out the possibility that primordial black holes less than 0.1 mm make up dark matter, by carrying out microlensing search of stars in the Andromeda galaxy (M31). Other faculty members also play leading roles in each field and include PIs of big international projects such as Belle II, T2K, KamLAND-Zen, PFS, and LiteBIRD.

Kai Martens has been appointed the first Director of the Kamioka-branch. This demonstrates the fact that the Kavli IPMU has established a truly international environment and support system, where a foreign researcher whose first language is not Japanese can take such a leadership role.

A large fraction of our researchers is non-Japanese. Out of 279 member researchers including faculty, postdoc, affiliate members, and long-time visitors, 136 (49%) are non-Japanese. During FY 2018, we had 1025 (1261) visitors (the numbers in the parentheses count multiple visits). Among them, 560 (632) are international and many of them are world-class scientists. The Kavli IPMU has been keeping its activity as a key hub for exciting intellectual exchange.

The Kavli IPMU hosted 21 international conferences and workshops in a broad range of fields: mathematics, string theory, theoretical astronomy, cosmology, galaxies, high energy physics phenomenology, the Hyper-Kamiokande project, Belle II, and dark matter experiments. Among 994 participants in total, 436 were from foreign institutions. Holding conferences in the Kavli IPMU is important to raise our visibility in the international community and to show our leading roles in different fields.

Kavli IPMU researchers are mandated to spend 1 to 3 months in oversea institutes. This provides great opportunities for collaborative work, and raises the visibility of the Kavli IPMU achievements. Researchers presented more than 171 invited talks at both overseas and domestic institutions and conferences.

The Kavli IPMU signed 23 cooperative research agreements or memoranda of understanding (MOU). The agreement, initiated in 2016, with the Department of Physics at the University of Oxford for the purpose of the Kavli IPMU Oxford D.Phil. Fellowships is working effectively. In 2018, three new research agreements were signed with the Johns Hopkins University together with the Institute for Solid State Physics (ISSP), Okinawa Institute of Science and Technology Graduate University (OIST), and the National Cancer Center Japan together with the Institute of Physical and Chemical Research (RIKEN).

Several doctoral students in astrophysics or particle physics at U. Oxford are being supervised by faculty members of the Kavli IPMU, and are being provided the opportunity to conduct research in collaboration with Kavli IPMU researchers [(7) of 9 challenges]. The Kavli IPMU is also working with another international graduate program in physics (GSGC), which we hope will be extended to astronomy. Young students are becoming attracted to the Kavli IPMU. A group of UTokyo and Kavli IPMU faculty members, including Y. Kawahigashi (representative), T. Kohno, A. Bondal, M. Kapranov, I. Ueda, and Y. Yamazaki, are 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). The proposal includes exchange of several graduate students per year, aiming to start in FY 2021. Five members visited the Hamburg University to discuss the proposal, and a proposal from the German side was submitted in February 2019.

We recruit the brightest young people from around the world as postdoctoral researchers and provide them with the best research environment so that they can conduct outstanding research. In the winter of 2018, the Kavli IPMU received 728 applications for our postdoctoral positions including Kavli fellows and newly established KIAA-Kavli IPMU fellows. Nearly 90% of these applications were from abroad. In total, 12 new postdocs will arrive in FY 2019. The Kavli IPMU has been successful in mentoring postdoctoral fellows. Many of our former fellows are now at leading academic institutions. Out of 21 postdocs who left the Kavli IPMU in FY 2018, 8 assumed faculty positions, and 9 moved to other postdoctoral positions in universities or research institutes including KEK, Leiden Observatory, John Moores University in Liverpool, Mathematical Science Research Institute, Max Planck Institute (MPI), the Open University of Japan, Parma, Nanjing Normal University, Shanghai Jiao Tong University, UTokyo, Tohoku University, Nagoya University, Osaka University, NAOJ, and Tsinghua University. A total of 170 (64) postdocs who were hired (those hired by other sources) have left the Kavli IPMU since its establishment in 2007, out of which 87 (24) have assumed faculty positions.

To further raise the Kavli IPMU’s profile as a globally visible institute, online science news service such as EurekAlert!, AlphaGalileo and ResearchSEA have been used effectively to publicize our research activities to the world. It was initiated in 2014 and a number of international media coverages jumped from about 20 in 2013 to 143 in 2018.

4. Making Organizational Reforms

* If innovated system reforms generated by the center have had a ripple effect on other departments of the host institutions or on other research institutions, clearly describe in what ways.
* Describe the center's operation and the host institution's commitment to the system reforms.

A group of Kavli IPMU administrative staff members was awarded the UTokyo's 2018 Special Prize for Business Transformation from the President for the sixth time, following 2008, 2013, 2015, 2016 and 2017. The Kavli IPMU team developed and is running a smartphone app, which provides step-by-step information in English about how to take public transport from the international airport, how to find and ride the free shuttle bus to Kashiwa campus from the train station, and maps that show where individual researcher offices are. This has triggered administrative staff in other departments to start developing their own smartphone apps, further advancing system reforms.

The 2008 achievement for "web site to accept the foreign researchers in Kashiwa Campus" has already been requested to be adopted by administrative sections of many other faculties. The 2013 "thoroughgoing safety education by network distribution of education video and final quiz" has been requested to be adopted by the UTokyo environmental and safety research center in Kashiwa, Graduate school of Engineering UTokyo, Graduate school of Mathematical Science UTokyo and ICRR. The 2015 "language website to explain UTokyo's employee procedures for international researchers" has been used freely through the UTokyo website. The 2016 "Win-Win project towards University Globalization" has been requested by the UTokyo hospital medical administrative section and ICRR. The 2017 "E-learning for Sexual Harassment Prevention" video in English has been adopted as the official education course of the University Harassment Counseling Center [(6) of 9 challenges].

The Kavli IPMU has already achieved many reforms, including more flexible uses of tenure positions, merit-based salary system, "nenpo" system for permanent faculty members, Kavli endowment and naming. Our successful system reforms have now spread across the University, and are expected to produce ripple effects to other research institutions to help boost the overall competitiveness of Japan on a global scale. One of the successful ripple effects through the host institute has been cross-appointments. The number of cross-appointments in UTokyo totaled more than 90 so far. It was initiated at the Kavli IPMU; in FY 2018 Prof. Y. Ito was cross-appointed between Nagoya University and M. Hartz was promoted to Associate Professor with cross-appointment between TRIUMF. It has now spread over not only within UTokyo, but also to other research institutions, such as ones between Kyoto University and MPI, and between KEK and Osaka University.

Regarding 'taking out walls between departments', H. Yokoyama, Professor in Science Communication and Policy, is acting as a catalyst between the Kavli IPMU and the Interfaculty Initiative in Information Studies by accepting their PhD students. She has been appointed as a research leader of Science Communication of UTokyo Bioethics Collaborative Research Organization which is founded as a collaborative research organization made up of the multiple departments of the UTokyo through the reintegration and arrangement of existing projects, and as a structure to become a hub of social collaboration, education, and research concerning bioethics. The LiteBIRD team started to collaborate with a group at the Graduate School of Frontier of Science UTokyo, and also with a group at the Institute for Photon Science and Technology UTokyo led by President M. Gonokami. We are providing information to the newly established WPI institute, International Research Center for Neurointelligence (IRCN), in UTokyo based on our 11 years of experiences.

5. Efforts to Secure the Center's Future Development over the Mid- to Long-term

* Address the following items, which are essential to mid- to long-term center development:
- Future prospects with regard to the research plan, research organization and PI composition; prospects for the fostering and securing of next-generation researchers
- Prospects for securing resources such as permanent positions and revenues; plan and/or implementation for defining the center's role and/or positioning the center within the host institution's institutional structure
- Measures to sustain the center as a world premier international research center after program funding ends
- Host institution's organizational reforms carried out for the Center's autonomous administration simultaneously with the creation of the Center.

The positioning of the Kavli IPMU within UTokyo is quite clear. President Gonokami's 'Vision 2020' emphasizes the importance of "Expansion and Establishment of Internationally-renowned Bases for Research". An action to realize this vision 'Action 2020' has been set up to "establish and expand

upon internationally-renowned bases for research at UTokyo by carrying out such initiatives as advancing the development of both the University's strongest fields in which it is leading the world and unique areas of original research which should unwaveringly continue to be studied, promoting joint research and international collaboration that goes beyond the framework of UTokyo, and creating new, interdisciplinary knowledge that is the first of its kind in the world." As has already been declared by the President at the WPI Program Committee meeting in recent years, the President recognizes the Kavli IPMU perfectly matches his vision as a role model for the rest of the University. The Kavli IPMU enhances the value of the University, which enables the University to attract new revenues. It is reasonable for UTokyo to support the Kavli IPMU with top priority. We have made the effort to strengthen the University's financial base.

Based on this stance, UTokyo has put together a plan for the extension period and beyond. 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.

A new budget request in the period from FY 2019 to FY 2021 was ranked as No.1 in UTokyo, and a budget for the first year has been secured. This budget request is crucial to sustain the Kavli IPMU permanently, and we will keep making the request for the following two years. [(9) of 9 challenges]

Through an initiative by the new Director, the Long-Term Strategic Planning Committee was formed to discuss goals of the Kavli IPMU in the upcoming 10 years, expanding the achievements and current scientific activities of the Kavli IPMU (see below). Also, to achieve an inclusive and supportive environment for increasing diversities, the following new leaders were appointed: H. Yokoyama is the first female member of our Steering Committee; K. Martens is the Director of our Kamioka Branch; A. Kusaka, a researcher at LBNL and a PI of LiteBIRD, is the director of our Berkeley Satellite.

Our scientific projects are making great progress. HSC, one of the main projects in the Kavli IPMU, led by M. Takada has performed an analysis based on the first two years data and has made advances in research in many areas of astronomy and physics. Construction of PFS, a powerful tool for spectroscopy, has been in progress and we expect to start science operation in 2021. The Kavli IPMU has been the key institute of this international collaborative project. The renovation for Gadolinium-doped Super-Kamiokande (SK) project, SK-Gd, has been completed and data taking resumed at Kamioka with pure water; it is expected to collect some new supernova neutrinos in about two years. The dark matter research project XMASS has completed data taking, and the team has decided to join XENONnT project at Gran Sasso in Italy, where accumulated experimental expertise of XMASS will contribute to handling of xenon with radio-purification, and neutron veto. LiteBIRD is one of the projects on the MEXT Roadmap in Japan and the master plan of Science Council. The Kavli IPMU team is the main proponent, involved in developing cryogenic detectors and relevant equipment to verify the technical feasibility of LiteBIRD.

Regarding neutrino experiments, the Kavli IPMU is a part of the new 'Next-generation Neutrino Science Organization' together with ICRR, the Faculty of Science and the recently joined Earthquake Research Institute, to advance future experiments for neutrino research. This organization is based on the newly defined category for interdisciplinary research in UTokyo. To make our research directly beneficial to the society, we started a Gamma-ray imaging project for medical research. A new laboratory has been set up at the Kavli IPMU for detector R&D, and an agreement between the Kavli IPMU and National Cancer Center (NCC) was signed and a new laboratory at NCC has started in-vivo imaging experiments of small animals using a variety of radio-isotopes. This research brings advanced technologies of space instruments to bio-medical and drug research, and gives an impact on innovation of cancer research targeting within about three years. Collaboration and stimulation among fields of mathematics and theoretical physics will be strengthened in coming years.

Two new PIs were appointed and the total number of Principal Investigators increased to 28, enhancing the research area and activities. All of our 28 Principal Investigators (7 non-Japanese: 25%) are world-leading scientists.

6. Others

* Describe what was accomplished in the center's outreach activities in FY 2018 and how the activities have contributed to enhancing the center's "globally visibility." In Appendix 6, describe concretely the contents of these outreach activities. In Appendix 7, describe media reports or coverage, if any, of the activities.
* In addition to the above 1-5 viewpoints, if there is anything else that deserves mention regarding the center project's progress, note it.

In FY 2018, the Kavli IPMU accomplished various outreach activities, including the following which particularly contributed to enhance the globally visibility of the Kavli IPMU.

Convergence of Science and Philosophy (invited Professor M. Gabriel)

On 10 June 2018, 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 Gabriel and Kavli IPMU Principal Investigator Y. Nomura, and their discussion. Transcripts of these talks were published in the October 2018 issue of Japanese magazine "Gendai Shiso (Contemporary Philosophy)". On the following day, Gabriel and Y. Nomura took part in another event "Science and Metaphysics", co-hosted by the International Research Center for Neurointelligence of UTokyo. It was an academic event attended by students and faculty members. Gabriel also appeared in a TV program "Philosophy in the Age of Desire – Markus Gabriel in Japan" aired on NHK BS1 on July 15, 2018, part of which was his talk from the "Universe x World" event. He is planning to visit the Kavli IPMU again in the spring of 2020 to discuss with our scientific members, especially in connection with his new book project on the existence of the Universe.

Convergences of Science and Art (Kavli IPMU Artist in Resident N. Hirakawa receives Excellence Award in the Art Division of the 22nd Japan Media Arts Festival)

N. Hirakawa, who took part in Kavli IPMU's Artist in Residence program in 2016, was awarded the Excellence Award in the Art Division at the 22nd Japan Media Arts Festival organized by the Agency of Cultural Affairs for his piece "datum". Hirakawa's award-winning piece was conceived at the Kavli IPMU during his stay, when he discussed with our researchers on theoretical physics, in particular on string theory, and he was inspired by the notion of "dimensions." The award citation praises "its unique and original idea that came about by engaging with mathematicians and physicists working at the forefront of their research fields." "datum" is being exhibited at Tokyo's Mori Art Museum's "Roppongi Crossing" exhibition series from 9 February to 26 May, 2019. It will then be exhibited at Tokyo's Miraikan from 1 to 16 June, 2019, along with other prize-winning pieces.

Kavli IPMU researcher involved in development of planetarium program (Commemorative Event for "HORIZON: What lies beyond the edge of the Universe")

To celebrate the Tamarokuto Science Center's 25th anniversary in Tokyo, Kavli IPMU Principal Investigator E. Komatsu was invited to speak at their commemorative event on 30 March, 2019. The event included a showing of "HORIZON: What lies beyond the edge of the Universe", a planetarium program starring Komatsu, who also helped as a scientific advisor, followed by a talk by E. Komatsu, then another talk by HORIZON director H. Kosaka, and finally a discussion by both speakers. This planetarium program was developed by the Tamarokuto Science Center, and its release was celebrated at a preview event on 10 July, 2017. The program was shown at the science center from 6 October, 2017, to 28 January, 2018. H. Kosaka is an award-winning film director who has also developed the popular planetarium program "HAYABUSA – BACK TO THE EARTH -", a story of robotic spacecraft Hayabusa's return to Earth in 2010. H. Kosaka and E. Komatsu met one another when the Kavli IPMU co-hosted the 9th National Astronomical Observatory of Japan workshop at Kashiwa campus. After the planetarium program was shown at the Tamarokuto Science Center, it has been shown at science museums in Sendai and Kagoshima. It has also been shown overseas, and has received several awards. This includes a showing at the Minsk International Fulldome Festival 2018 in Belarus in November, 2018, where it was awarded Best Documentary Fulldome Film. In June 2018, the program was also selected for the Best Movie Awards at the Fulldome Festival Brno 2018 in the Czech Republic in June, 2018.

Journalist in residence at Kavli IPMU leads to feature article in overseas media

From August 1 to 8, the Kavli IPMU hosted B. Martin, a reporter for Spanish major daily newspaper

El País journalist, as part of his fulfillment to the European network (Horizon2020 ITN Elusives, www.elusives.eu). During his stay, Martin attended our tea time and interacted with Kavli IPMU researchers, visited the High Energy Accelerator Research Organization in Tsukuba, and the Kamioka Observatory. He also carried out a follow up interview with Kavli IPMU Principal Investigator M. Vagins, and then wrote and published a feature length article about the introduction of Gadolinium into the Super-Kamiokande detector to study supernova neutrinos for El País.

Kavli IPMU Women in Physics events

In Japan, the number of women who choose careers in science, particular 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. To help resolve this problem, 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. At the event, a number of speakers talk about their own career paths, and discussion times are extended to encourage participants meet other participants to build up their own support network. Lately, an after-event dinner has been introduced for students wishing to have more time get to know other participants. Co-hosting the event has allowed the hosts to cover a wide range of research fields including particle physics, nuclear physics, astronomy, solid state physics, and engineering. 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.

The Science Movie "The Man from the 9 Dimensions" Supervised by Hirosi Ooguri Expands its Worldwide Distributions.

The movie, released in April 2016 and received the 2016 Best Educational Production Award from the International Planetarium Society, is continued 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 will be premiered in Hamburg in the fall 2019. During 2018, it was shown in Bogoda, Chicago, Hamburg, Hong Kong, Bangalore and Mumbai, as well as in several locations in Japan. Ooguri gave public talks together with the movie at some of these locations.

Principal Investigator Hitoshi Murayama in NHK documentary "Last Lecture"

Kavli IPMU Principal Investigator H. Murayama appeared on NHK documentary series Last Lecture as "Physicist Hitoshi Murayama". The show aired on NHK-BS1 on 20 February, 2019. Recording took place on 12 January, 2019, in a lecture hall at the UTokyo's Hongo campus. More than 100 university undergraduates and graduate students 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. "What message would you want to leave to the world?" Past presenters include manga writer J. Miura, and robot engineer and Osaka University Professor H. Ishiguro. 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 February. Because of its popularity, NHK-BS1 aired a re-run of the program on 23 February.

Organizing workshop for scientist and high-school students and teachers

In FY 2018, the Kavli IPMU kept collaborating 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 Kavli IPMU PI H. Murayama spoke and took part in. On July 29, 2018, high school students and teachers were invited to try learning about the universe. [(8) of 9 challenges]

7. Center's Response to Results of Last Year's Follow-up

* Transcribe the item from the "Actions required and recommendations" section in the site visit report and "Actions required and recommendations" in the Follow-up report, then note how the center has responded to them.
* For the center launched in FY 2018, describe the status of response to the pointed items in "Major points that need to be improved" of "The screening result for WPI centers launched in FY 2018."
* However, if you have already provided this information, indicate where in the report.

SITE VISIT REPORT

7. Actions required and recommendations

1) *Kavli IPMU has developed a nurturing culture for a generation of new explorations in physics together with promoting synergies among other fields. Kavli IPMU has a unique opportunity among universities / institutes to promote risk taking. Radically new directions in physics can be stimulated in this way. Naturally not all efforts will be successful. We have heard of successful experiments and theoretical investigations. It would be useful to hear about the failed explorations, as evidence of risk taking.*

Yes, indeed. Not all of our efforts have been successful. Discussing a specific case is difficult since it can be harmful to those involved if we name names. However, here is one example we can describe without going into specifics:

Several years ago, we hired a tenure-track assistant professor in mathematics, aiming to promote fusion research with physics at the Kavli IPMU. Some of our PIs expressed concerned at the time of the appointment since the research area seemed very abstract, with little overlap with physics, but we decided give it a try. In the end, the researcher was not granted tenure, unfortunately, due to lack of identifiable fusion. Before the researcher left us, however, a new collaboration with a theoretical physicist at the Kavli IPMU started. Several years later, they discovered an unexpected connection between the very abstract area of mathematics and an important problem in physics, and their joint paper at the interface of physics and mathematics was accepted for publication in a prestigious refereed journal. This example shows that sometime a risk we take leads to an apparent failure (in this case, the ambitious appointment did not end with tenure), but it also shows that, in basic science, we need to take a long view in deciding whether a particular exploration has ended up in success or failure.

In cosmology, a new class of benchtop experiments open exciting possibilities for significant new laboratory exploration of the dark sector. Major progress in detectors and benchtop instrumentation using quantum measurement and atomic interferometry has occurred within the last decade, enabling an improvement of the sensitivity of experiments by as many as 10 orders of magnitude. Serendipitously, during the same period new ideas emerged for the description of the behavior of quantum systems as well as the description of the dark matter and dark energy of the universe. Remarkably, these new ideas are within reach of the emerging new experimental techniques based on these technological breakthroughs.

This is one of the initiatives being discussed in our long-term strategic planning committee. To inform us on this area, a symposium was held at the Kavli IPMU on February 26 – 27, 2019, and one of its speakers, Dmitry Budker, was interviewed by the planning committee. Following the symposium, a collaboration with the group of Hidetoshi Katori, who is building precision clocks, is being explored. Tom Melia, our tenure-track, and a newly recruited postdoc are making progress in this field, and we have hired a new postdoctoral fellow, Yevgeny Stadnik, to work in this area.

2) *Since ISM involvement is rather limited (see 6. 2). It might be wise to bring in one or more of the new generation of astrophysicists, who have a track record of innovation in data-driven discovery.*

In addition to ISM, we have started to collaborate with other institutes together to develop new statistical methods. For example, together with researchers at NAOJ and ISM, we have developed a novel noise reduction method using deep learning. The joint venture of the Kavli IPMU and ISM is serving as a research hub in data science researches in Japan.

Regarding human resources, our project assistant professor Takahiro Nishimichi has been

promoted to associate professor at Kyoto University, and he is strengthening our collaboration with the Yukawa Institute on big data cosmology. We also have a new affiliate member, Tilman Hartwig, who is an assistant professor at the newly established Institute for Physics of Intelligence of the UTokyo, to lead astro-informatics projects at the Kavli IPMU. We are exchanging young and talented scientists with expertise on data science with domestic and foreign institutes. Current ongoing faculty search includes candidates with a strong background in machine learning/AI.

3) *Time to think about the future of SuMIRe is now. To leverage the current SuMIRe project, we recommend Kavli IPMU to get involved in the upcoming probes of the physics of dark energy, so-called "Stage IV" experiments. Due to the complexity of the data, it will require several years to develop effective analysis tools. Also, it is not too late to get involved in the upcoming next-generation probes of the physics of the universe.*

Opportunities with WFIRST and LSST are being discussed in our long-term strategic planning committee. We are discussing with NAOJ on Japanese participation to LSST.

4) *We have been told that Oxford students are doing very well. This is good. However, we have not heard anything about the philosophy of graduate education at Kavli IPMU. If a student program is to exist at Kavli IPMU, we hope to hear about its educational philosophy in the future. We understand that some students are brought in from Japanese universities for special projects such as LiteBIRD. The Kavli IPMU graduate school program should benefit Japanese students too. It might be the best way to globalize the entire Japanese research effort.*

Indeed, the Kavli IPMU provides unique opportunities for Japanese students to be exposed to the environment where scientists from all over the world work together on fundamental questions on the universe. Our new "Excellent Graduate Student Program" includes initiatives to leverage this, and we hope that it will be selected by MEXT.

Please see also the Follow-up Report section.

5) *Visitor program needs to be more open to domestic researchers so that they can take advantage of the international atmosphere of Kavli IPMU. Interdisciplinary workshops will be Kavli IPMU's most attractive elements where participants can learn new subjects. It might be a very efficient way to expand the reforms achieved by Kavli IPMU.*

The numbers of affiliate members from Japan and from abroad are roughly the same. Currently, we have 150 affiliate members, 60% of whom are from Japan and 40% are from abroad.

We are also having more joint workshops and conferences with other institutions in Japan, such as OIST, Kyoto University, and Tohoku University. This has given opportunities for administrative offices of these institutions to review their administrative practices in comparison with those at the Kavli IPMU. We plan to organize a school on experimental physics for Japanese graduate students, to make them feel welcomed and help them experience research environment in the Kavli IPMU.

6) *One junior staff member of the IPMU, when asked what could be improved at the IPMU, suggested installing an ombudsperson for potential future cases of internal conflicts or harassment issues. We understand that such a program already exits. It should be advertised.*

We have had an ombudsperson system, but it has not been widely advertised within the Kavli IPMU. We have appointed Hitoshi Murayama and Mark Vagins as our ombudsperson, and announced this appointment to the entire Kavli IPMU community. This information is included in our welcome package to new members.

FOLLOW UP REPORT

5. Actions required and recommendations

It is a sincere hope of the PC that the efforts made by Kavli IPMU and by UT towards their reforms will lead to a complete reform of the way research is being conducted in Japan. The value of setting up WPI at UT will be judged by these reforms which lead to the goal of WPI.

One outstanding issue is that many faculty members at Kavli IPMU cannot supervise graduate students. This is because Kavli IPMU is not a school and hence cannot grant degrees, Kavli IPMU is completely at the mercy of traditional departments to have access to graduate students. On site Kavli IPMU faculty members, if interested, should be appointed as graduate advisors in the respective departments and have access to students. This model is common in the United States and UK e.g. the Broad Institute in Boston and the Crick Institute in London. This would be an important system reform of the graduate education at UT.

UT should develop new opportunities such as research experience for undergraduates (REU) that will involve more students in the environment of this international research center. It is important to get to gifted undergraduates, so that they will have the courage to aim for graduate school and to be active in international environments.

This is an issue that research institutes in the US and Europe not attached to departments are also experiencing. We are trying to address the issue in the following ways:

- Currently, 15 out of our 30 professors are associated to departments and can supervise students.
- The Kavli IPMU is leading an “Excellent Graduate Student Program” proposal to MEXT, joining forces with IRCN and departments of physics and mathematics.
- The Oxford student program has been successful in the research fields of CMB, T2K, Xenon-DM, SK-Gd and Belle II project.
- We are also accepting undergraduate students from Harvard University for summer internships.