Application for Academy Center Certification
World Premier International Research Center Initiative (WPI)

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

Please prepare this application based on the content of your center's progress report and the progress plan you submitted for the center's final evaluation. Summarize the center's future plans with regard to the following 6 items within three A-4 pages. (Also fill out the appendices at the end of this form.)

1. Overall Image of Your Center

* Describe the Center's overall image including its current identity.

The Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) was proposed to study five interrelated, basic, yet ambitious questions about the Universe:

- How did the Universe start?
- What is the Universe made of?
- What is the fate of the Universe?
- What are its fundamental laws?
- Why do we exist?

The Kavli IPMU was founded from scratch with the WPI funding on October 1, 2007, as a unique interdisciplinary institute in the world that combines mathematics, theoretical and experimental physics, and astronomy. Since then, it has grown to an international research center of about 150 members. It has produced high impact signature papers with a clear "made in the Kavli IPMU" brand, with citation counts and the number of highly cited papers comparable to or better than world-leading institutes. We receive 800 visitors on average every year, half of them from abroad; about 700 job applications every year with more than 90% from overseas; and more than half of about 90 Ph.D. scientists on site are international. More than 40% of the postdocs who have left the institute found faculty positions. We created an environment for strong mutual inspiration between mathematics and physics, and unexpected synergies between astronomy and mathematics as well as connections with condensed matter physics have emerged.

We proposed to carry out experimental and observational programs from accelerators, underground laboratories, and telescopes, and have launched major experimental initiatives such as HSC, XMASS, and KamLAND-Zen successfully. The interdisciplinary environment allowed us to spawn new initiatives such as SuMIRe and LiteBIRD, garnering strong international attention. Our outreach program has been highly successful and mobilized more than 33,000 people, with strong media attention providing close to a thousand instances of international coverage. We spearheaded many unprecedented achievements in system reform at the University of Tokyo, such as split appointments, merit-based salary scales, and endowment donation from a foreign foundation.

What we should thrive for during the five-year extension period is to ensure that the Kavli IPMU will make a successful transition to a permanent research institute during the five-year extension period of the WPI funding. We should also make sure that our current research projects will be executed to produce world-leading discoveries, continue to open new areas of research, create new synergies among different fields, and plan for new projects to build on our successes. We should do so while maintaining and strengthening our high standard of research, attracting top-level scientists from all over the world, and fulfilling our mission to propagate system reforms to improve research and education in Japanese universities and to make them competitive internationally.

2. Research Activities

* Describe how the center will challenge new research fields and adopt new strategies.

We propose 9 challenges in the five-year extension period in research and organization management. For research activities, addressing new objectives to

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

In fact, we already developed a new image analysis tool that allowed us to identify 65,000 variables and 1,000 supernovae from the first 55TB of HSC data, which is a record-breaking detection rate. Our new statistical method allows extremely fast reconstruction of dark matter mass map from gravitational lensing. There may also be opportunities to apply modern statistical methods to other areas of science such as in high energy physics experiments and in theoretical physics, and we plan to explore them in coming years.

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

Recently, Ooguri and collaborators at Harvard pointed out that there is a global bound on gradients of effective potentials in all the known top-down constructions from string theory and that it puts theoretical constraints on the *w*-parameter in the equations of state of dark energy. They can be compared with experimental constraints on dark energy provided by SuMIRe's large statistics on stars and galaxies. There are similar constraints on the inflation potential for the early universe cosmology, which can give useful input into the LiteBIRD project.

Astronomy and Medicine: We set up a new joint research group with JAXA to apply expertise in X- and γ-ray instrumentation used in satellites to diagnosis and therapy of cancer.

(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. One major improvement is the appointments of Hiraku Nakajima, Yukari Ito, and Tom Melia who work at the interface between mathematics and physics. For instance, Nakajima works on precise mathematical formulation of geometry of Coulomb branch in supersymmetric gauge theories, while Melia employs Stiefel manifolds to parameterize relativistic phase space in collider experiments. At the interface of physics and mathematics, it has become increasingly clear that quantum information theory provides powerful mathematical language to study quantum field theory, quantum gravity, and string theory. Recently, Ooguri used it to derive new theorems on symmetry of quantum gravity, for example. Conversely, these areas of theoretical physics may pose problems and inspire progress in quantum information. For example, traversable wormholes in quantum gravity may provide a new efficient protocol for quantum teleportation. Some of PI's and faculty members at the Kavli IPMU are already familiar with ideas and techniques of quantum information theory and have started to use them in powerful ways. Activities in this direction can be strengthened by strategic hiring of postdoctoral fellows and by uses of focus weeks and conferences.

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

XMASS is concluding its mission with final scientific results, and the group is moving to more ambitious XENON-nT project. Gd-loading of SK will discover the diffuse supernova neutrinos, and the refurbishment of the water tank and the deployment of the new purification system will finish in 2018. The initial scientific results from the HSC survey were published in February 2018, and the first component of the PFS instrument was delivered to the Subaru telescope in April 2018. Rigorous tests of detector components and half-wave plates are underway in the Kavli IPMU building, and the design is being finalized. Now both NASA and ESA are planning to participate in LiteBIRD once chosen by JAXA later in 2018. In addition, we will start exploring new opportunities beyond the five-year extension period. Possible examples include study of innovative methods to detect gravitational waves to understand how the universe began, and precision quantum technologies for dark matter detection and search for subtle deviations from the Standard Model predictions. In this area, there are opportunities to collaborate with researchers in material science, nano-technology, and quantum optics.

(5) attracting and retaining the best and broadly minded scientists from around the world

We believe we have attained the world premier status in the initial 10 years, and our ambition is very clear. We would like to regularly create new theories and new data based on the interdisciplinary mutual stimulation of mathematics, theoretical physics, experimental physics, and astronomy. We will produce world-competitive results on dark energy properties, dark matter distributions, dark matter cross sections, and the inflationary scale. We will interpret them and build new theories of the Universe. We have created many synergies among disciplines, both proposed and unanticipated. We will create new synergies that were unimaginable before, e.g., between astronomy and string theory via new data, experiment and

mathematics via statistics, and enhanced connection to condensed matter physics. We will stick to the basic philosophy of the institute as originally proposed. The Five Questions are broad enough to encompass rapid changes in everyday research objectives. Just in the first year of five-year extension, we successfully recruited Hiromi Yokoyama, Yukari Ito, Tom Melia, Khee-Gan Lee, Tadayuki Takahashi, Tadashi Orita, Atsushi Yagishita, Shinichiro Takeda, and Hiraku Nakajima, all excellent faculty hires who bring in new expertise and opportunities.

Within the 10 years of existence, there have been major breakthroughs in our fields. A Higgs boson was discovered, allowing us to contemplate the Universe less than a billionth of a second after the Big Bang in a quantitative fashion, addressing "How did the Universe begin?" The new mixing angle among neutrinos was discovered, allowing for experimental tests on how the anti-matter disappeared since the Big Bang, addressing "Why do we exist?" Our PI, Takaaki Kajita was awarded the 2015 Nobel Prize in physics. The fundamental lemma in the Langlands program proven by Ngô Bảo Châu used Hitchin fibration that was inspired by integrable systems in physics and formulated with algebraic geometry; it confirms our choice of geometric approach and connection to physics in "What are the fundamental laws?" Because of these breakthroughs, we are readjusting ourselves getting prepared to the next breakthroughs.

3. System for Managing the Research Organization

* Describe the research organization and management system that the center will use to carry out the research strategy and plan described above.
* In Appendix 1-3, list the Principle Investigators, enter the number of center personnel, and provide a diagram of the center's management system.

The current management structure allows for quick decisions by the directorate for recruitments and retentions, as well as for arranging timely workshops and visitors to enhance our research. We will develop a wider "sense of ownership" of the Institute among younger members to carry the Institute into the future. We optimize top-down decisions on day-to-day management while exploit bottom-up initiatives on research agendas. The organization remains flat with no "departments" within the Institute, and the Directorate is always open to new initiatives from the individual faculty members.

We have been paying special attention to foster young researchers. We make sure that they receive sufficient exposure to secure their career paths, while learning the landscape of science on the international scene. Our policy requiring one to three months of travel a year outside Japan to promote their research with presentations and collaborations, as well as hosting a large number of workshops and visitors, has been extremely successful for this purpose. We intend our Assistant Professor positions to be tenure-track, some joint with other institutes.

In addition, we take up the following challenges.

(6) propagate system reform

We have many achievements in system reform. We take the active role of an evangelist to make these reforms permeate the system by working on other Japanese institutions to create split appointments following success of Murayama (Berkeley) and Bondal (Steklov). Our administrative staff won five President's awards for improvement in business practice, and many of them are being used widely within the University. The University of Tokyo was fortunate to institute another WPI center, International Research Center for Neurointelligence (IRCN). We will work closely with IRCN both on the scientific aspects (similarity between the large-scale structure of the universe and the network of neurons) and the administrative practice (novel hiring schemes and support for international scientists). Having two WPI centers at the same university, unparalleled in the current situation, should catalyze reform of the Japanese university system as a whole.

(7) create a New Graduate Program

We believe working with graduate students is a must for a world-class research institution. It is wonderful that some of our faculty have access to students from traditional departments while some others do not. We try to create an international graduate program with vigorous student exchanges. By a new program to bring Oxford students, three students have already joined and three more students are following. Initial set of students are soon to obtain Ph.D. degrees. We also joined a new international graduate program with physics (GSGC) to attract excellent graduate students from universities all over the world, and teamed up with Department of Astronomy and Department of Earth and Planetary Science to extend the GSGC program.

(8) young students

It is crucial to inspire young students to secure the next generation of scientists. Building on the success of our outreach program, we propose to conduct workshops to train scientists and high-school teachers in order to reach out to young students far beyond our own direct contacts, and teachers used

the material in the classroom in five high schools. Subsequently we tried the material directly on high school students, and plan for another workshop to create a package that can be distributed widely. Since there are other research institutions which also have such programs, such as the Perimeter Institute in Canada, rather than each of us trying to invent separate wheels, we may consider joining forces with them to develop effective ways to reach out to high school students and to improve their STEM experience.

(9) stability and sustainability

Most projects in our fields have long lead times of at least ten years. We need to have a stable and sustainable organization. We will work closely with UTokyo administration to make a transition from the model supported by WPI funds to a new model hosted by UTokyo. Starting with Japanese Fiscal Year 2018, ¥520,000,000 is rolled into the University operating funds on permanent basis, making the institute finally on a stable financial footing. University will place additional budget request this year to secure remaining needed funds to maintain and possibly expand the institute beyond JFY2022 when the WPI funds finish.

The most important thing for the Kavli IPMU to do would be to demonstrate that it is worthy of public support by producing ground-breaking discoveries in science, by training and mentoring students and young scientists to become world leaders, and by propagating systems reforms throughout universities in Japan. The directorate will enable our scientific staff members to perform at the highest levels by supporting their initiatives and by providing them an ideal research environment, and to communicate their achievements to our funding agencies and the general public.

4. International Circulation of Best Brains

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

From the development stage, we had a firm belief that the key to gaining international recognition is to bring top-level leaders and talented young researchers from around the world, and to create an environment in which researchers in different fields learn each other's languages and work together toward common goals. We have established such a fascinating research environment here at the Kavli IPMU. It functions as the center for the "brain circulation." In 2017, we envision 26 world-leading PIs among which 8 PIs are international and 10 are on site. Out of 259 member researchers including faculty members, postdoc, long-term visitors and graduate students, 91 (35%) are international and considered as world class. To keep the Kavli IPMU as a hub of exciting intellectual exchanges, we will keep to invite many Nobel laureates in Physics, Fields Medalists and prominent researchers to stimulate young researchers. Also we keep our policy that all full-time researchers have to spend one to three months abroad each year.

We successfully recruited topnotch scientists such as M. Kapranov, a former full professor at Yale, to one of our first tenured positions. Given his well-known status as a leader in higher category theory and driver behind many important mathematical concepts recently, this is a significant boost of our international standing. His activity at the Kavil IPMU attracts the world best brains. Also we recruited M. Hartz, a neutrino experimentalist, and retained K. Bundy and A. Leauthaud, a couple of astronomers, and S. More, also an astronomer. These are testaments of our exciting research program that cannot be done elsewhere in the world.

5. Support by Host institution

* Describe measures that the host institution will take to support and sustain your WPI center. Describe your strategy for extending the system reforms achieved by the center via the WPI program to the host institution and other institutions.

At the time of the original proposal, UTokyo made many exceptions to the Kavli IPMU as a "special district" within the University: flexible salary system, longer appointments than traditional fixed-term positions, moving some PIs with advantageous arrangements with retirements from traditional departments, appointments beyond the retirement age, etc. UTokyo also committed to build the main research building specifically for the Kavli IPMU, and a new international lodge near the Kashiwa campus. A creation of UTIAS in 2011 is outstanding support providing a permanent place for the Kavli IPMU within the University. Following the interim evaluation, UTokyo made several measures to make the Kavli IPMU sustainable. UTokyo guarantees 10 tenured positions, and permanent assignment of administrative staff.

UTokyo confirms that it is crucially important for the Kavli IPMU to have 26 permanent positions for the core of faculty and to keep the critical mass. System reforms originated in the Kavli IPMU are awarded UTokyo Special Prize for business innovation 4 times. Its unique measures are gradually spreading out inside UTokyo and outside.

6. Financial Measures

* In Appendix 4, describe the measures to be taken by the host institution for sustaining the center's functions and activities over a period of 5 years, and describe what external funding will be used to carry out the center's research activities.

UTokyo understands that the operating resource necessary to sustain the world "leading" premier status is at least the current funding level from the WPI program. These figures are quite standard to run so-called institute of advanced study in healthy conditions. UTokyo put together a plan for the 5-year extension period and beyond. The budget request from UTokyo to MEXT has also been fully secured for 13 positions and for operation. The University puts an additional request as the top priority for science fields for the next year to sustain as its flagship beyond the WPI funding. The University will maintain and hopefully expand the Kavli IPMU even after WPI support finishes. As a result of the Kavli IPMU's high visibility, and also the University's effort to sustain the Institute, the Kavli foundation boosted the endowment from ¥750M to ¥1250M ($1=¥100). The University will keep making effort during the extension period in many ways to boost the reputation of the Kavli IPMU to further increase the endowment. The Kavli IPMU and Hamamatsu Photonics K.K. established the Endowed Research Unit in 2014 for 5-year program.

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List of Principal Investigators

- If the number of principal investigators exceeds 10, add columns as appropriate.
- Place an asterisk (*) by the name of the investigators who are considered to be ranked among the world's top researchers.
- Give age as of 2 July 2018
- For investigators who cannot participate in the center project from its beginning, indicate the time that their participation will start in the "Notes" column.

Name	Age	Current affiliation (organization, department)	Academic degree and current specialties	Notes (Enter "new" or ongoing")
1.Hirosi Ooguri*	56	Kavli IPMU (Director), California Institute of Technology (Professor, Physics Dept and Mathematics Dept., Director, Burke Institute)	Ph.D. string theory	ongoing
2.Hitoshi Murayama*	54	Kavli IPMU (Professor), University of California, Berkeley (Professor, Physics Dept)	Ph.D. particle theory, cosmology	ongoing
3.Hiroaki Aihara*	62	UTokyo (Executive Vice President, Professor, Dept of Physics), Kavli IPMU (Deputy Director)	Ph.D. high energy physics	ongoing
4.Alexey Bondal*	56	Steklov Mathematical Institute (Professor), Kavli IPMU (Professor)	Ph.D. mathematics	ongoing
5.Kunio Inoue*	52	Tohoku University (Director, Professor, RCNS)	Ph.D. astroparticle physics	ongoing
6.Takaaki Kajita*	59	UTokyo (Director, Professor, ICRR)	Ph.D. astroparticle physics	ongoing
7.Stavros Katsanevas*	64	University of Paris 7 (Professor, Physics Dept)	Ph.D. astroparticle physics	ongoing
8.Masahiro Kawasaki*	57	UTokyo (Professor, ICRR)	Ph.D. particle cosmology	ongoing
9.Toshiyuki Kobayashi*	55	UTokyo (Professor, Graduate School of Mathematical Sciences)	Ph.D. mathematics	ongoing
10.Toshitake Kohno*	62	UTokyo (Professor, Graduate School of Mathematical Sciences)	Ph.D. mathematics	ongoing

11.Masayuki Nakahata*	58	UTokyo (Director, Professor, Kamioka Observatory, ICRR)	Ph.D. astroparticle physics	ongoing
12.Mihoko Nojiri*	55	KEK (Professor)	Ph.D. particle theory	ongoing
13.David Spergel*	57	Princeton University (Professor, Chair, Dept of Astrophysical Sciences)	Ph.D. cosmology	ongoing
14.Naoshi Sugiyama*	56	Nagoya University (Professor, Physics Dept)	Ph.D. cosmology	ongoing
15.Kentaro Hori*	52	Kavli IPMU (Professor)	Ph.D. string theory	new
16.Mikhail Kapranov*	55	Kavli IPMU (Professor)	Ph.D. mathematics	new
17.Young-Kee Kim*	55	University of Chicago (Professor)	Ph.D. experimental physics	new
18.Eiichiro Komatsu*	43	Max Planck Institute for Astrophysics (Director of the Department of Physical Cosmology)	Ph.D. cosmology	new
19.Kai Martens*	54	Kavli IPMU (Associate Professor)	Ph.D. experimental physics	new
20.Shigeki Matsumoto*	45	Kavli IPMU (Associate Professor)	Ph.D. particle theory, cosmology	new
21.Shigetaka Moriyama*	48	UTokyo (Associate Professor, ICRR)	Ph.D. experimental physics	new
22.Yasunori Nomura*	44	University of California, Berkeley (Professor)	Ph.D. particle physics	new
23.Masahiro Takada*	44	Kavli IPMU (Professor)	Ph.D. cosmology /astrophysics	new

24.Yukinobu Toda*	38	Kavli IPMU (Associate Professor)	Ph.D. mathematics	new
25.Mark Vagins*	52	Kavli IPMU (Professor)	Ph.D. astroparticle physics	new
26.Naoki Yoshida*	44	UTokyo (Professor, Dept of Physics) Kavli IPMU (Professor)	Ph.D. astrophysics	new
27.Tadayuki Takahashi*	59	Kavli IPMU (Professor)	Ph.D. experimental physics	new

World Premier International Research Center Initiative (WPI)
The number of Center personnel

	FY2017
Principal Investigators	26
Other Researchers	261
Post-Doctor researchers	62
Research Support Staffs	31
Administrative Staffs	10

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Diagram of Management System

as of October 15, 2018