Summary of Proposal

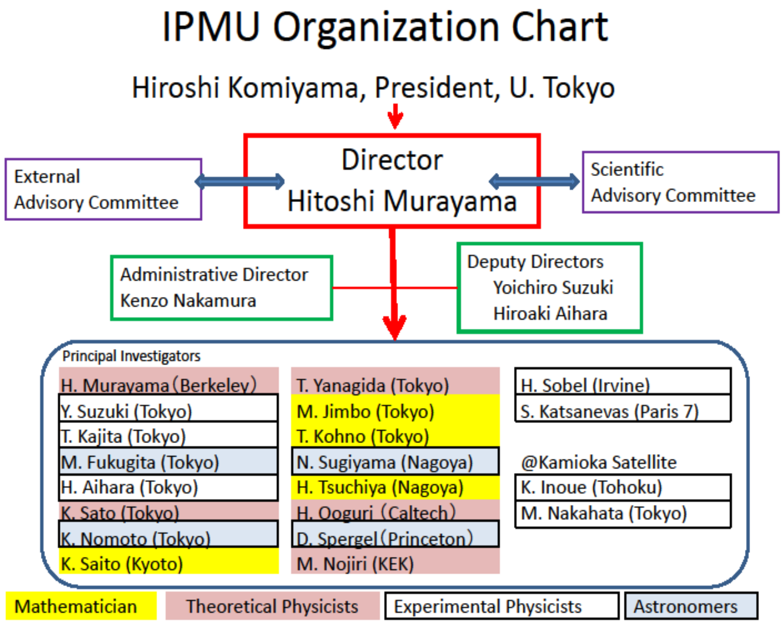
Host institution name	The University of Tokyo
Head of host institution	Hiroshi Komiyama,（President, The University of Tokyo）
Center Director	Hitoshi Murayama
Administrative director	Kenzo Nakamura
Title of center project	Institute for the Physics and Mathematics of the Universe
Center name	Institute for the Physics and Mathematics of the Universe
Project Summary	This center aims at establishing a multi-disciplinary research institute with the unifying goal of understanding the universe from the synergistic perspectives of physics, cosmology and mathematics. The Institute will bring many of the world's leading theoretical physicists and mathematicians together to develop new formulations of the fundamental laws of nature, a crucial step toward solving the mysteries of the universe. We will study dark energy, dark matter, neutrinos, and physics beyond the Standard Model of elementary particles and will follow these closely related research threads toward a deeper and more comprehensive view of the cosmos. The Institute will utilize state-of-the-art facilities (Super-Kamiokande, KamLAND, Subaru telescope, and LHC accelerator) and will produce an unprecedented volume of precision data. We will invent new mathematical tools to analyze the data and develop new strategies for future experiments. This center is a unique research institute in the world on the forefront of physics, cosmology and mathematics. It will attract highly motivated young researchers, as well as established leading scientists from around the world and will greatly strengthen the foundation of mathematical and physical sciences in Japan.
Research fields	Physics and Mathematics Science's fundamental and historic search for the fundamental laws of Nature is built on the invention of new mathematics, and it has inspired many important developments in the field. Approximately 40% of Field Medalists in mathematics since 1990 have worked in areas closely related to quantum field theory or string theory. No other area of science has had such a great impact on mathematics in the past few decades, and the rate of progress in this area suggests that this trend will only accelerate in the future. Japan has long been strong in both physics and mathematics. The Institute will bring the world's leading physicists and mathematicians together, build a unified community, redefine the boundaries between them, and help nurture future generations of mathematical scientists. The Insititue will also support and take advantage of superb experimental programs. Japan continues to lead the world in the field of underground physics including dark matter searches and the study of neutrinos by capitalizing on two major underground detectors (Super-Kamiokande and KamLAND). A new instrument that enables a

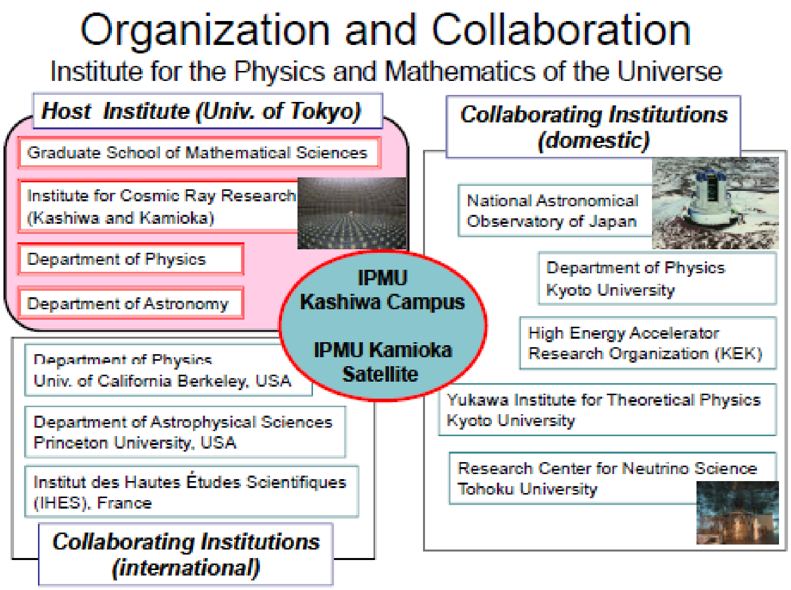
	wide-field, deep-sky survey of galaxies is being built for Japan's largest telescope, Subaru, which has a unique technical capability for such projects. The world highest energy accelerator LHC, to which Japan has made significant contributions for construction, will become operational by the end of this year, and the data on high energy collisions that mimic those which occurred during the Big Bang, the birth of the Universe, will be available to us. Thus, the Institute will be a globally unique research center that spans pure mathematics, theoretical physics, experimental physics, astronomy, and applied mathematics. Frontier research projects in each field will motivate efforts in the others in a way not possible within the usual structure of academic institutions.
Research objectives	We will address a set of basic and deep questions about the universe, its fundamental laws, its beginning, its fate and its mysterious components, especially Dark Matter and Dark Energy. For this purpose, we will create the new mathematics needed for a unified description of the universe. This mathematical foundation will allow the formulation of new physical theories with well-defined and testable predictions. Technological innovations will follow to make new experiments possible; the resulting data streams will stimulate further developments in mathematics. The ambitious ten-year goals of the Institute's activities are as follows: • Using new data from underground (neutrino) and accelerator (high energy particle) experiments, we aim to unveil the nature of dark matter and develop a new paradigm in particle physics, based on a unified physical theory and founded upon new mathematical tools and insights. • The vast data volumes produced by next-generation galaxy surveys will motivate applied mathematicians and statisticians to develop the novel methods needed to extract subtle signals and maximal information, thus uncovering any unanticipated behavior of the universe's mysterious Dark Energy component. • We will enumerate and classify solutions of string theory that will lead to the development of new types of geometries. • Mathematical developments in integrable systems will allow string theorists to find new classes of solutions which determine the dynamical behavior of Dark Energy. Taken together these goals will produce revolutionary and unifying advances in physics, mathematics and cosmology.
Outline of management	The Institute Directorate consisting of the Director, Deputy Directors and Administrative Director will have direct access to the Office of the President, will be able to consult with the President and his staff members and will thus share their management resources. Thanks to this arrangement, we envision our administrative organization to be *streamlined,* yet very *effective*. More than 50% of the staff members will be bilingual. Aside from the appointment of the Director and approval of PI selections, the Director will have the authority to make nearly all decisions on the Institute's composition, organization and operation. The Scientific Advisory Committee (SAC) to the Director consists of four to five PIs of his choice. It will advise the Director on planning and hiring staff members, as well as scientific directions, but the Director is solely responsible for the final decisions. The PIs will have great autonomy in the research they conduct and will be encouraged to fund their research through competitive grants. They can make proposals to the Director to hire postdocs and term professors. The Director's approval of such appointments will reflect the scientific vision and priorities set by the

	Director, advised by the SAC. An External Advisory Board (EAB) will review the Institute's activities annually and advise the Director on the effectiveness of its operational priorities and research activities with respect to the proposed science goals summarized above. At least half of the EAB's members will be scientists from outside the University of Tokyo.
Researchers and other center staffs	Initially the Institute will have 20 Principal Investigators and 3 administrative staff members. By March, 2011, the Institute will have grown to 22 PI's, 173 other researchers, 20 research support staff members and 10 administrative staff, totaling 225 core members of the Institute. The initial list of PI's is: H.Murayama, Y.Suzuki, T.Kajita, M.Nakahata, M.Fukugita, H. Aihara, K. Sato, K. Nomoto, T. Yanagida, M. Jimbo, T. Kohno, M. Sugiyama, A. Tsuchiya, K.Inoue, H. Ooguri, K.Saito, M.Nojiri, D.Spergel. S.Katsanevas, H.Sobel. A satellite activity center will be established at Kamioka. Department of Astrophysical Sciences of Princeton University, Department of Physics of University of California Berkeley, IHES in France, the Physics Department and the YITP at Kyoto University, NAOJ, KEK, and Tohoku University Research Center for Neutrino Science will be collaborating institutions.
Outline of research environment	The Director has extensive experience leading research groups at Berkeley and the Institute for Advanced Study and via service on numerous scientific-policy making committees in the US and Japan. The agreements with the University and the funds secured by the Director will enable Institute researchers to focus on their research and on scientific interactions with each other. The new Institute building, with a large open area and amenities, will provide an attractive and stimulating environment for scientists from around the world. International conferences and workshops held at the Institute will bring visitors to further stimulate the intellectual activities and to keep the Institute at the forefront of global science. The Institute will adopt a merit-based compensation system with salaries based on individual performance criteria.
Outline of indicators for evaluating a center's global standing	The number of refereed journal papers by Institute authors and their citation impact, plus the number of presentations the researchers deliver at major international conferences will be monitored. The number of visitors, and the number of foreign scientists among them, are other objective indicators of the Institute's contributions and visibility. We plan to monitor the number of publications co-authored by mathematicians and physicists as a measure of the synergy between the two disciplines.
Securing research funding	The initial Institute PIs received a total of approximately $57M in competitive funding during the last five years, and they have already secured approximately the same amount for the future. We are, therefore, confident that they can maintain a similar funding profile in the era of this new Institute.
Summary of host institution's commitment	A world-class center of excellence for international research aligns with the University's medium-term objectives and plan extremely well; hence the Institute will be the most important and visible organizational unit and endeavor reporting to the President. It will thus receive university-wide support under the specified achievement targets. Top priority will be given to financing and appropriating land for the Institute's new research building. Until the new research building is constructed at the Kashiwa Campus, rooms and other space in the Kashiwa General Research Building will be provided for activities of the Institute on a priority basis.

Research Center Project

Host institution name	The University of Tokyo
Head of host institution	Hiroshi Komiyama (President, The University of Tokyo)
Title of center project	Institute for the Physics and Mathematics of the Universe
Center name	Institute for the Physics and Mathematics of the Universe
Project summary	This center aims at establishing a multi-disciplinary research institute with the unifying goal of understanding the universe from the synergistic perspectives of physics, cosmology and mathematics. The institute brings the world's leading theoretical physicists and mathematicians together to develop new formulations of the fundamental laws of nature, a crucial step toward solving the mysteries of the universe. We will develop infinite analysis, the mathematics for systems with infinite dimensional degrees of freedom, which will be used to build new physical theories and derive their experimental predictions and to invent statistical methods to analyze geometric data. We will study dark energy, dark matter, neutrinos, and physics beyond the Standard Model of elementary particle physics. The institute builds on the state-of-the-art facilities (Super-Kamiokande, KamLAND, Subaru telescope, and LHC accelerator) that will produce an unprecedented amount of precision data for observational cosmology, astronomy and elementary particles physics. We aim to develop new mathematical tools to analyze the data by taking full advantage of collaboration between mathematicians and physicists, and will develop new experimental strategies to attack the mysteries. This center is a unique research institute in the world on the forefront of physics, cosmology and mathematics and will lead to a new paradigm of sciences in the 21st century. It will attract highly motivated young researchers, as well as established leading scientists from around the world and will greatly strengthen the foundation of mathematical and physical sciences in Japan. We will also bring topnotch female researchers as role model to inspire women in Japan and promote Asian diversity. □Include a chart that illustrates the center's overall structure including its collaborative linkages with other domestic and foreign institutions, its system of external evaluation, and its management framework





(1) Research fields

・Fill in the name of the research field of the project.

・ Choose relevant fields from among ①—⑦ below, specifying the inter disciplinary field(s) that the project addresses.

①Biosciences, ②Chemistry, ③Material sciences, ④Electronics engineering and information sciences,

⑤Precision and mechanical engineering, ⑥Physics, ⑦Mathematics

Physics and Mathematics

・Describe the importance of the proposed research, including domestic and international R&D trends in the field and Japan’s advantages.

□If centers in similar fields already exist in Japan or overseas, please list them.

Science’s fundamental and historic search for the fundamental laws of Nature is built on the invention of new mathematics, and it has inspired many important developments in the field. Famous examples include the simultaneous invention of Calculus and Newton’s mechanics and the use of Riemannian Geometry in General Relativity. The interface of physics and mathematics is alive and well. Approximately 40% of Fields Medalists in mathematics since 1990 have worked in areas closely related to quantum field theory and string theory. Conformal field theory in two dimensions, whose development was largely motivated by string theory, has been used to explain the remarkable identities about the Monster group (Field Medal to Borcherds) and to describe stochastic geometry (Fields Medal to Werner). Methods of topological string theory have revealed deep connections among the Gromov-Witten invariants, gauge theory instantons, and combinatorics (Fields Medals to Kontsevich and Okounkov). In return, these mathematical developments have provided powerful tools for quantum field theory and string theory.

No other area of science has had such a great impact on mathematics in the past few decades, and the rate of progress in this area suggests that this trend will only accelerate in future. As stressed, for example, in a recent National Research Council report, “Rising Above the Gathering Storm,” in the United States, building up strength of mathematical and physical science is a key to lead in a highly competitive world scene of science and technology. Coincidentally, the Science Council of Japan warned recently that Japan’s foundation of mathematics is at risk due to not attracting young talented minds into this fundamental field. At the proposed Institute, we will build a community of physicists and mathematicians, redefine the boundaries between them and help nurture future generations of mathematical scientists. Uniquely to this Institute, we anticipate cross-career development between mathematics and physics, such as a statistician moving to experimental physics.

Mathematicians and physicists have very different work styles. Although two PI’s for mathematics stay in their current Komaba campus, Tsuchiya and Saito will reside in Kashiwa as Principal Investigators, who facilitate communication between physicists and mathematicians and maintain activities in this area throughout the year. There will be semi-annual workshops that bring mathematicians and physicists together where they will share their common problems. Once that is established, they will keep communicating over phone and video on individual bases, visiting each other on as-needed basis, as well as organized seminars broadcast over the video to maintain mutual interest. We also plan to have a state-of-art video conference system and internet-blackboards between Kashiwa and Komaba that stay on 24/7 to make impromptu discussions possible.

Our advantage of experimental programs is evident. Japan continues to lead the field of underground physics including dark matter search and study of neutrinos by capitalizing on two major underground detectors (Super-Kamiokande and KamLAND) at Kamioka, where a satellite of the Institute will be established. Some principal investigators of the Institute are now building a new instrument that enables a wide-field, deep survey of galaxies at Subaru telescope. The data from this instrument will most likely dominate the field of observational cosmology and astronomy well into the next decade. Scientists in our Institute will have the first-hand access to high quality, high precision data available from these world premier facilities. LHC, the world highest energy accelerator, will become operational by the end of this year and the data of high energy collisions that mimic Big Bang, the birth of the Universe, will be available to us. By bringing together the world-leading mathematicians, theoretical physicists and experimental physicists and taking advantage of the data available at the Institute, we will take on challenges of solving the mysteries of the Universe. This is another reason why most active world-class scientists should come to work at the Institute.

The Institute we will establish is a unique research center in the world that spans pure mathematics, theoretical physics, experimental physics, astronomy, and applied mathematics. This kind of Institute will be truly unique in the world. Kavli Institute for Theoretical Physics is an excellent institution, yet does only theoretical physics. There are many first-rate institutions that combine research in mathematics and theoretical physics, such as Isaac Newton Institute for Mathematical Sciences in Cambridge, Institute for Advanced Study in Princeton, IHES in France, and MSRI in Berkeley, but none of them include experimental physics in their program. There are also great institutions on both theoretical and experimental physics, such as CERN, Fermilab, SLAC, KEK, but none of them have mathematicians. The combination of science the proposed Institute will include should attract best people from the world because of its uniqueness and potential for major breakthroughs.

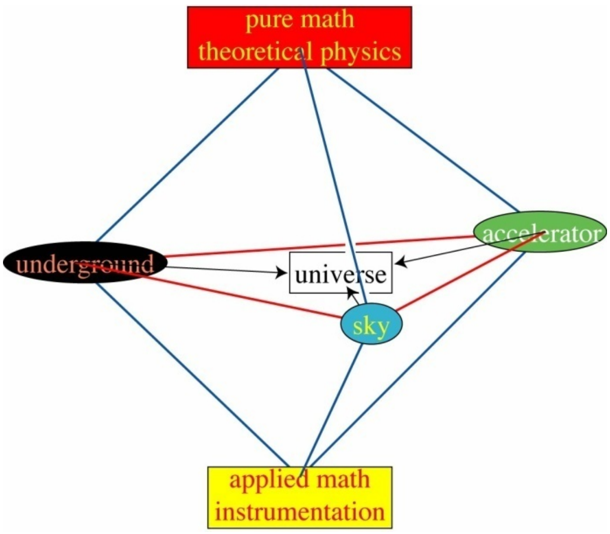
This project is timely and important in that Japan has currently positioned herself to lead this research field and in that this initiative meets demand for Japan to keep a cutting edge in global and competitive Science and Technology environment.

(2) Research objectives

□Describe in a clear and easy-to-understand manner the research objectives that the project seeks to achieve by the end of the grant period (in 10 years). In describing the objectives, the following should be articulated in an easily understandable manner: What new domains are expected to be pioneered by fusing the target fields. In the process, what world-level scientific issues are sought to be resolved. What is the expected impact of the scientific advances to be achieved on society in the future.

□Describe concretely the research plan to achieve the objectives, and any related past achievements by the host institution.

At this Institute we address big questions about the universe, its fundamental laws, its beginning, its fate, and its mysterious components, such as Dark Matter and Dark Energy. For this purpose, we will create new mathematics needed for the unified description of the universe. It will enable new physical theories with testable predictions. Technological innovations follow to make new experiments possible; whose data will further stimulate development in mathematics. This upward spiral will move the science forward, exciting the public at large and motivating students to enter mathematics, science, and engineering to become the next-generation workforce.



Even though it is difficult to accurately predict the possible deliverables from this Institute aimed at basic (not applied) research, here are a few examples of new possible domains we may pioneer on the ten-year time scale:

- Effort by string theorists to enumerate and classify solutions leads to development of new class of geometries.
- New data on dark matter from underground and accelerator experiments of the Institute require new paradigm in particle physics changing the course towards the unified theory in physics, and require new mathematics.
- Mathematical developments in integrable systems allow string theorists to work out new class of solutions that suggest a dynamical behavior of Dark Energy, and prompt new type of observational strategies in spectroscopic galaxy surveys.
- The vast data from the next-generation galaxy surveys nudge the applied mathematicians and statisticians to develop a novel method to extract subtle information from the last data set, uncovering an unanticipated new behavior of Dark Energy.

In all anticipated examples including those above, pure mathematics, theoretical physics, experimental physics underground, astrophysical, and accelerator-based, and instrumentation will motivate each other’s efforts in a way not possible in the usual structure of academic institutions where these activities tend to be decoupled from each other. All of these scientific objectives are keenly shared worldwide, and any discoveries at the Institute will have immediate impacts on the global scale.

To ensure this cross-development of this type, we assembled an amazing group of researchers from around the world. They all have a strong track record in working on subjects not confined in their specific research areas, but extend well beyond the boundaries.

The Institute also builds on the strengths of the Japanese science community in many ways. University of Tokyo and Tohoku University lead the world in well-known success in neutrino physics and move to wider scopes of underground experiments such as dark matter searches. The Subaru telescope, the largest field of view among the world 8m class telescopes, will be exploited.

There is a long tradition for physicists and mathematics to work together which was especially true in the 90’s and can be revamped in the 21st century. There is close relationship between theoretical and experimental particle physicists working on physics beyond the standard model which is unparalleled in the world.

The research plan is mostly about bringing in superb scientists in the relevant areas as termed professors, postdocs, and visitors. All Principal Investigators have a strong track record in securing and managing competitive grants for their research. Focused workshops at the interface of physics, mathematics, and astronomy will bring in worldwide leading scientists to the Institute and breed new directions in the fields and redefine their boundaries. Generous start-up packages and seed money for developing new ideas towards future experiments will bring in competitive grants further. Frequent interactions among the PI’s ensure new directions will emerge at the interface of the traditional boundaries of the subfields.

We anticipate big societal impacts of the Institute in the following way. The questions that the proposed Institute addresses are easy to relate to for laypersons. Excitement in the new paradigms in our understanding of the universe spark interest and imagination among young students and more of them enter the fields of mathematics, sciences and engineering to build a stronger future workforce. New experimental initiatives from the Institute will require new technologies in particular in instrumentations, which get transferred to the industry for new purposes. For instance, development in multi-fiber technology needed for future galaxy surveys may well lead to medical applications. It also reverses the tide of brain-drain from Japan not only by bringing back the Japanese researchers who left the country, but also bringing worldwide researchers to Japan because of the attractive research opportunities.

(3) Management

i) Center director

□Fill in the name of the prospective center director, his/her age (as of 1 October 2007), current affiliation and position title, and specialties. Describe his/her qualifications to be the center director.

□Attach a biographical sketch of the prospective center director using Appendix 2.

□How does the prospective center director intend to construct the center and what is his/her vision of objectives to be achieved? Provide a synopsis written by the prospective center director (free format).

□If possible, attach a letter (s) of recommendation for the prospective center director from researchers with world-standard achievements in the subject field.

Hitoshi Murayama (Age of 43),

MacAdams Professor of Physics, University of California, Berkeley,
Department of Physics, and
Faculty Senior Staff, Lawrence Berkeley National Laboratory,
Theoretical Physics

Qualifications to be the center director:

Professor Murayama is one of the world’s leading theoretical elementary particle physicists and of an outstanding stature. His research specialty and achievements span from the fundamental mathematical physics to phenomenological physics and to experimental research of neutrino physics. His scientific *breadth* is one of key qualifications to be considered as director. He is highly respected and has been deemed as one of the young leaders in the fundamental science community. Professor Murayama has served on numerous scientific-policy making committees in US, Japan and Europe. His breadth of scientific visions and outstanding communications skills together with his tremendous scientific achievements distinguish him as one of the true leaders in the field. Professor Drell emphasizes that one of the most critical roles of the institute director, in addition to articulating the scientific vision, will be to attract talent and foster a culture of collaboration at the institute. Professor Drell attests that Professor Murayama is one of very few gifted people who have the ability to bring people together and develop the institute into something greater than the sum of its individuals. Professor Murayama is best qualified to command this new, bold and timely WPI program, “the Institute for the Physics and Mathematics of the Universe.”

Professor Murayama will return to the University of Tokyo in January 2008 and will work for the project as its full-time director

ii) Administrative director

- Fill in the name of the prospective administrative director, his/her age (as of 1 October 2007), current affiliation and position title. Describe his/her qualifications to be the administrative director.
- Attach a CV of the prospective administrative director (free format).

Kenzo Nakamura (Age of 62)

Professor, Institute of Particle and Nuclear Studies, KEK

Qualifications to be the administrative director:

Professor Nakamura had served as Head of Experimental Planning & Coordination Group at KEK for 1995-1997, and subsequently as Head of Physics Department III of Institute of Particle and Nuclear Studies at KEK for 1997-2006. His experience and excellent administrative skills will be indispensable to start up the administrative organization of the Institute and maintain highly efficient and effective function of the administration. He has extensive experience of how to supervise administrative staff members. Because he is a physicist by training he will be readily integrated to the scientific organization and will be able to work coherently with researchers in the Institute. Professor Nakamura knows and understands what makes a work environment most adequate to researchers. We are extremely pleased and fortunate to have Professor Nakamura as head of the administrative staff.

iii) Composition of administrative staff

- Concretely describe how the administrative staff is organized.

The administrative staff is an integral part of the Institute. The administrative organization belongs to Directorate that consists of the Director, Deputy Directors and Administrative director. Because this Institute belongs *directly* to the Office of the President (without any other intervening layers of administration), the University has committed to make administration resource at the University headquarter available to the Institute. The Institute directorate will have direct access to the administration office at the University headquarter and will share its resources. With this direct coupling to the Office of the President, we envision our administrative organization will be streamlined, yet very effective to provide the best possible environment to the researchers in the Institute.

On site, we will have, under the administrative director’s supervision, offices devoted to 1) general affairs and human resources, 2) financial/budget planning and accounting 3) information and public communication/outreach, and 4) international affairs. Each office consists of a chief officer and a few assistants. These offices will perform day-to-day administrative function and will, whenever necessary, work directly with the directors of the institute. The office of international affairs is particularly important for the institute. It helps our foreign employees and visitors to find houses, international schools for their children, and helps for organizing international conferences and workshops. We hire skilled experts for many sections and plan to fill more than 50% of staff member positions by persons who are bilingual.

iv) Decision-making system

- Concretely describe the center’s decision-making system.

As shown in the organization chart included in the section of Project Summary, except for personnel decisions regarding the center director and principal investigators (PI’s), which will be made by the President, the center Director has a complete authority of making a wide range of decisions, including proposing recruitment of PI’s to the President, appointing staff researchers, postdoctoral researchers, research support staff members and administrative employees. The Director will be assisted, whenever needed, by two deputy directors and by the administrative director.

The administrative director conducts administrative business and oversees the staff members who take care of visitors from other Japanese institutions and from abroad. His function enables the Director to spend more time to consider the Institute at large and to focus on the direction of the research. The Director will have direct access to the Office of the President and will be able to consult with the President and his assistant staff members.

The Scientific Advisory Committee (SAC) reporting to the Director consists of four to five PI's of his choice. They advise the Director on planning of hiring staff members as well as scientific directions. The role is strictly advisory. The Director is solely responsible for making the final decisions. The PI's have a large autonomy in the research they conduct and they are encouraged to fund their research through competitive grants. They can make a proposal to the Director to hire postdocs and termed professors to help their research. The Director's approval on the proposed appointments will reflect the scientific vision and priorities set by the Director, who may consult the SAC as needed.

Of particular importance is the External Advisory Board (EAB) who will review annually the scientific achievement and activities of the Institute and advise the Director on the scientific priorities and the research activities to keep the Institute stay on the course of the proposed science. At least half of EAB members consist of scientists from institutes other than the University of Tokyo.

v) Allocation of authority between the center director and the host institution's side

・Concretely describe how authority is allocated between the center director and the host institution's side.

We have agreement with the Office of the President that except for the appointment of the Director and approval of appointments of PIs, the center Director has the authority to make a wide range of decisions from how to compose and organize the institute to how to operate it.

(4) Researchers and other center staffs

i) The "core" to be established within the host institution

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

	numbers		
	At beginning	At end of FY 2007	Final goal (Date: month, year)
Researchers from within the host institution	10	10	10 (Mar,2009)
Foreign researchers invited from abroad	5	5	7 (Mar,2009)
Researchers invited from other Japanese institutions	5	5	5
Total principal investigators	20	20	22 (Mar,2009)

・Describe the concrete plan to achieve final staffing goal, including steps and timetables.
・Attach a list of principal investigators who are expected to join the center at the time of the application using Appendix 1. Place an asterisk (*) by names of the investigators considered to be ranked among the world's top researchers. Describe the policy and strategy for inviting the rest of PIs who are to be invited in the future.
・Attach a biographical sketch of each investigator using Appendix 2.
・As for the researchers invited from abroad or from other Japanese institutions, attach a letter of intent from each of them to join the center project (free format).

By the end of FY 2008 (Mar, 2009) we plan to recruit two more PI's who work on theoretical cosmology and/or particle physics phenomenology. Potential candidates have been identified and we will actively pursue the opportunities.

b) Total members

	Numbers		
	At beginning	At end of FY 2007	Final goal (Date: month, year)
Researchers (Number of foreign researchers among them and their percentage)	20 (5, 25%)	66 (Mar,2009) (14, 21%)	195(Mar,2011) (69, 35%)
Principal investigators (Number of foreign researchers among them and their percentage)	20 (5, 25%)	20 (5, 25%)	22 (Mar,2009) (6, 27%)
Other researchers (Number of foreign researchers among them and their percentage)	0	48 (9, 19%)	173(Mar,2011) (63, 36%)
Research support staffs	0	10	20 (Mar,2009)
Administrative staffs	3	10	10
Total number of people who form the “core” of the research center	23	86	225 (Mar, 2011)

- Describe your concrete plan to achieve the final staffing goal, including steps and timetables.

We plan to hire two or more termed associated professors who work with PI’s in the area of observational and theoretical cosmology by the end of JFY2008.

We have identified as a candidate for the termed professor a mid-career mathematical physicist who is currently a faculty member with a joint appointment between Mathematics and Physics Departments in a major research university abroad. We also plan to make an appointment of a termed associate professor who will lead the analysis of LHC data. Both of the appointments are to be made by the end of JFY2008.

Starting immediately we aggressively solicit postdoctoral fellows. We plan to make 7 appointments in JFY2007 and additional 21 in FY2008. Three administrative staffs will be transferred from the University headquarter to the Institute. Three additional administrative staffs will be hired by the Institute in FY2007.

Therefore, the Institute as a whole, including researchers from collaborating institutions and others, will become an organization consisting of more than 200 researchers.

ii) Collaboration with other institutions

- If the “core” forms linkages with other institutions, domestic and/or foreign, by establishing satellite functions, fill in the name of the partner institution(s), and describe the role of the satellite functions, personnel composition and structure, and collaborative framework between the host institution and the said partner institutions (e.g., contracts to be concluded, scheme for resource transfer).
- If some of the principal investigators will be stationed at satellites, attach a list of these principal investigators and the name of their satellite organizations using Appendix 1, and provide a biographical sketch of each using Appendix 2.
- If the “core” forms organic linkages with other institutions, domestic and/or foreign, without establishing satellite functions, fill in the names of the partner institutions and describe their roles and linkages within the center project.

The institute establishes an IPMU Kamioka satellite to promote closer collaboration with the neutrino group. It locates close to the Super-Kamiokande and KamLAND detectors. It gathers researchers who work on the underground experimental activities such as study of neutrino physics and XMASS, a new dark matter search experiment that has recently been funded. Two PI's, Professor Masayuki Nakahata of University of Tokyo and Professor Kunio Inoue of Tohoku University, will be stationed at the satellite and we will have researches jointly appointed from neutrino group.

One of the PI'S has already a grant with scientists at NAOJ to pursue the dark energy project. We also gather scientists from the world to conduct an analysis on the data from LHC. We have already a candidate for an associate professor.

Principal Investigators of the Institute collaborate with scientists from the following institutions:

1) IHES (Institut des Hautes Études Scientifiques) in France (for mathematics),
2) Yukawa Institute for Theoretical Physics, Kyoto University (for theoretical physics),
3) Department of Physics, Kyoto University (for neutrino physics),
4) High Energy Accelerator Research Organization (KEK) (for neutrino physics),
5) National Astronomical Observatory in Japan (NAOJ) (for dark energy survey and astronomy),
6) Department of Astrophysical Sciences, Princeton University in USA (for dark energy survey and astronomy)
7) Department of Physics, University of California, Berkeley in USA (for theoretical physics),
8) Research Center for Neutrino Science, Tohoku University.

(５) Research Environment

ｉ) Provide an environment in which researchers can devote themselves exclusively to their research, by exempting them from other duties and providing them with adequate staff support to handle paperwork and other administrative functions.

The Director will secure the funds to hire administrative staff and research support staffs to assure that researchers of the Institute be exempt from paper works associated with conducing researchers. In addition, for PI's from University of Tokyo, the Office of the President will provide resources that enable PI's to substitute their teaching duties in their original departments.

ii） Provide startup research funding as necessary to ensure that top-caliber researchers invited to the center do not upon arrival lose momentum in vigorously pursuing their work out of concern over the need to apply immediately for competitive grants.

Many of PI's of the Institute have already secured research fund by winning competitive grants. The Director will secure startup funds for young researchers and postdoctotal fellows hired by the Institute.

iii) As a rule, fill postdoctoral positions through open international solicitations.

We will post all the job openings on major journals of the community such as Physics Today and will contact proactively via Emails leading scientists of the field, both in Japan and abroad, to solicit outstanding candidates.

iv) Establish English as the primary language for work-related communication, and appoint administrative personnel who can facilitate the use of English in the work process.

In the fields of particle physics, mathematics and astronomy it has been the standard practice for researchers to speak English for work-related communication. We will assemble administrative staff members as well as research support members who are fluent in English with help from the Office of the President.

ｖ) Adopt a rigorous system for evaluating research and a system of merit-based compensation. (For example, institute a merit-based annual salary system primarily for researchers from outside the host institution. As a basic rule, the salaries of researchers who were already employed at the host institution prior to the centers' establishment are to be paid by the host institution.)

Salary of the center director will be negotiated through the office of the President. Annual salaries for PI's will be decided by the Director. Salaries of researchers other than PI's will be decided by the Director with consultation to Deputy Directors. Evaluation of researchers will be strictly merit-based and will include citation counts, invited talks at international conference, cross-disciplinary papers, salaries at competing institutions abroad, and leadership roles at the Institute.

ⅵ) Provide equipment and facilities, including laboratory space, appropriate to a top world-level research center.

The University administration pledges to build a new building on Kashiwa campus for the Institute. The architecture will follow the style of Kavli Institute for Theoretical Physics at UC Santa Barbara and Center for Theoretical Physics at UC Berkeley with a large open area and amenities. It will provide an attractive and competitive environment for researchers from around the world.

We plan to have a state-of-art video conference system and internet-blackboards among Kashiwa, Hongo, Komaba, Kamioka and other collaborating institutions that stay on 24hours a day, 7days a week to make impromptu discussions possible.

ⅶ) Hold international research conferences or symposiums regularly (at least once a year) to bring the world's leading researchers together at the center.

Annual international conference at the Institute as well as long-duration workshops à la Kavli Institute for Theoretical Physics and Aspen Center for Physics will be held. They will bring in visitors to further stimulate the intellectual activities and keep the Institute at the forefront of worldwide science.

ⅷ) Other measures to ensure that top-caliber researchers from around the world can comfortably devote themselves to their research in a competitive international environment, if any.

The University is constructing Kashiwa International Lodge that will be a main residential facility for foreign researchers who have moved to the Institute and short-term visitors. Meanwhile, the University will help the foreign researchers to find housings. The Institute's foreign affairs office will fully conduct the business related to foreign researchers together with the Office of the President.

(6) Indicators for evaluating a center's global standing

ⅰ) Criteria and methods to be used forevaluating the center's global standing in the subject field
ii) Results of current assessment made using said criteria and methods
ii) Goals to be achieved through the project (at time of interim and final evaluations)

1) We introduce quantitative and objective methods to evaluate the Institute's global standing. The number of refereed journal papers, the number of citations of the papers the Institute researchers published, and the number of presentations our researchers deliver in the major international conferences will be kept monitored and tracked. These "numbers" form a base of evaluation of the center 's global standing.

2) The number of visitors and the number of foreign visitors among them are another objective indicator to measure the activity and visibility of the Institute.

3) In order to evaluate how effective the Institute is to bring mathematicians and physicists together, we plan to monitor the number of publications co-authored by mathematicians and physicists. It will be a measure of the synergy between the two disciplines.

The proposed institute has already positioned itself as one of the most cited Institutions in Physics research. This is because all the principal investigators we assembled are leading scientists in their own discipline and the number of citations of each investigator is outstanding.

Criteria 2 and 3 are, of course, yet to be applied.

The goal to meet the criteria 1) is clear. We will maintain the statue of the most cited Institution in Physics and Mathematics. We aim to be one of the most visible research organizations in Physics and Mathematics.

(7) Securing research funding

ｉ)Past record

- Indicate the total amount of research funding (e.g., competitive funding) secured by principal investigators who will join the center project. Itemize by fiscal year (FY2002-2006) taking into account the percentage of time each will devote to research activities at the center vis-à-vis the total time they spend conducting research activities（"Effort ②" in Appendix 2）. For example, if this percentage is 70%, then 70% of his/her research funds can be counted in calculating the total amount of research funds.

FY2002: $9.7M, FY2003: $10.9M, FY2004: $9.5M, FY2005: $13.2M, FY2006: $13.6M
(in units of US dollars, Exchange Rate: JPY/USD=120)

Grand total of competitive funding awarded to PI's over past 5 years is $56.9M.

ii) Prospects after establishment of the center

・ Based on the past record, describe the concrete prospects for securing resources that match or exceed the project grant.
・ Calculate the total amount of research funding (e.g., competitive funding) based on the percentage of time the researchers devote to research activities at the center vis-à-vis the total time they spend conducting research activities（"Effort ②" in Appendix 2）. Be sure the prospects are realistically based on the past record.

Principal Investigators of the Institute have already secured competitive funding that amounts to approximately $55M, the same level as that of the past five years. We are, therefore, confident to maintain the same funding profile well into the era of this new Institute.

Others

・ Describe activities and initiatives to be taken after project funding ends.

We intend to keep the Institute as the advanced institute of the University, a permanent entity that belongs to the University. We plan to work, with the Office of the President, to raise the fund.

・ Describe expected ripple effects（e.g., how the proposed research center project will have trailblazing components that can be referred to by other departments in the host institution and/or other research institutions when attempting to build their own top world-level research centers）.

We are confident that our aggressive approach to assemble the world-leading scientists from other institutions from within Japan or from abroad and our ambitious organization will have significant impact to the University. Also the merit-based evaluation system we introduce would be so attractive to young researchers that it could become a model that other institutions would follow.

・ Describe other important measures to be taken in creating a world premier international research center, if any.

We will be proactive to raise funding for the Institute. In particular, we engage fundraising from the private sector both in Japan and abroad.

In order to promote competitive atmosphere among PI's and senior researchers, we plan to institute a named distinguished professorship. It will be awarded by the Institute Director to an Institute professor after rigorous evaluation of his/her performance at the Institute.

- If one or more of the projects applying for Global COE program have some connections with this research center project, list the project title(s) , outline(s), group leader(s) and the relationship(s) with this project.

Since the call for proposal of Global COE program for the disciplines related to the Institute, which are mathematics and physics, is scheduled for FY2008, there are no Global COE programs to list. Some of PI's, however, will definitely be involved in some of Global COE proposals that are under consideration. We as the Institute will seek close collaboration with such Global COE programs once they have been more developed and its relevance to the Institute has become more evident.

Institute
for the Physics and Mathematics
of the Universe

September 27, 2007

Vision by the Director, Hitoshi Murayama, University of California, Berkeley

The Institute for the Physics and Mathematics of the Universe is a unique research center in the world that spans from pure mathematics to theoretical physics, to experimental physics, astronomy, and applied mathematics. We address big questions about the universe, its fundamental laws, its beginning, its fate, and its mysterious components, such as Dark Matter and Dark Energy. For this purpose, we will create new mathematics needed for the unified description of the universe. It will enable new physical theories with testable predictions. Technological innovations follow to make new experiments possible; whose data will further stimulate development in mathematics. This upward spiral will move the science forward, exciting the public at large and motivating students to enter mathematics, science, and engineering to become the next-generation workforce.

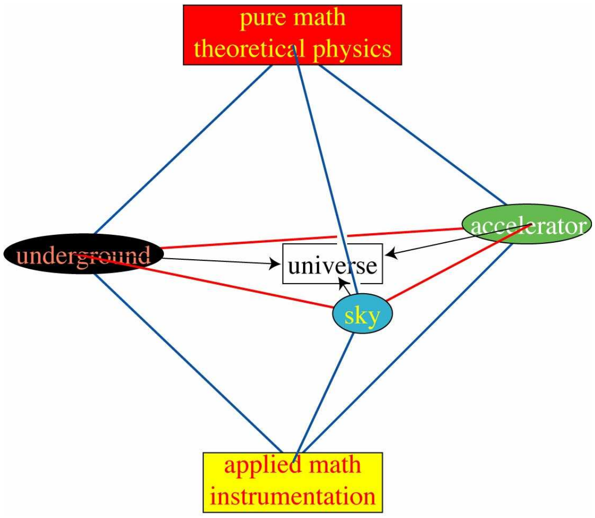
1. Introduction

As far back as the history goes, human beings have always pondered about the origin of the universe, how it is structured, how it works, and where it is going. The study of the universe is the most ancient science and most fundamental. By using modern technology and development of theoretical framework, we can now address the ancient questions that were once studied only by pure thought. This Institute is nothing but an attack on the ultimate questions of humans:

(1) How did the universe start?
(2) What is the universe made of?
(3) What is the fate of the universe?
(4) What are its fundamental laws?
(5) Why do we exist?

There is no doubt that they are truly fundamental, worthwhile, yet extremely challenging questions. Answers to these questions are what Einstein once dreamed about in his quest of the "unified field theory." The Institute we propose is aimed squarely at the unified description of the universe, based on multi-disciplinary framework that combines physics, astronomy, and mathematics. It will be a unique research center in the world that spans the disciplines from mathematics to experimental physics addressing the big questions about the universe. In addition, the list of the Principal Investigators we managed to assemble will be a magnet to attract more world-leading scientists to the Institute as visitors and collaborators. There is a good potential that the Institute will uncover a new paradigm of the universe based on a new mathematical framework and new precision data developed by the participating scientists.

2. Science



My vision of the Institute is a multi-prong but coherent attack on the fundamental questions about the universe. It is based on three broad experimental approaches, tied together with two common threads.

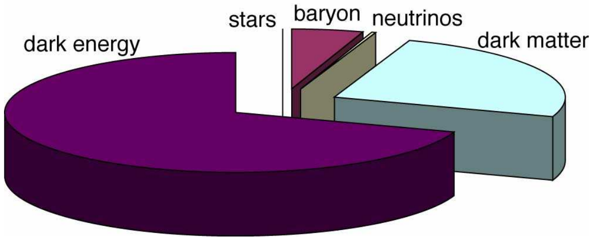
2.1 Why Physics and Mathematics?

The reason for the combination of physics, mathematics, and astronomy is quite obvious. It has been the case, and will be for the foreseeable future, that mathematics is the foundation for all sciences. Physics and astronomy are the most quantitative among sciences and rely heavily on the most advanced types of mathematics. At the same time, the need to build cutting-edge theories in physics sparked inspiration among mathematicians, often opening new directions in mathematics research as evidenced by recent Fields medals.

The fundamental impact of mathematics on our understanding of the universe is well described in this quote from Galileo Galilei: *"Philosophy is written in this grand book – I mean the Universe – which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, without which it is humanly impossible to understand a single word of."*

This type of cross-development has been an important strength of science in Japan, and some of the best practitioners in this area are represented as Principal Investigators of the Institute. The Institute will provide a meeting place for physicists and mathematicians interested in fundamental questions of the universe. It will enhance their interaction, nurture young talents, and help secure future progress of mathematical and physical sciences in Japan. New theories of physics developed with help of mathematics provide further motivation to use the universe as a whole as a laboratory, requiring advances in astronomy. Conversely, data from astrophysical observations have been the key impetus to develop deep insight into the inner workings of the universe since the time of Copernicus, Newton, to Einstein and today.

2.2 The Three Experimental Approaches



Let me briefly review what we know about what the universe is made of. For centuries, humans had believed that the entire universe is made of the same material we are made of, namely atoms. In the past decade, this belief was completely overturned. The atoms make up less than 5% of the universe. The dark matter comprises the rest of the matter, about 23% of the universe, yet we do not know what it is. The remainder of about 72% is dark energy that is supposed to be responsible for the accelerated expansion of the universe. We know even less about what dark energy is. In addition to the discovery that there are unknown components in the universe, there are also mysteries about the components that should exist yet we don't find. Anti-matter can be created in the laboratory and was surely created in Big Bang. Yet we do not see it in the universe. In addition, we know the universe is superconducting and makes certain kinds of forces short-ranged within a billionth of a nanometer while keeping electromagnetism and gravity long-ranged. The energy density of the superconductor should contribute about 10^{62}% to that of the universe, which must be cancelled by yet another component at an incredible accuracy. All of these observations cry out for a new paradigm of the universe, and hence new physics and new mathematics.

a) Underground

One broad experimental approach to address these questions is underground experiments for rare processes. This is precisely where Japan is leading the world and we can build on the existing strength. Prof. Koshiba won 2002 Nobel prize in physics for his discovery of neutrinos from the supernova 1987A, a massive star that had reached its end of life with a tremendous explosion as bright as an entire galaxy. He demonstrated that neutrinos can be used to study the universe in a way not imagined before with the Kamiokande detector. The SuperKamiokande and KamLAND experiments running right now undoubtedly lead the world in this area, addressing fundamental questions about the universe and the unified theory behind it. To a great surprise to the scientific community, they discovered that ghostly neutrinos have tiny but finite masses at the level predicted by the unified theories at 13 orders of magnitude beyond the reach of the current accelerator experiments. Thus, the neutrino masses are giving us a precious glimpse of physics at the ultra-high energy and very early universe.

I anticipate this tradition will continue, because the underground science is far from over but is actually flourishing. For example, underground experiments are likely avenues to discover the dark matter of the universe. While dark matter makes up most of the mass of the Galaxy, its nature remains a mystery. It is perhaps ironic that the best way to study the universe is to go underground. Another example is the discovery of a new type of neutrino mixing at SuperKamiokande with a neutrino beam from the J-PARC accelerator in Tokai village. It opens a novel way to attack the mystery why we exist in the universe at all, namely the preponderance of matter over anti-matter.

b) Sky

On the other hand, the experimental approach to look up at the sky is undoubtedly a very essential one. Both in ground-based and space-based observations, we have made great strides in recent years. For instance, we have determined the breakdown of the composition of the universe. In addition to the unknown dark matter component, the universe is dominated by the dark energy that is even less understood. It is ripping the universe apart, and appears to be an infinite source of energy. Large-scale galaxy surveys, in particular aimed at the baryonic acoustic oscillations that would precisely determine how quickly the dark energy generates energy, more detailed studies of cosmic microwave background, in particular aimed at the B-mode polarization that would determine the energy scale of the inflation, and advanced computing for sophisticated data analysis will further revolutionize our understanding of the universe. Japan is catching up with the Americans and Europeans in this area, and is poised to make critical advances thanks to the new Subaru telescope.

c) Accelerator

Finally the most direct assault on the mysteries of the universe comes from the brute-force method that tries to recreate the Big Bang in the laboratory, namely particle accelerators. They smash microscopic particles at ever increasing energies to mimic the Big Bang in a “Little Bang” that brings us direct and critical information on the condition at the birth of the universe. Japan leads the world in construction and operation of particle accelerators as evidenced by the incredible success of KEK-B; it beats the closest competitor in the US by more than a factor of three in its performance. This year, the new highest energy accelerator, LHC, starts operation in Europe, and Japan is an essential member of this frontier science. It contributed both financially and technologically. On the other hand, Japan needs to be stronger in the large-scale data analysis with increased human resources, exploiting the precious data set, competing with the European center, to ensure a successful future in this area.

Note that the Institute funds will not be used to subsidize the existing experimental programs with these three approaches that are already funded through competitive grants. Instead, the Institute will maximize the scientific output from these programs by freeing up time of PIs from duties to focus on research, hiring postdocs and termed professors to add personnel for data analyses, and start development work for future projects with small seed money.

2.3 Common Threads

It is clear to me that the mysteries of the universe can be revealed only through the multi-prong experimental assault on these three fronts: underground, sky, and accelerator. The Institute we propose will push all of these approaches in a realistic manner that builds on the current strengths of science in Japan. On the other hand, this push will not succeed without common threads that tie them together. The threads I envision are theoretical physics that is closely tied with the highly advanced mathematics, and instrumentation and applied mathematics that can be shared by the disparate experimental approaches.

Theoretical physics aims to develop the unified description of the universe based on the available data, and allows us to guide the future plans for next-generation experiments. To tackle the challenging mystery at the birth of the universe, new types of highly sophisticated mathematics will be needed. The multi-disciplinary fusion of physics, mathematics, and astronomy, therefore, will be crucial for the success of the Institute. Japan has a long-standing tradition in this area, starting from the past Nobel prizes awarded to Yukawa and Tomonaga. Historically, many critical advances in mathematics came from the need to formulate important questions in physics, and this tradition continues to date. I envision the effort to come up with unified understanding of the universe at its most fundamental level would require new mathematics not available today; it will spark inspiration among world-leading mathematicians of the Institute to launch new directions in mathematics. At the same time, world-leading theoretical physicists at the Institute will benefit from such new directions and use them in their effort to build the unified theory of the universe.

In addition, applied mathematics and statistics would provide novel approach to deal with huge data set provided from next-generation experiments. The future data from galaxy surveys, accelerator and underground data will be measured in Pentabytes (billion Megabytes) and pose an incredible challenge in extracting critical scientific information out of them. Recently new methodologies such as neural networks, boosted decision tree, and Markov chain Monte Carlo, have been applied to large data set; on the other hand, the need to deal with such a huge data set inspires applied mathematicians to discover further innovative methodologies. For example, there is need to treat geometric objects, such as event displays and galaxy images, on a statistical bases. The "stochastic geometry" that addresses these needs has been hampered by a slow progress in part due to the lack of specific problems to attack. The data from experiments the Institute will deal with provide specific problems and boost progress in developing new methodologies in this new area of mathematics/statistics. This way, the Institute will cope with data from disparate experimental efforts that nonetheless benefit from this common problem and interaction with mathematicians.

Furthermore, new experimental ideas emerge from the interaction of theorists and experimentalists, which would require "try-outs" at small scales to refine the ideas before they can be proposed as realistic projects. Sharing expertise and experience in instrumentation and data analysis will be the key, and small amounts of "seed money" supported by the Institute will kick-start the actual development work. Once the development work matures, the PIs will seek support from competitive grants for the actual experiments. The initial examples will include development of multi-fiber spectrograph for future large-scale spectroscopic galaxy surveys, phototubes and ultralow background environment for future underground experiments. As a highly technological country, Japan surely can provide leadership in this area.

This way, theory/pure mathematics and instrumentation/applied mathematics provide two critical common threads to the three broad experimental approaches mentioned above.

Putting them together, I believe this Institute will provide an exciting environment that builds on the current strengths in the Japanese scientific scene, makes a strong push in three broad experimental approaches, yet provides critical common threads to keep the diverse activity coherent.

This kind of Institute will be truly unique in the world. Kavli Institute for Theoretical Physics is a fantastic place, yet does only theoretical physics. There are many first-rate institutions that combine research in mathematics and theoretical physics, such as Isaac Newton Institute for Mathematical Sciences in Cambridge, Institute for Advanced Study in Princeton, IHES in France, such as MSRI in Berkeley, but none of them include experimental physics in their program. There are also great institutions on both theoretical and experimental physics, such as CERN, Fermilab, SLAC, KEK, but none of them have mathematicians. The combination of science this Institute will include should attract best people from the world because of its uniqueness and potential for major breakthroughs.

3. Synergy of Mathematics and Physics

Since it may not be obvious how exactly mathematics and physics can stimulate each other's progress, I'd like to describe some background behind this anticipated fruitful fusion based on historical examples with an emphasis on the role played by our members.

The search for the fundamental laws of Nature requires inventing new mathematics, and it has inspired many important developments in mathematics. For example, approximately 40% of Fields Medalists in mathematics since 1990 have worked in areas closely related to quantum field theory and string theory. No other area of science has had such a great impact on mathematics in the past few decades, and the rate of progress in this area suggests that this trend will only accelerate in future. At the same time, new theoretical tools developed by mathematicians have had an enormous impact on progress of particle physics. For example, they have enabled physicists to evaluate strongly coupled effects in quantum field theory and string theory at the level that was unimaginable 20 years ago.

In the past couple of decades, remarkable progress has been made in applications of string theory to problems in geometry. The mirror symmetry, predicted by physicists and proven by mathematicians, gave a powerful tool to compute Gromov-Witten invariants of symplectic manifolds. Moreover, collaborations of mathematicians and physicists have uncovered surprising relations of these computations to gauge theory instantons, integrable statistical systems, and combinatorics. Currently, this is one of the most active areas in geometry, and its progress has lead to two Fields Medals in mathematics (Kontsevich and Okounkov).

Hirosi Ooguri has been one of the leaders in this area in physics, and he has used Gromov-Witten invariants and related mathematics to address fundamental questions in the unification and quantum gravity. I have also identified another mathematical physicist, who has made important contributions in this area, as a candidate for a mid-career member in residence at Kashiwa. The candidate is currently a faculty member in a joint appointment in mathematics and physics at a major research university abroad with an extensive record of collaborations with both mathematicians and physicists. Moreover, there are mathematics faculty members in Komaba, who have worked on Gromov-Witten invariants and related mathematics. Kontsevich and Nekrasov of IHES, France have also agreed to be collaborative researchers of the Institute. I expect that the Institute will lead the world in this area.

Arguably, the most famous example of discovery of new mathematics inspired by physics is the simultaneous invention of Calculus and Newton's Mechanics. In this case, precise mathematical formulations of infinitesimal and continuity were essential. Looking forward to future, I expect that developing tools to analyze systems with infinite dimensional degrees of freedom – infinite analysis – will play an equally important role in mathematics and physics of the 21st century.

QCD, which describes strong interactions of elementary particles, is an example of an infinite dimensional system. In 2000, the Clay Mathematics Institute posed Seven Millennium Problems. One of them is an existence proof of QCD with a demonstration of its confinement property since it is expected that its solution would totally alter our view of the short-distance frontier in physics while opening up new and fertile ground for mathematical research. Another example of infinite analysis would be stringy geometry. Traditionally, mathematicians have studied geometric objects with a point-like object as a probe. String, as being an object extended in space, would provide a new perspective in geometry. This has already been evidenced in the mirror symmetry and Gromov-Witten invariant, discussed in the above. But, I think they are just tips of a big iceberg and more will come from this direction in mathematics. Mathematical tools developed in this area would enable physicists to derive more robust predictions from string theory.

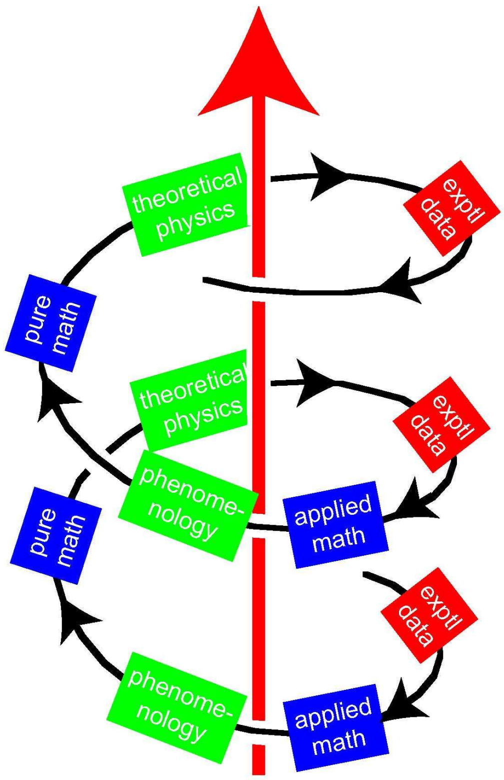
Infinite analysis is also relevant to statistics of geometrical objects. For example, techniques of conformal field theory have been used to study stochastic geometry of self-avoiding random walks – the citation of Fields Medal to Werner last year. Research in this direction may lead to new tools to analyze geometric data from astrophysical observations and accelerator physics experiments.

In the late 80's and early 90's, collaborations between mathematicians and physicists in Japan interested in infinite analysis were very strong. In the early 90's, JSPS funded a grant in this interdisciplinary area at the level of $9M for 4 years. Some of PI's of this proposal, Jimbo, Kohno, and Tsuchiya of mathematics and Ooguri of physics, were PI's of this JSPS project. This was an enormous success, and produced several important joint projects between mathematicians and physicists. It also helped to identify and nurture new talents in mathematics and theoretical physics. In particular, at least 10 physics graduate students, who have grown up in this environment, subsequently moved to mathematics and received faculty appointments in mathematics departments of major universities in Japan. I myself grew up in this exciting environment as a graduate student at University of Tokyo, and my very first two publications in 1988-9 concerned with connections between physics and mathematics following up on the Fields Medal paper by Witten.

Worldwide, this area at the interface of mathematics and physics has made a remarkable stride in the past ten years. Yet, in Japan, collaborations between mathematicians and physicists have somewhat weakened in the same period. I have re-assembled many of the original members of the JPSP project, by attracting Ooguri from Caltech and by including Jimbo, Kohno and Tsuchiya as PI's of mathematics. They will re-ignite collaborations of mathematicians and physicists, and I expect that their efforts will lead to a new paradigm of mathematics and physics in the 21st century.

4. Discovery scenarios and Deliverables

I foresee unprecedented cross-pollination within the Institute that can be explained in a few likely examples. This type of advancement will go in an upward “spiral” that brings mathematics, physics, and astronomy together.



4.1 Initial Activities

I see the initial activities of the Institute focusing on the following areas.

- New galaxy surveys that address nature of dark energy, which may exclude the quantum vacuum energy as its source and require a new dynamics in quantum field theory.
- Improved understanding of neutrino parameters that constrain unified theories, dynamics of supernova explosions, and origin of matter
- Exploitation of the coming LHC data

jointly by experimentalists and theorists that may reveal new forces and symmetries of nature that existed at the birth of the universe.

- Development of new underground experiments that may establish the dark matter in our galactic halo as a new kind of elementary particle and let us see inside the Earth using neutrinos.
- Full understanding of the behavior of quantum field theories in the strong-coupled regime, one of the "Millennium Problems" of the Clay Mathematics Institute, using methods of integrable systems and through equivalence of quantum field theories to the theory of gravity, i.e. the AdS/CFT correspondence.
- Developments of new tools in geometry that help us understand the full scope of solutions to the string theory.
- Discovery of new algorithms that allow us to extract science from Pentabyte-scale astrophysical data about dark energy.

4.2 Potential Deliverables

Even though it cannot be predicted precisely what the Institute will deliver, I can describe a few potential scenarios of exciting research output from the Institute:

- Consistent picture of the dark matter of the universe among the data from the underground detection experiments in Kamioka and from the advanced analyses of LHC data, based on new mathematical techniques developed at the Institute. The Institute theorists provide a framework to explain this diverse data set, making predictions of neutrino and gamma ray signals that spark new experimental effort. At the same time, new effort is launched to incorporate the newly gained information on dark matter into the unified theory. New mathematical tools are developed at the Institute to let physicists build a candidate unified theory out of the string theory and to derive its experimental predictions. At the same time, these tools are used by the Institute mathematicians to define new invariants of manifolds and help them solve outstanding problems in geometry.
- Large-scale galaxy surveys reveal the properties of the dark energy that accelerates the expansion of the universe. A large-scale computing developed by applied mathematicians of the Institute will allow them to explore the "landscape" of solutions to the string theory, which show a large fraction of them exhibits the same behavior of the dark energy as the data suggest. It will show that the fate of the universe is not the accelerated expansion forever, but rather a quantum tunneling of the universe to a state with slower expansion by the formation of bubbles in a several billions of years from now.
- Another outcome from the galaxy surveys is the measurement of the spectral index, which constrains the models of inflation. Time-dependent solutions to the string theory, such as the inflationary universe, are not well understood. Institute physicists join forces with experts of integrable systems in mathematics to develop a new mathematical framework to describe these solutions. Through collaboration among astrophysical, particle, and string theorists, it is found that

the data severely limit the possible solutions from the string theory, and makes further predictions on the cosmological data, in particular tensor-mode density fluctuation that will be pursued by new initiatives at the Institute. In addition, the vast data from the next-generation galaxy surveys nudge the applied mathematicians and statisticians to develop a novel method to extract subtle information from the last data set, uncovering an unanticipated new behavior of Dark Energy.

- Institute supports data analysis of the next-generation neutrino experiments, which discover a new type of neutrino mixing. It influences the study of supernova explosions to see if they are responsible for the formation of trans-iron elements on the Earth. In addition, it also completes the information about the structure of fermion masses and mixings, and it constraints compactifications of the string theory. It further points to the possible origin of our existence through the topological transitions in gauge theories.
- Combination of possible discoveries such as the ultimate instability of all matter, hints of multiverse, and ever accelerating expansion of the universe will reach the mind of public at large, influencing the society in its philosophical, spiritual, as well as religious sectors.

4.3 Assembled membership to achieve our goals

For the membership, I believe we have managed to assemble an amazing group of world-leading, not just world-class, scientists.

We already have the world-leading core group working on underground experiments, led by Yoichiro Suzuki, Takaaki Kajita, Masayuki Nakahata, and Kunio Inoue. Hank Sobel from Irvine and Stavros Katsanevas from Paris further boost the strength of this group. As for the "sky" approach, we have a core strength in hardware and data acquisition represented by Masataka Fukugita and Hiroaki Aihara, and on large-scale data interpretation by Naoshi Sugiyama. David Spergel from Princeton has successfully extracted science from the huge WMAP data set and is involved in Hyper Suprime-Cam at Subaru, and Ken'ichi Nomoto provides much-needed expertise in stellar dynamics. On the accelerator side, Aihara's hardware skill needs to be matched with the simulation and data analysis effort. I myself will be heavily involved in building a group of theorists studying the data from the LHC. We have identified a candidate experimental physicist dedicated on the LHC research as well as a candidate theoretical physicist studying the signal of various new theories at the LHC to be appointed at the Associate Professor level to further strengthens this area and improve standing of the Japanese group overall.

Tsutomu Yanagida will pursue unified theories locally, and also by Ooguri from Caltech, who is a world-expert on the string theory, the best candidate for the unified theory. Akihiro Tsuchiya, who is a former chairman of Mathematics Department of Nagoya University, will join the Institute. He has an extensive record of conducting research at the interface of mathematics and physics as well as organizing research groups in this area. With Ooguri, he will spearhead the math/physics collaboration at the Institute.

Local mathematicians Michio Jimbo and Toshitake Kohno are experts in exactly solvable systems and in geometry, respectively, and they will add further strengths to build collaboration between mathematicians and physicists to develop new mathematical frameworks towards the unified theory. We have already identified collaborators (including mathematicians in Kyoto Tetsuji Miwa and Hiraku Nakajima, with track records in successful collaborations with physicists, YITP Director Tohru Eguchi, and a Fields medalist Konsevitch, and Nikita Nekrasov from IHES) to further strengthen this area. Cosmological theories in inflation and Big Bang itself are well covered by Katsuhiko Sato, one of the initiators of the inflation theory.

I had a personal experience at the tail end of the Center for Particle Astrophysics (CfPA) in Berkeley, which was an NSF-funded Science and Technology Center for ten years, as well as Berkeley Center for Theoretical Physics, in which I was deeply involved in building up. I've learned two important lessons for a success of a multi-disciplinary institute of this type. One is that the postdocs provide the "free-streaming glue" to the Institute. They do not have duties to teach or serve on committees, yet are curious enough to move from one research group to another, and bring the Principal Investigators from varied subfields together. In addition, bringing the top-notch researchers from the world as visitors and workshop participants is the key to inspire postdocs and educate graduate students to take the maximum benefit from the Institute. The other is to provide an inviting atmosphere for casual interactions through an open architecture of the facility, which naturally draws people out of their offices into the interaction area to exchange ideas and have discussions. Especially in Japan where people tend to be shy about discussing not-so-well-fleshed-out ideas because they do not want to be embarrassed, encouraging interactions with the mutual understanding that "no questions and ideas are stupid" is a *must* for a successful Institute.

5. Management

The Director who is ultimately responsible for all decisions about personnel, finances, infrastructure, instrumentation, computing, and outreach will manage the Institute. Yoichiro Suzuki and Hiroaki Aihara will serve as Deputy Directors to assist the Director in day-to-day operations of the Institute. The Administrative Director, Kenzo Nakamura, will conduct business under the supervision and guidance of the Deputy Directors. He will oversee all expenditures, administrative duties, and facilitate the activity of the scientists using a group of assistant administrators. This is a wonderful team both from scientific and administrative points of view, and I'm confident that they will provide all needed help to me to run the Institute.

The Scientific Advisory Committee (SAC) to the Director consists of four to five PIs of his choice. They advise the Director on the appropriate budget planning as well as scientific directions. The role is strictly advisory; the Director makes the final decisions.

The PIs have a large autonomy in the research they conduct. Their research is funded through competitive grants, but they can propose hiring of postdocs and termed professors to the Director in order to carry out their research. The Director's approval on the proposed appointments will reflect the scientific vision and priorities set by the Director, who consults the SAC as needed.

We will form the External Advisory Board (EAB) which will review the scientific activities of the Institute and give advise to the Director on the scientific priorities and the research activities annually to keep the Institute stay on the course of the proposed science.

In addition to the role to manage and lead the Institute, I anticipate that the Director will be busy recruiting the best young talents to the Institute as well as informing the scientific community about our contributions.

6. Organization

The Institute must achieve a fine balance between two conflicting requirements. One requirement is to give as much time and autonomy to individual Principal Investigators to carry out their research plans with sufficient financial support to hire postdocs, invite visiting professors, and organize workshops in their respective fields. The other is to make sure that investigators from different subfields learn to speak each other's language and seek for mutual inspiration, through organized seminars, workshops, and a visitor program. It is a big challenge to meet both requirements and the Institute is committed to achieve this goal.

One essential ingredient is the new building on the Kashiwa campus of University of Tokyo. Borrowing from the future overhead money thanks to the generosity of the University administration, we plan to build an infrastructure that would make it easy for researchers to meet each other and exchange new ideas. The architecture will follow the style of Kavli Institute for Theoretical Physics at UC Santa Barbara and Center for Theoretical Physics at UC Berkeley with a large open area and amenities (*i.e.*, ample skylight, espresso machines, refrigerators, with all walls covered by blackboards to stimulate spontaneous discussions). It will provide an attractive and competitive environment for researchers from around the world.

Tsuchiya and Saito will reside full-time in Kashiwa as Principal Investigators, and the mid-career mathematical physicist we have identified, as mentioned in section 3, as well as all postdocs in mathematics hired by the Institute will reside in Kashiwa, facilitate communication between physicists and mathematicians, and maintain activities in this area throughout the year. There will be semi-annual workshops that bring mathematicians and physicists together where they will share their common problems. We will also have regular tutorials on the problems, not results, between mathematicians and physicists to break down the intellectual barriers. Once that is established, they will keep communicating over phone and video on individual bases, visiting each other on as-needed basis, as well as organized seminars broadcast over the video to maintain mutual interest. We will secure enough office space on the Kashiwa campus so that the mathematicians from Komaba can drop in any time. We also plan to have a state-of-art videoconference system and internet-blackboards between Kashiwa and Komaba that stay on 24/7 to make impromptu discussions possible.

Most experimental physicists spend a good fraction of their time on the Kashiwa campus, analyzing data, sharing seminars, developing new instruments, and discussing issues of their mutual interest among each other as well as with the theoretical physicists and mathematicians. For the SuperKamiokande, XMASS, and T2K experiments, the Institute hosts the data analysis activities. For the HyperSprimeCam project at Subaru telescope, the Institute will host a computing cluster that allows extensive numerical simulations needed for the data analysis. We plan to hire Assistant Professors on the ATLAS experiment who can frequently come back from CERN using the Institute travel funds, have regular meetings with phenomenologists about new theoretical ideas, and give schools to both theorists and experimentalists in Japan. It is also important to keep strong ties between the Physics Department on the Hongo campus and the Institute. We plan to include faculty members in Hongo on joint appointments with the Institute to maintain constant flow of researchers between the campuses.

External Advisory Board will review the activities of the Institute annually, where all the PIs will be present. In addition, we plan to have annual Institute retreats that also have all PIs participating. This way, we keep the diverse activities of the Institute coherent and well informed among the entire spectrum of the PIs, that enables communication and collaboration.

In the Kashiwa Institute building, we will have daily tea at 3pm and everybody is *required* to attend if they are in town. Individual or groups of PIs organize seminar series that everybody is invited to attend. Long-duration workshops à la Kavli Institute for Theoretical Physics and Aspen Center for Physics bring in visitors to further stimulate the intellectual activities and keep the Institute at the forefront of worldwide science.

I cannot leave Berkeley for the Fall 2007 semester because of the teaching responsibilities. However I will be physically in Kashiwa at the earliest possible occasion allowed by the system, namely January 2008. All the arrangements are being made surprisingly quickly and smoothly. I have my full confidence in both Tokyo and Berkeley that everything will be properly arranged in time for my Directorship in January.

7. Broader Impact

The basic research in physics and mathematics to understand the universe at its deepest level by itself would not have direct practical applications, unlike biomedical research or nanotechnology development. However, there are always young students who are attracted to the most fundamental quest at its frontier, and historically they include some of the best and the brightest minds in each generation. Discoveries that address major questions about the universe by the Institute scientists will undoubtedly inspire high-school and college students in Japan, which motivate them to study mathematics and sciences at large leading to the next-generation workforce. Uniquely to this Institute, we anticipate cross-career development between mathematics and physics, such as a statistician moving to experimental physics. Needless to say, the questions the Institute will ask are easy to relate to for any laymen. This connection between fundamental research and education was highlighted, for example, by a recent National Research Council report, "Rising Above the Gathering Storm," in the United States.

We put strong emphasis on diversity. Currently in Japan, the fraction of female full professors in Physics Departments hover around 2-3 percents. We have currently one female PI, which we will bring up soon to the 10% level. In addition, we promote ethnic diversity with emphasis on Asian representation. We have already secured participation of strong physicists in India and are discussing collaborations with Chinese and Korean institutions.

The Institute will promote public awareness of mathematics and physics through an organized series of public lectures, collaboration with media on TV shows, and education of students at the participating institutions. Japan has been quite effective in communicating exciting discoveries in science and advances in technology to the public at large, compared to similar efforts in the United States, inspiring young minds to enter science and engineering. I myself have been involved in public outreach through easy-to-read texts, radio shows, and public lectures. The Institute will further strengthen the public outreach by major discoveries and concerted efforts by the Institute scientists.

In addition, we believe that much of the methodologies and technologies developed by the research at the Institute will likely benefit the society. New methodologies to deal with large-scale astrophysical and accelerator data will influence the study of financial markets and biological data. New instruments developed to build next-generation experiments will help the industry to acquire technology that will otherwise fall into the cracks of profit-oriented research. One such example is the development of 20-inch photomultipliers that allowed a company to become the single-handedly dominant player in the worldwide marketplace of phototubes, especially in medical applications. Future development of neutrino detectors would allow monitoring of nuclear power plants. Multi-fiber technique needed for future astrophysical surveys will likely lead to medical applications of diagnosis and laser treatments.

An important impact of the Institute would be to reverse the "*brain-drain*" of the talented scientists from Japan and bring some of them back. I myself am attracted to this opportunity to design a research center according to my own vision, and also because the Institute I envision is unique in the world. The fact that I have already managed to bring Ooguri from Caltech, Sobel from Irvine, and Spergel from Princeton to join the Institute as PIs, and identified more from abroad for the termed professorships, demonstrates how attractive and unique the proposed Institute is. I am optimistic that the Institute will attract even more researchers from the world to join the effort, redefine the boundaries between mathematics and physics, and make it a truly leading and exciting research center in the world.

8. Conclusions

This Institute is a unique research center in the world that spans from pure mathematics to theoretical physics, to experimental physics, astronomy, and applied mathematics. All of these elements must come together to address the big questions about the universe. The Institute will create new mathematical framework motivated by the desire to explain the precision data, which require new theories, for which no suitable mathematics exists. In turn the new mathematics allow for new theories that spark technological innovations to design new experiments. The Institute explores the uncharted territory at a crossroads of Mathematics and Physics. This multiple-connected activities and inspiration will move the science forward in an upward spiral. We make effort to inform the public at large about the new discoveries from the Institute, which will motivate students to enter mathematics, science, and engineering to become the next-generation workforce. It will bring researchers from around the world, and turn Japan a unique place to advance the human knowledge on its most fundamental quest.

Host Institution's Commitment

September 25, 2007

To MEXT

The University of Tokyo
President, Hiroshi Komiyama
Signature

I confirm that the measures listed below will be taken faithfully as the Institute for the Physics and Mathematics of the Universe is adopted under the World Premier International Research Center (WPI) Initiative.

＜Provision in host institution's mid-to-long-term plan＞

The University of Tokyo's medium-term research objectives include "investigating exploratory and advanced research and unconventional research areas or actively approaching a new fusion of different academic fields with full respect for research schematization and succession, thereby playing a role to drive forward network-based research with a global perspective." The accompanying medium-term plan states that the university is dedicated to "promoting the establishment of a center for advanced research of excellent creativity and originality in new fields, while fostering the development of new academic areas through interdisciplinary research and collaboration" and "in response to issues newly rising out of academic development and social changes, promoting the establishment of an international research center to deal with such issues in a pioneering, flexible, and practical manner beyond existing academic areas and organizational frameworks."

In order to implement the medium-term plan mentioned above, the University of Tokyo has set up the Integrated Research System for Sustainability Science, the Network for Life Science Research, and other inter-departmental organizations under Office of the President to establish a system to promote multi-disciplinary research. Institute for the Physics and Mathematics of the Universe (IPMU), facilitated by the WPI Initiative, most appropriately meets the University's medium-term goals and plans, hence it shall be positioned as the largest and most important organization among those under Office of the President, and enjoy university-wide support under the specific achievement targets.

＜Concrete Measures＞

(1)
The University of Tokyo will position the IPMU as an organization directly under Office of the President working as a natural facilitator with existing university organizations. The Administration Bureau shall develop an ideal research environment to ensure that chief researchers engaged in research at the IPMU have minimum possible university duties to allow ample time for them to fully focus on research activities, and that research funding may be more readily secured. As part of developing such an environment, with the aim of securing excellent researchers as well as high-caliber support staff, a new employment scheme has already been implemented whereby it is even possible to recruit exceptionally qualified staff at salaries higher than that of the President. Priority is also given for the use of school research space. Furthermore, the Administration Bureau shall have an organization named the Financial Strategy Office whose task is to develop plans strategically to obtain external funding and to allocate it effectively. This shall allow the maximum financial support for the IPMU, while making full use of university resources including overhead costs for the program.

(2)
The University of Tokyo has newly developed an innovative scheme to allow the positioning of the IPMU as an organization directly under Office of the President working in an organic linkage with existing university organizations. Under this scheme, the IPMU may take charge in the operation of the organization under the managerial supervision of the director of IPMU, including for the recruitment of researchers.

(3)
In order to ensure that education and research activities may be implemented smoothly with no disturbance to the university faculties and institutions from which the researchers are gathered for the IPMU, the Administration Bureau shall provide any necessary financial support, such as for personnel

expenses of substitute teaching staff, to the concerned university departments and divisions. This shall not only allow such departments and divisions to take measurements including securing substitute teaching staff, but the mobility of researchers within the university may be further improved.

(4)
As described above, the University of Tokyo has developed an innovative scheme to allow positioning of the IPMU as an organization directly under Office of the President working as a natural facilitator with existing university organizations. Under this scheme, the IPMU may take charge in the operation of the organization under the managerial supervision of the director of IPMU, including for the recruitment of researchers, while new special regulations are also to be established designating the IPMU as a special zone in which participating researchers and support staff members may be allowed a limited exemption from some restrictions under the work rules that are generally applied within the university.

(5)
The University of Tokyo places great importance on the development of an environment to permit excellent researchers from overseas to steadily concentrate on their research activities. Currently, active initiatives to promote a more international campus are under way under the leadership of the President, and several residential facilities for foreigners are being developed near the campus and are due to open in a few years' time. Priority allocation of such residences for researchers invited to the IPMU from overseas has also been under discussion. The University also develops a number of world-class research facilities and actively promotes sharing the use of such facilities. Measures shall be taken to ensure the priority use of such research facilities. Top priority shall be given to the appropriation of land for a research building for the IPMU and its financing. Until the new research building is constructed in Kashiwa Campus, Chiba Prefecture, rooms and other space of the Kashiwa General Research Building shall be provided in priority for activities of the IPMU.

(6)
With the aim of supporting the establishment of an internationally competitive center through the program, the University of Tokyo has set up a committee headed by the board member in charge of the program. The committee, in addition to ensuring university-wide support for the IPMU, shall work in close cooperation with the Global COE (Centers of Excellence) Program and other schemes, as part of its role to produce maximum synergy. The administrative functions of the Administrative Bureau are to be reorganized in July 2007, where the Research Network Support Group is to be set up to intensively support the IPMU, among other organizations. With these schemes, the University shall provide the maximum possible consistent support for the promotion of the IPMU concept.

List of Principal Investigators

Name		Current affiliation (organization, department) and specialties	Academic degree
①	Hitoshi Murayama (*)	University of California, Berkeley, Department of Physics, Theoretical particle physics and cosmology	Ph. D.
②	Yoichiro Suzuki (*)	The University of Tokyo, Institute for Cosmic Ray Research, Neutrino and astroparticle physics and non-accelerator particle physics	Ph. D.
③	Takaaki Kajita (*)	The University of Tokyo, Institute for Cosmic Ray Research. Neutrino physics	Ph. D.
④	Masayuki Nakahata (*)	The University of Tokyo, Institute for Cosmic Ray Research,Neutrino astronomy	Ph. D.
⑤	Masataka Fukugita (*)	The University of Tokyo, Institute for Cosmic Ray Research, Cosmology(theoretical and observational)	Ph. D.
⑥	Hiroaki Aihara (*)	The University of Tokyo, Department of Physics, High Energy Physics	Ph. D.
⑦	Tsutomu Yanagida (*)	The University of Tokyo, Department of Physics, High-energy particle physics(theory)	Ph. D.
⑧	Katsuhiko Sato (*)	The University of Tokyo, Department of Physics, Cosmology, astrophysics.	Ph. D.
⑨	Ken'ichi Nomoto (*)	The University of Tokyo, Department of Physics, Theoretical astrophysics	Ph. D.
⑩	Michio Jinbo (*)	The University of Tokyo, Graduate School of Mathematical Sciences, Integrable Systems	Ph. D.

⑪	Toshitake Kohno (*)	The University of Tokyo, Graduate School of Mathematical Sciences, Geometry and Topology	Ph. D.
⑫	Kunio Inoue (*)	Tohoku University, Research Center for Neutrino Science, Neutrino Physics	Ph. D.
⑬	Naoshi Sugiyama (*)	Nagoya University, Graduate School of Science, observational cosmology	Ph. D.
⑭	Akihiro Tsuchiya (*)	Nagoya University, professor, Emeritus, Conformal Field Theory	Ph. D.
⑮	Hirosi Ooguri (*)	California Institute of Technology; Division of Physics, Mathematics, and Astronomy, Theoretical High Energy Physics	Ph. D.
⑯	David. Spergel(*)	Princeton University, Dept. of Astrophysical Sciences, observational cosmology	Ph. D.
⑰	Henry W. Sobel (*)	University of California, Irvine, Dept of Physics and Astronomy, Neutrino physics	Ph. D.
⑱	Stavros Katsanevas (*)	University Paris 7, Dept. of physics, Neutrino physics, astroparticle physics	Ph. D.
⑲	Kyouji Saito(*)	Kyoto University,Research Institute for Mathematical Sciences,Complex analytic geometry	Ph. D.
⑳	Mihoko Nojiri(*)	High Energy Accelerator Research Organization,KEK,Theoretical particle pluqics physics	Ph. D.