Self-Evaluation Report for Interim Evaluation
World Premier International Research Center Initiative (WPI)

Host Institution	The University of Tokyo	Host Institution Head	Junichi Hamada
Research Center	Institute for the Physics and Mathematics of the Universe	Center Director	Hitoshi Murayama

Report Abstract (2 pages)

Science Level

The IPMU aims to address the deepest and biggest questions about the nature of the Universe. We have assembled a multi-disciplinary research institute lead by 18 principal investigators of world's leading level in theoretical physics, experimental physics, astronomy and cosmology, and mathematics.

The Super-Kamiokande and KamLAND experiments have been at mature stages and the IPMU has been contributing to the ongoing operations. Three new initiatives have started by the IPMU members, ZEN, EGADS, and XMASS, all of which are making substantial progress. They address questions about our origin and the nature of dark matter.

Addressing the nature of dark matter and the fate of the Universe requires large-scale astronomical survey observations. Data analyses of Sloan Digital Sky Survey III (Apache Point telescope) and construction of HyperSuprimeCam (Subaru telescope) are well underway. The SuMIRe project which combines information of imaging and spectroscopy on the Subaru telescope moves forward with the start of building new multi-object spectrograph (PrimeFocusSpectrograph).

Study of supernovae in both theory and experiment settled one of the major concerns about the Type-Ia supernovae as the standard candle. Detailed simulation study of the evolution of the structure in the universe revealed a mechanism of forming first stars in the early universe and subsequent formation of black holes, galaxies, and large-scale structure. Novel ways of analyzing large-scale data had been proposed to maximize science output.

In particle theory, people working on phenomenology proposed new interpretations for several anomalies that were reported from the collider and cosmic ray experiments, while others worked on more fundamental problems of the universe using quantum field theory and string theory.

Application of string theory, which has a rich structure and makes it possible to accommodate a wide range of physical systems, has been vigorously extended to other areas such as quarks and lepton masses, baryon masses, condensed matter physics. Some quantum aspects of black holes were clarified in string theory. On the other hand, alternative quantum gravity theory that does not depend on string theory has been actively studied, and was shown to solve the horizon problem, one of the outstanding problems in cosmology.

Mathematicians at IPMU work closely with physicists. Cross-fertilization, especially with string physicists is obvious by now. They discuss together in the subjects of the mirror symmetry and Calabi-Yau manifolds, derived category, D-branes, integrable systems, interest shared with physicists. Our members are making progress towards attacking problems such as Beilinson conjecture, Generalized Moonshine Conjecture, Strominger-Yau-Zaslow conjecture.

The excellence of the assembled researchers is shown in 21 awards and prizes given to the members since their appointments. Research activities at the IPMU have resulted in 562 publications in refereed journals in total, 124 in FY2007-2008, 202 in FY2009, and 236 in FY2010. Among those articles, average number of citations per article is 7.6, and 8 articles has more than 50 citations so far. The publication metrics are comparable to those of other leading research institutes in the world in similar areas, indicating that the IPMU has well developed into a mature and world-class institute.

Globalization of the Institution

Out of 67 full time faculty and postdoctoral members, 38 are foreign. We were visited by 540 researchers (168 from abroad) in FY 2007-2008, 432 (345 from abroad) in FY 2009, and 862 (478 from abroad) in FY 2010. The number of long-term visitors of more than one month was 14 (13 from abroad) in FY 2007-2008, 30 (29 from abroad) in FY 2009, and 32 (32 from abroad) in FY 2010.

The number of international conferences and workshop we hosted at IPMU were 11 in FY 2007-2008, 12 in FY 2009, and 16 in FY 2010. Attendees of these meetings were typically at least 1/3 from abroad. Among our 38 full-time foreign members, 11 obtained research funding from JSPS's grant-in-aid in FY 2010.

Out of 36 administrative and research support staff, 20 are bilingual. We have set up English language website that is used for seminar notices, registering publications and conference presentations, filling travel reports, as well as for living information such as housing, hospital, children's school, and banking. The same website is also a place to publicize IPMU's mission and activities to the international community.

We are making definite progress for globalization in terms of personnel and style in both research and administration.

Interdisciplinary Research Activities

Focus Week on new invariants and wall crossing which was held in May, 2009 was attended by 32 mathematicians and 34 physicists. They together discussed this subject which provides new insight into the classification of higher dimensional geometry in mathematics, while playing fundamental roles in deriving low-energy effective theories from superstring theory, in analyzing quantum states of black holes, and in studying strongly-coupled effects in gauge theories.

Focus week named "Condensed Matter Physics Meets High Energy Physics" of February, 2010 was attended by approximately 200 researchers from both sides around the world. Holographic principle, an important recent development in superstring theory, is attracting attention among high-temperature superconductivity researchers, while conformal field theory, a building block of superstring theory, has been used to understand quantum hall effect, carbon nano-tubes, and quantum computation. It was extremely stimulating and enhanced new collaboration between the two communities.

Participant of IPMU Workshop on Black Holes, which was held in February, 2011, was limited to 40. They discussed a wide topic regarding black holes, from their astronomical observations to their quantum properties in superstring theory and loop quantum gravity. Small number of leading researchers got together and spent sufficient time discussing different aspects of the black holes.

It has been a daily scene at IPMU that researchers of different disciplines host conferences and workshops together. Some had lead to co-authored publications, while some are still in a stage of being inspired and motivated to see their own subjects from different perspectives.

Organizational Reform

When launched in October 2007, the IPMU was given a status of "special district" within the University of Tokyo where top-down management, flexible hiring system and merit-based salary system had been made possible.

In January 2011, the University of Tokyo established the Todai Institutes for Advanced Study (TODIAS), and approved IPMU as the first member institute within this new and permanent organization the same month. The TODIAS was established as a university-wide organization and comprises research institutes, each demonstrating its function as a world-leading center of knowledge, aiming to enhance the University's academic excellence as a whole and further advance its internationalization. This is a critical step for IPMU to become a permanent entity within the university.

1. Summary of Center Project

<Initial plan>

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.

<Current status>

We have assembled a multi-disciplinary research institute which is lead by 18 principal investigators of world's leading level. In the traditional sense, their research fields can be classified into 4 in theoretical physics, 6 in experimental physics, 5 in astronomy and cosmology, and 3 in mathematics. In reality, however, many work beyond the traditional barrier and we encourage younger staff to do so as well. We have assembled highly qualified staff at junior faculty and postdoctoral levels. We invite many visitors as long as they are active in related fields, some for just few days at a time and some for longer stay. All of our scientific members are loosely organized with minimum hierarchical structure, but work toward a common aim which is to understand the universe. Our young researchers are doing very well in finding the next position after a few years at the IPMU, establishing the "global flow of outstanding human resources" as required by the WPI program.

We study dark matter using data from Subaru and other large telescopes in the world and applying the gravitational lensing technique. The necessary imaging instrument HyperSuprimeCam (HSC) is getting ready for the first light later this year. Investigation of dark energy requires precise measurement of the expansion history. We proceed with this investigation using presently available data from SDSS and others. The next-generation instrument PrimeFocusSpectrograph (PFS) is moving to the conceptual design stage. We conduct direct search of dark matter at XMASS, whose construction is now completed and commissioning is well underway. Study of neutrino oscillation continues at Super-Kamiokande and KamLAND. Particle theorists are looking for new physics beyond the Standard Model from both the LHC data and astronomical observations, and study their connection to dark matter.

Mathematicians and theoretical physicists are interacting on the daily basis, sharing seminars and jointly organizing workshops. Mutual inspiration is providing new impetus to their individual research. Some fruits are already published in interdisciplinary journals between physics and mathematics.

The numbers of female researchers are 1 for principal investigators, zero for faculty, and 5 for postdoctoral fellow. We continue recruiting effort for qualified female researchers. We promote Asian diversity by sharing the travel

	schedule of expected visitors from Europe and America with other research centers in nearby countries.

<Future prospects>

The data from major projects, XMASS on dark matter and HSC on dark matter and dark energy, are expected to become available the next year. Right now, the progress towards the construction of PFS is limited by the resources available to the international partners, Caltech, NASA Jet Propulsion Laboratory, Princeton, and Laboratoire d'Astrophysics Marseille. We hope to have the instrument ready by the expected completion of the HSC survey in 2016. The combination of HSC and PFS should produce the best measurement of the dark energy properties this decade in the world.

The data from the LHC started to appear this year, and the activities in interpretation of data are intensifying. The continuous run of the LHC in this and next years may well produce exciting information about nature of dark matter.

We are trying to add a new PI in mathematics to enhance the interaction between mathematicians and physicists. Searches for more non-Japanese and female PIs had been hampered by lack of tenured positions, but we will continue our vigorous effort in this important activity. Also with the new idea to host an annual retreat among all members of IPMU, the interaction between theorists in Kashiwa and experimentalists in Kamioka will be expanded.

With the founding of Todai Institutes for Advanced Study (TODIAS) and incorporation of the IPMU into this new framework, we are in a closer contact with the Todai administration to discuss the future of the IPMU. Even though the resources will not be available quickly, the will of Todai to sustain the IPMU as its permanent entity is stronger than ever.

To better reach out to the young Japanese researchers, we plan to conduct "schools" with lectures by international prominent researchers and presentations by Japanese graduate students, starting this summer.

2. Center's Research Activities

2-1. Initial plan

<Research fields>

Integration of 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. 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 will spend time in Kashiwa as a Principal Investigator, and Saito will reside in Kashiwa, 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.

Japan's Advantages

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.

Centers in Similar Fields

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.

<Research objectives>

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.

2-2 Research results to date

2-2-1 Center's research activities and results (within 8 pages)

The IPMU aims to address the deepest and biggest questions about the nature of the Universe: How it started, what it is made of, what its fate is, what laws govern it, and why we exist in it. In order to address such questions, we need a team that has varied approaches yet working cohesively together. The team has to range from experimentalists and observers who take the real data about the nature of the Universe, theoretical physicists and astrophysicists who interpret the data and make new predictions, those who build foundational theories that inspire mathematics, and mathematicians who provide new frameworks for use in theoretical physics. Since the launch of the IPMU, we have been assembling such a coherent team with some significant fruits already produced by this stage. Given the progress in mounting the next-generation experiments and devising observational strategies, we anticipate even greater output in the next few years.

To describe the progress and results to date, we use the categories based on traditional disciplines below. But we try to emphasize the cross-connections among them to demonstrate the emerging fusion among disciplines. Note that the selection of results described here is meant to be examples, not exhaustive. Names of co-authors outside IPMU are not mentioned due to space limitation.

(1) Experimental Physics

Experimental physics is the primary way to directly obtaining information about the nature of the Universe. IPMU has been participating in two major experiments, the Super-Kamiokande and KamLAND experiments in the Kamioka observatory. Solar neutrino results were reported from both phases SK-II (Phys. Rev. **D78**, 032002 (2008)) and SK-III (Phys. Rev. D **83**, 052010 (2011)) and confirmed the global picture of the solar neutrino physics in statistically and systematically independent fashion. The SK-II result was particularly difficult because of the high energy threshold. KamLAND clearly showed that neutrinos oscillate at more than 5 sigma confidence level (Phys. Rev. Lett. **100**, 221803 (2008)), and provided the most accurate measurement of θ_{12}, hinting at non-zero θ_{13} which would be important for the future of the field (Phys. Rev. **D83**, 052002 (2011)). These experiments have been at mature stages and the IPMU has been contributing to the ongoing operations.

We are making progress in three major new initiatives, ZEN, EGADS, and XMASS. While no concrete results had been obtained yet by long-term efforts to start new experiments, substantial progress has been made on all three of them.

(a) ZEN

The ZEN project is being put together to look for a possible conversion of anti-matter (anti-neutrino) to matter (neutrino) in a very rare process called neutrinoless double beta decay.

It was motivated by the celebrated results from the Super-Kamiokande experiment that discovered the extremely small but finite mass of neutrinos in 1998, followed by the resolution of the decades-long solar neutrino problem by the KamLAND experiment in 2002. These results showed that, in addition to the right-handed anti-neutrinos discovered back in 1950's, there must also be electrically neutral left-handed ones. The question is whether such left-handed ones are identical to left-handed neutrinos which are also known to exist, or a completely new variety of elementary particle not discovered to date. If the former case is true, called Majorana neutrinos, there is no fundamental distinction between matter and anti-matter. Then the neutrinos could have played a critical role in reshuffling the amount of matter and anti-matter in the early universe, creating a small excess matter at the level of one part in a billion, leading to the atomic matter in the Universe today after the rest of matter and anti-matter had annihilated into photons. This theory is called *leptogenesis*, pointed out by PI Tsutomu Yanagida that Majorana neutrinos naturally arise with tiny masses in grand unified theories, and later together with another PI Masataka Fukugita that neutrinos could indeed explain the origin of atomic matter. If leptogenesis is true, neutrinos

and anti-neutrinos can transform to each other, addressing the question why we exist in the Universe.

The concept for the ZEN project was developed by Alexandre Kozlov in 2007. It utilizes the existing KamLAND detector, which has 1kt of liquid scintillator with radio contaminants below 3.5×10^{-18} g/g for uranium and 5.2×10^{-17} g/g for thorium. Using this ultra-clean environment and decent energy resolution, ZEN looks for the neutrinoless double beta decay: a neutron inside a large nucleus decays into a proton, electron, and anti-neutrino, where the anti-neutrino transforms to a neutrino, and is reabsorbed by another neutron in the same nucleus, thereby emitting two electrons but no neutrinos in the nuclear transition. He pointed out that a large amount of gaseous xenon can be dissolved into the liquid scintillator, allowing for the search for this rare process which may occur only once in 10^{26} years. IPMU appointed Kozlov in 2008 as a distinguished (long-term) postdoc, and he has been leading the effort to convert the KamLAND experiment into the new phase. The lead institution for the KamLAND experiment, Research Center for Neutrino Science, is lead by the PI Kunio Inoue who acquired necessary funding for the first stage of the ZEN project in 2009. Already 290 kg of isotope enriched ^{136}Xe is at hand, and 420 kg is expected by August. By the same time, a small balloon will be suspended into the center of the KamLAND detector to house xenon-dissolved liquid scintillator inside. The data taking is expected to start in this August. Even though there are many ongoing experiments looking for a similar process around the world, ZEN is expected to overtake them quickly and produce the world's best result in the 2012-2013 timeframe. It has sensitivity to the effective neutrino mass of 50 meV, eventually improving to the 20 meV with a future upgrade.

(b) EGADS

Most of the chemical elements we see around us had been forged deep inside stars by nuclear fusion process, then were subsequently blown off into the space by supernova explosions. Our Sun is believed to be a third-generation star that was composed of such elements produced by the earlier generation of stars. Therefore, the history when and how many supernova explosions occurred is directly tied to the chemical evolution of the Universe, hence the question why we exist. The PI Ken Nomoto has been one of the leading experts in the theory of supernova explosions while he pointed out that we have not obtained the detailed quantitative understanding of chemical abundance of the Universe.

While ZEN addresses the question why there is atomic matter at all, EGADS tries to address the question of chemical evolution by observing supernovae at billions of light years away using neutrinos. The Kamiokande experiment observed about ten (anti-)neutrinos from the SN1987A in the Large Magellanic Cloud and confirmed the basic understanding of core collapse supernova, leading to the Nobel prize to Masatoshi Koshiba. The current Super-Kamiokande will be able to detect thousands of neutrinos if another supernova explosion occurs in our Milky Way galaxy. However, study of chemical evolution requires observation of supernova neutrinos from cosmological distances (billions of light years), and the current detector does not have adequate sensitivity.

Mark Vagins, together with a theorist John Beacom in 2004, proposed to dump chemical compound of gadolinium into the ultrapure water in the SuperKamiokande detector to enhance the sensitivity of detecting (anti-)neutrinos from the distant supernovae. This is well known in the community as the "GADZOOKS!" proposal. The IPMU appointed Vagins in 2008 as a Professor to kickstart this effort. Such a study will provide complementary information to the direct observation of supernova using large telescopes, which is the research carried led by Assistant Professor Keiichi Maeda discussed below. Our PI Masayuki Nakahata and Vagins obtained funding of 133M yen from JSPS in 2009 to study the experimental feasibility of this proposal. With this funding, they constructed a new water tank inside the Kamioka mine to study the impact of gadolinium on the transparency and stability of water, which started in 2011. The Super-Kamokande collaboration will judge whether to dump gadolinium compound based on the results from this R&D in the next few years.

(c) XMASS

Beyond the origin of atomic matter studied by ZEN and its chemical composition by EGADS, they do not address more than 80% of matter in the Universe called dark matter. Currently there is very little empirical information about its nature except for its gravitational influence on motion of stars, galaxies, and light.

XMASS was conceived by our PI Yoichiro Suzuki in 2000, and funding was acquired in 2007. Even though there was already an ongoing effort at the Institute for Cosmic Ray Research, IPMU naturally joined the effort to build the detector and analyze the data. We appointed Associate Professor Kai Martens in 2008 with expertise in reducing the radon background in the liquid xenon, as well as a very able postdoc Jing Liu.

The first generation of the experiment has one kiloton of liquid xenon surrounded by a hexagonal array of photomultiplier tubes, which is further suspended inside a 5kt water tank to shield external neutron background. The tubes are specially fabricated to satisfy the stringent cleanliness requirements. The sphere had been assembled in October 2010, and the commissioning started in November. The external background is suppressed by the water shield with veto counter as well as the fiducial volume cut using the reconstructed vertex positions. The physics run will start this summer and the first result expected probably the next year. Being the largest dedicated dark

matter detector in the world, it should provide competitive sensitivity to other competing experiments even with a tight fiducial volume cut down to approximately 100 tons.

(2) Observational Astronomy

The most direct way to study the Universe is by observing it with telescopes. There are two complementary approaches, one is to perform a dedicated study of a particular type of astronomical objects, while the other is to conduct a wide survey of the sky. They are not mutually exclusive and often a large survey does provide a crucial catalog of a particular type of objects. Yet we discuss each approach separately for simplicity.

(a) Wide-scale surveys

To study the overall trend of the Universe, in particular its expansion history driven by dark matter and dark energy, we try to avoid distraction by properties of individual objects marred by their own peculiarities. Rather, we should try to observe a similar type of objects as a probe over a wide range of areas and depths to conduct a kind of "cosmic census" with as unbiased sampling as possible in order to unveil the nature of the Universe itself. Of special interest is the nature of dark energy, which is responsible for the accelerated expansion of the Universe, yet its nature is unknown. By accurately measuring the expansion history, we hope to determine the nature of dark energy behind it, and extrapolate the history into the future to address the question what the fate of the Universe is. Moreover, the dark energy poses a serious challenge to particle physicists because the estimated size of the vacuum energy is 10^{120} too large. To overcome this challenge, many theoretical possibilities had been proposed to explain the accelerated expansion, including "alternative gravity" theories different from that by Einstein.

(i) Sloan Digital Sky Survey III

Immediately after the launch, IPMU joined the largest scale survey project called Sloan Digital Sky Survey, which was slated to start in 2009 on a 2.5m telescope on Apache Point, New Mexico, USA. The current phase combines the imaging and spectroscopic survey over a large area of 10,000 square degrees.

The IPMU contributed CCDs, the critical element of the imaging survey which is now completed. The resulting publication called Data Release 8 (H. Aihara *et al.*, Astroph. J. Suppl., **193**, 29 (2011)) is the largest image of the Universe obtained in astronomy to date with more than a trillion pixels.

The collaboration is now in the mode of spectroscopic survey to precisely determine the motion of galaxies along the line of sight using the redshift of spectral lines. The completed imaging survey will allow us to identify a particular type of galaxy called Luminous Red Galaxy that serves as an unbiased sample. The combination of imaging and spectroscopic survey allows us to observe the characteristic distance scale in the distribution of galaxies called the baryon acoustic oscillation (BAO) which results from the sound waves in the hot plasma of atomic nuclei (baryons), electrons, and photons when the Universe was as hot as 3,500 degrees. The distance of BAO acoustic peaks can be precisely calculated based on the current data so that it provides a "standard ruler" to measure distances over the cosmological scales accurately. Since the distance is synonymous to time, and the redshift is nothing but the expansion of space, we will obtain far more precise data of the expansion history from z~0.6 and on than currently available. Seven faculty members and many postdocs are involved in SDSS-III at the IPMU.

(ii) HyperSuprimeCam

The next major survey project is an imaging survey using the 8.2m Subaru telescope on Manua Kea owned by National Astronomical Observatory of Japan (NAOJ). The new digital camera called HyperSuprimeCam (HSC) is being built with approximately 0.9 billion pixels weighing 3 tons together with the sophisticated and precise corrector lens system. Thanks to the much bigger mirror, the survey will probe much deeper into the younger Universe to extend the measurement of the expansion history back to earlier times, and determine the nature of the dark energy with the best accuracy anticipated in the next five years in a head-to-head competition with the US project Dark Energy Survey (DES).

The project was already underway before the IPMU started based on the collaboration of NAOJ, the University of Tokyo, KEK, Princeton University, and ASIAA (Taiwan). The primary measurement technique is based on the weak gravitational lensing that maps out the distribution of (invisible) dark matter by the shear of images of distant galaxies. The growth of the dark matter structure is determined by the expansion history, which depends on the nature of dark energy.

Immediately after the launch, the IPMU quickly created a hub of activities for the HSC hosting regular meetings and assembling a team for analyzing the data, building upon the experience with SDSS-III. We put together the core team for this project, by appointing Associate Professor Masahiro Takada with an expertise in analyzing the weak lensing data, Associate Professor Naoki Yoshida who can create mock catalog using computer simulations, and Professor Naoki Yasuda with expertise on data

handling. Further addition of Assistant Professors John Silverman, Masamune Oguri, and Kevin Bundy (this fall) expands the scientific scope of the imaging survey into supermassive blackholes and galaxy evolution. In addition, the project turned out to be impossible without the financial contributions from the IPMU which amount to approximately a half of the project cost. The major portion comes from the ¥3.4B award from the FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program to Director Hitoshi Murayama starting in 2010.

We are making steady progress for this major survey. The camera is being readied for the first light in the fall this year. The first data challenge took place in 2010. The actual survey is expected to start in the year 2012.

(iii) PrimeFocusSpectrograph and SuMIRe

It is clear from the experience with SDSS-III that we obtain drastically enhanced information by following up an imaging survey with a spectroscopic survey. Currently no major spectroscopic survey is planned beyond SDSS-III in the world. Murayama's FIRST award is precisely the combination of the HSC imaging survey and the new spectroscopic survey on the same Subaru telescope to cover about the same comoving volume as the SDSS-III extending into much younger Universe. The combination is dubbed SuMIRe (Subaru Measurement of Images and Redshifts). Even though Murayama was trained as a theoretical particle physicist, he now leads an international collaboration of astronomers and instrumentalists to build the next generation multi-object spectrograph with a robotic fiber positioner that can simultaneously take spectra of thousands of galaxies at the same time, an example among many cross-disciplinary developments at the IPMU.

Even though the award of ¥3.4B is not sufficient for SuMIRe, international partners pledged to contribute resources to build the proposed multi-object spectrograph. Caltech and NASA Jet Propulsion Laboratory will contribute the robotic fiber positioner with 10 micron accuracy, Princeton and Laboratoire d'Astrophysique Marseille will build spectrographs covering 380 to 1300 nm, allowing for a continuous redshift survey of galaxies from nearby to z~6 using OII and Lyman alpha lines. The formation of collaboration is well underway and the conceptual design will be fixed by this September.

(b) Dedicated Studies

Even though the large-scale surveys are the key to the most cosmological studies, dedicated studies of particular type of astronomical objects prove crucial for detailed understanding and interpretation of survey results. Such studies are already well underway at the IPMU and many results had been obtained, providing important input on systematic errors for the SDSS-III, HSC, and PFS surveys.

(i) Supernovae

The initial discovery of accelerating expansion and hence dark energy was based on the observation of Type-Ia supernovae billions of light years away. Type-Ia supernovae are exploding stars that become brighter than their host galaxies, and are clearly visible even at such distances. PI Ken Nomoto pioneered theoretical investigations of the nature of such explosions, concluding that they are the binary system of a white dwarf and an accompanying star, where the accretion of gas from the star onto the white dwarf exceeds the Chandrasekhar limit against the instability to form a blackhole. Because the Chandrasekhar limit does not depend on the precise nature of the object or the environment, Type-Ia supernova exhibit a remarkable universality that their luminosities are more or less the same dubbed "standard candles," at least for those observed nearby. However, it remained an important question if those far away are indeed the same, which was the basic assumption behind the claimed discovery of dark energy. If there is a systematic variation among the supernovae, it would cast doubt on the discovery of dark energy.

We appointed Assistant Professor Keiichi Maeda to look into the possibility of such a systematic variation among the supernovae, because he had proposed new ways to calibrate the individuality among supernovae in a series of theoretical investigations. He then turned into observing supernovae himself, an example of cross-disciplinary developments at the IPMU. He quickly showed that supernova explosions are not spherical, by observing the supernovae intentionally 100 days after the initial dramatic phase when they became "boring." This way, the "dust has cleared" and he could observe the core of the explosion, which exhibited the bipolar spectrum of the oxygen lines. The bipolar spectrum implies that the Doppler shifts due to the expanding core shows two prominent velocities along the line of sight, demonstrating the aspheric explosions (Science, **319**, 1220 (2008)). However, this observation was about a different type of supernova explosions called core-collapse, targeted by the EGADS discussed earlier.

Maeda then extended the study to Type-Ia, the critical ones for the dark energy. There indeed has been a concern that the evolution of spectra from Type-Ia supernovae appears to show individuality, casting doubt on the purported standard candle. In his publication (Nature, **466**, 82 (2010)), he had demonstrated using the new observations that the apparent individuality is due to the viewing angle of aspheric explosions. This work settles one of the major concerns about the Type-Ia supernovae

as the standard candle.

At the same time, obtaining more samples of Type-Ia supernovae for close examinations would be extremely useful. PI Ken Nomoto managed to re-observe the supernova reported by Tycho Brahe back in 1572, thanks to a dust cloud that reflects light and produced an "echo". Using the modern telescope, he showed that it was a Type-Ia supernova (Nature,**456**, 617 (2008)).

To continue calibration of the Type-Ia supernovae, we appoint a distinguished postdoc Robert Quimby this fall who had discovered a new and the brightest type of supernovae, and get involved in the Palomar Transient Factory II to assemble the largest sample of supernovae ever.

(ii) Clusters

Clusters of galaxies have high concentrations of dark matter which had been shown conclusively by the strong gravitational lensing, where a distant galaxy which happens to be exactly behind the cluster is seen as a "giant arc." However, modern statistical analysis allows for a systematic study of shear of images even when the gravitational lensing effect is not as dramatic. This study requires an excellent imaging, possible only with some of the newest and best telescopes, and careful analyses of systematics. Furthermore, this weak lensing effect constitutes the basis of the HSC survey to map out dark matter distribution and the nature of dark energy behind it. Understanding systematic errors would be the key question for the HSC survey.

Associate Professor Masahiro Takada was trained as a theoretical astrophysicist, but now is moving into mapping the dark matter distributions from observations of a large number of galaxy clusters even when the gravitational lensing effect is only as small as 10%. Using his expertise, he demonstrated that the distribution of dark matter in 25 clusters is not spherical with a high statistical significance (*MNRAS*, **405**, 2215 (2010)), consistent with expectation by computer simulations like those by Naoki Yoshida discussed below. By using an improved theoretical prediction and observation, he also placed a theoretically robust limit on the mass of neutrinos (Phys. Rev. D**79**, 023520 (2009).

Distinguished Postdoc Masayuki Tanaka discovered the most distant spectroscopically confirmed X-ray cluster in the Subaru/XMM-Newton deep field (Astrophys. J. Lett. **716**, L152 (2010)). It exemplifies kinds of observations we can perform more routinely with the HyperSuprimeCam in the future that allows us to search systematically for distant clusters, which will test theoretically predicted formation of structure using numerical simulations by Yoshida and others.

(3) Theoretical Astrophysics and Phenomenological Particle Physics

Results from the large-scale surveys, dedicated observations, and big experiments have to be interpreted in the context of theoretical frameworks. At the same time, theory makes quantitative predictions and provides service to make the analyses of the data possible. Having both types of researchers under the same roof (and sometimes in the same bodies!) makes this cross-fertilization an important aspect of the IPMU research program.

(a) Computational Astrophysics and Cosmology

Computational cosmology studies the evolution of the structure in the Universe from the initial condition observed in the cosmic microwave background, the ancient light from the Universe only 380,000 years old. So-called "N-body simulations" that studies the structure in the dark matter distribution are well established, thanks to their non-interacting nature that makes the simulation relatively easy. However, inclusion of atomic matter proves highly non-trivial as they interact via the electromagnetic as well as gravitational forces, complicating the simulation. In addition, study of the observed structure requires a huge dynamic range from the billions of light years (size of the observable Universe) down to a few light minutes (distance between the Sun and the Earth).

Associate Professor Naoki Yoshida pioneered numerical simulation to study the interaction of atomic matter over the required huge dynamic range. In his publication (Nature, **459**, 49 (2009)), he outlines the evolution from the so-called *dark ages* to the formation of first stars and galaxies. In another publication together with the PI Ken Nomoto, they proposed a new theory of forming supermassive blackholes in early galaxies by accretion of gas and dark matter (*JCAP*, **8**, 024 (2009)). His simulations are roughly five years ahead of the competition. The work by Yoshida together with a particle physics postdoc Cosimo Bambi and others showed an obstacle of accretion to super-spinning blackholes (Phys. Rev D **80**, 104023 (2009)).

In addition to theoretically understanding the observed structure, his work provides the mock catalog of stars and galaxies that can be compared to the forthcoming large-scale surveys to understand the systematic errors. For example, PI Naoshi Sugiyama, together with Yoshida, Takada, and IPMU postdocs, published a detailed examination of the non-Gaussian errors which turned out to be a non-issue despite claims otherwise in the literature (Astrophys. J., **701**, 945 (2009)).

(b) Large-scale structure

The evolution of structure can be worked out theoretically using the linear approximations, namely to the first order in its inhomogeneity. However, the observed structure shows non-linear effects that are crucial in comparison between the observations and theory. Obtaining accurate theoretical predictions in the non-linear regime is becoming a focus of attention in the recent research worldwide.

For instance, the constraint on the neutrino mass from the large-scale structure of the Universe is an interesting area of research at the intersection of particle physics and astronomy. However, obtaining accurate theoretical predictions has been the major obstacle. Takada, a theoretical astrophysicist, developed an improved theory at higher orders in inhomegeneities in the presence of massive neutrinos, as demonstrated by the Super-Kamiokande and KamLAND experiments and predicted by PI Yanagida, to attain a robust theoretical predictions and published in a physics journal (Phys. Rev. Lett., **100**, 191301 (2008), Phys. Rev. D**80**, 083528 (2009)), another example of cross-fertilization.

In addition, Takada and others showed that the combination of imaging and spectroscopic surveys would be sensitive to alternative theories of gravity at cosmological distances (Phys. Rev. D**81**, 023503 (2010)). This direction of research appears to fuse the research on fundamental theories and astronomical observations.

(c) Collider phenomenology

Collider experiments provide unique opportunities to probe the conditions of the early Universe beyond what can ever be studied optically, namely the surface of last scattering where atoms are ionized due to high temperatures and the mean free path of photons is microscopic. Similarly to the observational astronomy, data from the collider experiments such as Tevatron and the LHC are vast and complicated, and require detailed theoretical studies that allow for extracting crucial information. Of particular interest is the production of dark matter particles that escape detection, and their existence and properties need to be inferred from other particles produced at the same time. Such an analysis requires clever ideas as well as detailed and accurate theoretical predictions. On the other hand, as the data inspire new models, it is critical to work out the consequences of new models to the collider signal. This is the two-way bridge that would be indispensable when new physics is discovered. Sometimes direct collaboration between theorists and experimentalists proves useful.

For example, measuring masses of new particles that decay into an invisible particle in a cascade is a well-known difficult problem. A kinematic variable called m_{T2} had been proposed as a means to address this problem. However, the initial state radiation, which becomes increasingly harder as the particle mass increases, complicates the definition of m_{T2}. We added a new PI Mihoko Nojiri right after the launch, and she proposed a new strategy based on $m_{T2}^{\min}$ to solve this complication (Phys. Rev. Lett., **103**, 151802 (2009)). An even more difficult problem is to measure spins of new particles. PI Hitoshi Murayama proposed a novel technique using interference among the helicity states that are free from model assumptions (Phys. Rev. **D 78**, 014028 (2008)).

On the other hand, Nojiri picked up a novel model proposed by IPMU postdocs Park and Shu inspired by the cosmic-ray data and developed its detailed phenomenology of its collider signals for the first time (JHEP, **9**, 078 (2009)). Murayama proposed a different model motivated by the unexpected large forward-backward asymmetry in the top-quark pair production at Tevatron and worked out its collider consequences (Phys. Rev. **D 81**, 015004 (2010)). PI Tsutomu Yanagida collaborated with an experimentalist for a detailed study of how to test the anomaly-mediated supersymmetry breaking mechanism (proposed by Murayama and others) at the LHC (Phys. Lett. B, **664**, 185 (2008)).

(d) Cosmic-ray phenomenology

IPMU is addressing the nature of dark matter with the underground experiment XMASS, astronomical observations, theoretical models, and collider data. In addition, cosmic rays may contain products of dark matter annihilations in the Milky Way halo. In fact, some of the recent data from PAMELA (positrons), ATIC, and FERMI (electrons and positrons) showed excess beyond past expectations, while their interpretation is not clear yet.

Assistant Professor Fuminobu Takahashi had proposed a novel possibility to explain the older cosmic-ray data from dark-matter decays while avoiding excessive production of anti-protons *before* the recent data by assigning lepton numbers (similar to electrons) to the dark matter particles (JCAP, **02**, 004 (2009)). The model became one of the targets of more recent experiments. PI Tsutomu Yanagida proposed dark-matter *decays* instead of annihilations that avoid many of other existing constraints within the lifetime range motivated by grand-unified models (Phys. Lett. B, **673**, 247 (2009)). Their joint work was the first paper to propose a hidden gauge boson (Phys. Lett. B, **673**, 255 (2009)). Postdocs Jing Shu and Seongchan Park worked by themselves and proposed a new kind of extra-dimensional model to explain the data (Phys. Rev. D, **79**, 091702 (2009)).

Note that many models proposed in the literature that enhance the dark matter annihilation in the halo relies on the Sommerfeld enhancement effect which had been

proposed by PI Nojiri and Associate Professor Shigeki Matsumoto back in 2003. In addition, PI Yanagida and Murayama pointed out a different mechanism to enhance the annihilation in the halo dubbed Breit-Wigner enhancement (Phys. Rev. D, **79**, 095009 (2009)), which may be relevant in the future even when the current interpretation of data will not turn out to be correct.

(4) Fundamental Theory

Based on the experiments and observations, and using the bridge between data and theory, IPMU aims at deciphering the basic laws of the Universe. Using quantum field theory and string theory, new theories are being developed. In addition, many of them turn out to be useful for applications to other branches of science.

(a) Model building

Motivated by observed data and inspired by the proposed fundamental theories such as string theory, "model building" serves as the link to build the fundamental theory. For instance, the observed masses of three generations of quark and lepton are different by order(s) of magnitudes among generations and the standard theory offers no explanations. F-theory, a version of string theory compactified on elliptic Calabi-Yau four-folds, was proposed as a natural way to explain this pattern. However, complications in understanding these manifolds make the link technically challenging. Associate Professors Taizan Watari (physicist) and Yukinobu Toda (mathematician) tackled these complications with a careful analysis of sheaves and showed that the original model proposed by Cumrun Vafa and others actually did not work as hoped (Nucl. Phys. B, **806**, 224 (2009)). Watari further published a series of papers studying how new models can be constructed to achieve the original aim.

Explicit models often receive severe constraints from many apparently disconnected experimental data sets. PI Tsutomu Yanagida has been working on models of the mechanism of gauge-mediated supersymmetry breaking. In a series of papers, he managed to demonstrate that it is possible to satisfy all constraints from the large-scale structure of the Universe, dark matter searches, collider searches, stability against quantum tunneling.

(b) Fundamental laws and alternative gravity theories

To construct fundamental laws to describe the Universe, in particular the black holes or the Big Bang itself, it is crucial to incorporate microscopic physics (quantum mechanics) and macroscopic physics (general relativity) into a single framework. This effort has been hampered by uncontrollable infinities in theoretical calculations. Currently the string theory presents the best hope in this direction. However, the string theory still lacks a precise definition while it is very rich in its structure, and hence working out explicit consequences of the theory is very challenging.

There has been a long-standing problem in the quantum aspects of black holes. As Stephen Hawking pointed out, black holes actually have entropy. However entropy in thermodynamics arises from microscopic degrees of freedom in statistical mechanics, and how to count the microscopic degrees of freedom has been the challenge. PI Hirosi Ooguri tackled this problem using the topological string theory and a recent mathematical works by Okounkov and others on the wall crossing in the Donaldson-Thomas theory, and generalized the consistent counting by the previous works to arbitrary non-compact toric Calabi-Yau manifolds (Comm. Math. Phys., **292**, 179 (2009)). The counting was found equivalent to the ways atoms can be removed from melting crystals. He further showed how the smooth classical description arises from this picture (Phys. Rev. Lett., **102**, 161601 (2009)). Ooguri also has a series of papers to address the mechanism of supersymmetry breaking from the string-theory perspective, connecting to the model-building activity in view of the experimental and observational constraints.

Recently, Petr Hořava proposed a novel way to unify quantum mechanics and gravity keeping the divergences in calculations under control (renormalizable). Wether the proposal correctly reproduces Einstein's general relativity is still not clear. Associate Professor Shinji Mukohyama quickly took up this proposal and studied its relevance to cosmology. He pointed out it naturally produces the scale-invariant cosmological perturbation needed to explain the observed structure of the Universe without resorting to the accelerated expansion of space called inflation (JCAP, **6**, 001 (2009)). It provided a strong motivation to study this Hořava-Lifshitz model further worldwide. In addition, postdocs Domenico Orlando and Susanne Reffert (Class. Quant. Grav., **26**, 155021 (2009)) showed that the Hořava-Lifshitz model is indeed likely to be renormalizable by relating its divergence structure to that of the topologically massive gravity. This paper was cited as 2010 Highlights Of Classical Quantum Gravity Journal.

(c) Applications to other areas

String theory has such a rich structure that makes it possible to accommodate a wide range of physical systems. In recent years, it became a very active subject to use the string theory as a framework rather than the fundamental theory of gravity.

Professor Shigeki Sugimoto is well-known for the Sakai-Sugimoto model to describe theory of strong nuclear force using the string theory, as exemplified by his Kimura Prize in Theoretical Physics, Yukawa-Tomonaga Prize, and Outstanding Paper Prizes from Japanese Physical Society for three times. Using his model, he carried out the first detailed investigations of the properties of baryons (proton, neutron, etc) including their magnetic moments and form factors, and showed that the predictions are quite consistent with the data beyond the anticipated level of accuracies (Prog. Theor. Phys., **120**, 1093 (2008)).

Associate Professor Tadashi Takayangi has produced a series of papers discussing the application of string theory to condensed matter physics. In particular, topological insulators are arguably the hottest subject in condensed matter physics in recent years. Takayanagi demonstrated that the string theory is useful in classifying different types of topological insulators (Phys. Lett. **B693**, 175 (2010); Phys. Rev. D**82**, 086014 (2010)). He has also pointed out the relationship between the evolution of the black hole entropy and the entanglement entropy in condensed matter systems with a Todai graduate student (JHEP, **1011**, 054 (2010)).

(5) Mathematics

Research in mathematics strongly influences research in theoretical physics as it enables attack on problems not conceivable before. At the same time, needs and progress in theoretical physics inspire new directions in mathematics research. The IPMU intends to develop this type of cross-fertilization not possible with the traditional departmental structure in the University. In addition to the original group of PIs, we have appointed a new PI Alexey Bondal who is half-time at the IPMU, Associate Professor Yukinobu Toda, and Assistant Professors Satoshi Kondo, Todor Milanov. In addition, some of our physicists have strong background in mathematics. We appointed Professor Kentaro Hori away from Toronto University, where he held a half-time position each in Physics and Mathematics departments. PI Ooguri, a *physicist*, won the inaugural award of the Leonard Eisenbud Prize from American *Mathematical* Society, and holds a position both in the Physics and Mathematics Departments at Caltech. Many of our members publish in the journals at the interface between physics and mathematics, such as Advances in Theoretical and Mathematical Physics, Communications in Mathematical Physics, Communications in Number Theory and Physics. Despite very different style in publications, there are even articles co-authored by physicists and mathematicians as mentioned above.

One particular interest among mathematicians is the mirror symmetry between complex analytic and symplectic manifolds, which was originally suggested by the string theorists studying the compactification of string theory on Calabi-Yau 3-folds. Further developed by Kontsevich, Fukaya and others into the homological mirror symmetry conjecture, this is an active area of research closely related to the string theory. The latest appointment, Assistant Professor Todor Milanov works on a unique approach to the mirror symmetry by constructing generating function for the Gromov-Witten invariant for mirror-symmetric pairs using the integral systems (KdV hierarchy). PI Alexey Bondal pioneered derived category of coherent sheaves, which has become the basis for understanding properties of D-branes in string theory. Our members attack various hard mathematical problems such as Beilinson conjecture, Generalized Moonshine Conjecture, Strominger-Yau-Zaslow conjecture. We added new PIs Kyoji Saito and Alexey Bondal since the launch because of their strong track record for laying foundations for the branches of mathematics that became crucial tools for physics research later.

As mentioned already above, Toda has helped Watari to work out consequences on the quark and lepton masses of a model based on the F-theory formulation of the string theory. He has been working on the derived category of the sheaves, relevant to the dynamics of D-branes in the string theory as well as structure of Calabi-Yau manifolds on which string theory is compactified. He introduced new enumerate invariants of curves on Calabi-Yau 3-folds which generalized counting invariants of stable pairs introduced by Pandharipande and Thomas (Duke Math. Journ., **149**, 157-208 (2009)). He then investigated the space of certain weak stability conditions on the triangulated category of D0-D2-D6 bound states on a smooth projective Calabi-Yau 3-fold, and constructed the DT type invariants counting semi-stable objects in his triangulated category, which are new curve counting invariants on a Calabi-Yau 3-fold (Journ. Amer. Math. Soc., **23**, 1119-1157 (2010)). Both works have close relationship to the wall-crossing phenomena, and were inspired partially by the joint workshop on wall crossing between physicists and mathematicians at the IPMU.

Since the Fields-Medal paper by the physicist Witten, which related topological field theories to the theory of knots and braids, this also has been a common area of interest between physicists and mathematicians. PI Toshitake Kohno showed that the bar complex of the configuration space of ordered distinct points in the complex plane is acyclic (Topology and its Applications, **157**, 2-9 (2010)). The 0-dimensional cohomology of this bar complex is identified with the space of finite type invariants for braids. He constructed a universal holonomy homomorphism from the braid group to the space of horizontal chord diagrams over Q, which provides finite type invariants for braids with values in Q.

PI Hirosi Ooguri discovered that the elliptic genus of the K3 surface has a natural decomposition in terms of dimensions of irreducible representations of the largest Mathieu group M_{24} (Exper. Math. **20**, 91 (2011)). This observation has inspired mathematicians worldwide to understand the origin of this mysterious connection. In his other work (Comm. Number Theory Physics, **2**, 743-801 (2008)), he obtained constraints on the spectrum of primary fields in 2D conformal field theories from the

moduliary of the elliptic genus. Modular forms lie at the intersection of quantum field theory in physics and many areas of mathematics including arithmetic geometry.

Assistant Professor Satoshi Kondo works on arithmetic geometry. In his publication (Journal of Pure and Applied Algebra, **215**, 511-522 (2011)), he showed that the product structures of motivic cohomology groups and of higher Chow groups are compatible under the comparison isomorphism of Voevodsky, extending the result of Weibel, where he used the comparison isomorphism which assumed that the base field admits resolution of singularities. The mod n motivic cohomology groups and product structures in motivic homotopy theory are defined, and it is shown that the product structures are compatible under the comparison isomorphisms. In a series of papers yet to be published, he has shown how to generalize a theorem of Beilinson on K_2 of a modular curve to the situation of Drinfel'd modular curves, and the existence of a formula that should be regarded as the first evidence, in higher dimensions, toward the correct statement of Beilinson's conjectures for function fields. We will appoint Assistant Professor Tomoyuki Abe who works also on the arithmetic geometry but from the algebraic point of view.

PI Kyoji Saito is interested in the global transcendental nature of functions and numbers, which appear in connection with several moduli problems in mathematics. In one approach he developed the theory of period integrals of primitive forms, which had big impact on the string-theory research and became one of the basic tools called the Frobenius manifold structure. The other approach he takes is by statistical mechanical limit procedure, connected to thermal and statistical physics. In his recent work (Publ. RIMS, **46**, 37-113 (2010)), he developed a general frame work on the space $\Omega(\Gamma, G)$ of thermo-dynamical limit functions (free energy) associated to the Cayley graph of any cancellative monoid Γ. They are, at present, abstractly defined in certain Hopf algebra as accumulating points of finite free energy, is hardly calculable. But, in certain good cases he showed that some traces of such limit F-functions can be expressed as a residue of certain meromorphic functions.

2-2-2 Research Achievements (Enter the total number and number per year in each of the below blocks.)

A. Refereed papers (published or accepted for publication)
Total: 562

FY 2007-2008	124	FY 2009	202	FY 2010	236

B. Invited lectures, plenary addresses (etc.) at international conferences and international research meetings
Total: 177

FY 2007-2008	63	FY 2009	52	FY 2010	62

C. General lectures at international conferences
Total: oral 167 0 poster (We do not keep record of posters as the research achievement)

FY 2007-2008	oral	poster	FY 2009	oral	poster	FY 2010	oral	poster
	38	0		63	0		66	0

D. Invited lectures at domestic scientific societies and research meetings
Total: 79

FY 2007-2008	14	FY 2009	16	FY 2010	49

E. General lectures at domestic scientific societies and research meetings
Total: oral 99 (not including ordinary university seminars) 0 poster (We do not keep record of posters as the research achievement)

FY 2007-2008	oral	poster	FY 2009	oral	poster	FY 2010	oral	poster
	34	0		35	0		30	0

F. Books (e.g., scientific, specialized volumes)
Total volumes: 0

FY 2007-2008	0	FY 2009	0	FY 2010	0

G. Industrial property rights
Total: 0 registered 0 being processed

FY 2007-2008	registered	processed	FY 2009	registered	processed	FY 2010	registered	processed
	0	0		0	0		0	0

H. Major awards received (including those formally announced)
Total: 21

FY 2007-2008	6	FY 2009	5	FY 2010	10

2-3 Future Policy and Concrete Plans (within 4 pages)

<Research fields>

With the current composition of the institute, mathematics and experiments/observations sit at the opposite ends of the spectrum, connected through the research activities on theoretical physics and astrophysics. However, we envisioned connecting them directly by adding researchers on statistics. Statistics is a branch of mathematics, broadly speaking, yet provides crucial tools in analyzing large data sets from modern experimental and observational projects. We had conducted the first workshop on this subject, bringing in interested astrophysicists and statisticians together. We will repeat this exercise to bring in wider community and try to identify individuals who are interested in joining our effort at the IPMU.

An unexpected direction was presented to us when we saw an application from a highly unique individual. Dr. Marcus Werner obtained a doctoral degree in astronomy from Cambrige working on the gravitational lensing by supermassive black holes. He then moved to Mathematics Department at Durham University, where he has been publishing mathematical results. For example, he has discovered a topological invariant associated with the gravitational lensing related to the index theorems. We were delighted when he accepted our postdoc offer starting this fall. This example shows that there may be more direct connections between mathematics and observational astronomy or experimental physics beyond what we initially anticipated. We will keep exploring such connections.

Assistant professor Fuminobu Takahashi, who had won the Young Physicist Prize from the Japanese Physics Society, has left for a tenured Associate Professor position at Tohoku University. He was very active on the early universe cosmology, especially inflation, and dark matter models, bridging particle physicists and astrophysicists. His departure left a gap in this area and we need to find an equally excellent scientist in this area. We will interview a candidate in June. It is hoped that this is an isolated example, rather than a systematic trend for our faculty members to move to traditional tenured positions at other Universities, which we cannot offer. So far there are no other examples of this kind.

Several PIs had left since the launch of the IPMU. In the mathematical research, PI Michio Jimbo left to Rikkyo University, while another PI Akihiro Tsuchiya decided to step down from the role of a PI because of his desire to concentrate on his own research. We have appointed new PIs Kyoji Saito and Alexey Bondal, and the process to appoint another from the Komaba campus is well underway. Another PI who has left is Katsuhiko Sato, who assumed the position of the director of NINS (National Institute for Natural Sciences). We are actively looking for a replacement.

<Research objectives>

Observational astronomy, experimental physics, and mathematics research share one aspect in common: their timespan is very long. A project typically takes five years. KamLAND-ZEN, XMASS, and HyperSuprimeCam are well underway poised for data taking this or next year. On the other hand, EGADS is yet to demonstrate its feasibility, and PrimeFocusSpectrograph depends on funding at other institutions beyond our control. Sustaining funding for the IPMU to embark on long-term projects will be the key to the future scientific output.

< Major changes >

No major changes are planned.

One point which may be noteworthy concerns the name of the institute. As a part of our attempt to stabilize the funding in the future, as well as a part of the organization reform of the University, we have been following leads of multi-million dollar donations from a foundation. If successful, the IPMU will bear the name of the foundation.

3. Management

<Initial plan>	<Efforts to date and current state>
1) Composition of administrative staff 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	1) Composition of administrative staff The number of administrative staff is 36, of which 25 are in the category of research support staff and hired directly by IPMU as contrast to the 11 staff that belongs to the administrative bureau of the University. While big items of the administrative matter are handled by the Directorate in direct contact with the office of the President, day-to-day function is performed by the administrative division that is supervised by the Administrative Director with

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.

2) 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

the help of the General Manager. There are 9 staff in the general affairs section (including 1 public relation specialist and 4 secretarial staff), 4 in the accounting section, 5 in the international relations section (including 1 in charge of conference and 1 Japanese instructor), 2 in the financing section, 4 in the purchasing section, 4 in the Kamioka Satellite office, 2 for computing and website, 1 for the library and 1 for documentation.

Out of 36, 20 staff members are bilingual, and 3 are with particle physics background. This team handles all logistics for newly arriving staff and visitors, in particular those from abroad. The team helps organizing International conferences and workshops, and filing research grant applications and other paper works. They are also responsible for organizing various public relations program such as public lectures, publication of IPMU NEWS magazines, and updating IPMU website covering a wide variety of information.

2) Decision-making system

The Director continues to uplift the Institute by recruiting very best scientists from all over the world, and promoting the science that is carried out at the Institute in both scientific community and public sector. For achieving this goal, the Director receives advice at different levels from the Executive Board (EB), Scientific Advisory Committee (SAC), and External Advisory Committee (EAC).

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

Present SAC members are Hiroaki Aihara, Yoichiro Suzuki, Toshitake Kohno, Hirosi Ooguri, Kyoji Saito, David Spergel, and Tsutomu Yanagida. They provide frequent advice to the Director on hiring new scientific staff, distributing research fund, and setting research strategies of the Institute.

Present EAC members are John Ellis (CERN), Makoto Gonokami (U of Tokyo), Young-Kee Kim (Fermilab/U of Chicago), Sadayoshi Kojima (Tokyo Tech), David Morrison (UC Santa Barbara), Roberto Peccei (UCLA; Chair), Steven Kahn (SLAC and Stanford U), and Nicolai Reshetikhin (UC Berkeley). They have met in March 2008, November 2008, and in August 2009. They

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. 3) Allocation of authority between center director and host institution 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.	provided valuable advice to the University President on the activities and achievement at IPMU. Although IPMU was established as an institute within TODIAS in January 2011 (see 9. Host institution's commitment, <Progress to date>), this introduced no difference in the decision-making system of IPMU. However, IPMU Director reports to the Director of TODIAS when appointment of a new principal investigator or employment of a new faculty member is decided. Also, to clear the university's formality in employing faculty members, the IPMU Director's decision has to be endorsed by the IPMU's Steering Committee. Present members of the Steering Committee are the EB members plus Kyoji Saito and Tsutomu Yanagida (see Appendix 7). 3) Allocation of authority between center director and host institution The allocation of authority has been properly functioning. In 2009, the University President negotiated with the University of California and made a final decision regarding the change of Director Hitoshi Murayama's status. The University President also approved the changes of principal investigators. All the rest of decisions regarding IPMU were made by Director Murayama.

< Future policy and concrete plans >

1) Composition of administrative staff

The present number of administrative staff, which is appropriate for the operation of IPMU, will be kept, while the number of bilingual administrative staff will be increased as much as possible.

2) Decision-making system

The present decision-making system is appropriate for the operation of IPMU. It will be maintained.

3) Allocation of authority between center director and host institution

As has been pointed out by the External Advisory Committee, it will be needed for IPMU Director, who is now under double appointment with University of Tokyo and UC-Berkeley, to appoint an on-site full-time associate director who will act on behalf of the Director when he is absent from the Kashiwa campus.

4. Researchers and center staffs, satellites, partner institutions

4-1. Number of researchers in the "core" established within the host institution

All members

	Goal set in proposal	Results at end of FY 2008	Results at end of FY 2009	Results at end of FY 2010	Final goal (Date: March, 2013)
Researchers	195 < 69, 35%> [, %]	125 < 60, 48%> [6 ,5 %]	165 < 92, 56 %> [10, 6 %]	194 < 100, 52 %> [10, 5%]	195 < 100, 51%> [12, 6%]
Principal investigators	22 < 6, 27 %> [, %]	20 < 3, 15 %> [1, 5 %]	19 < 4, 21 %> [1, 5 %]	18 < 4, 22%> [1, 6%]	22 < 5, 23%> [2, 9%]
Other researchers	173 < 63, 36 %> [, %]	105 < 56, 53 %> [5, 5 %]	146 < 88, 60 %> [9, 6 %]	176 < 96, 55%> [9, 5%]	173 < 95, 55%> [10, 6%]
Research support staffs	20	22	27	25	25
Administrative staffs	10	11	10	11	10
Total	225	158	202	230	230

"Other researchers" is the sum of 6 professors (1 foreign, 0 female) excluding principal investigators, 9 associate professors (2 foreign, 0 female), 5 assistant professors (2 foreign, 0 female), 43 postdoctoral fellows (33 foreign, 5 female), 61 joint appointments (24 foreign, 3 female), 20 students (2 foreign, 0 female) and 32 long-term visitors of more than one month(32 foreign, 1 female).

Other matters of special mention

We plan to appoint a new PI in the area of mathematics in 2011 and another one in the area of cosmology in 2012. We also have a mid-term plan to increase the number of foreign PI's as well as the number of female PI's.

In the initial year of the IPMU, we hired 23 postdocs from around the world. Before their three-year term expires this fall, 21 of them have already acquired next positions. Some to faculty positions (Arizona State, Chonnan National, Yokohama National, Kyushu, Tohoku, Zhejiang, IPMU, Academa Sinica Institute for Astronomy and Astrophysics in Taiwan) and others to another postdoc position (McGill, Max-Planck Institute for Gravitational Physics, CERNx2, Durham, Argonne, Santa Fe Institute, SISSA, Ludwig Maximillian, Chinese University of Hong Kong). Two decided to work outside the academia using their expertise (Pentagon for large-scale data analysis and Massachusetts General Hospital for radiation therapy). We extend one (Kozlov) for two extra years because he is leading KamLAND-ZEN. Only two out of 23 are still looking for the next position.

Among those appointed later, already some had moved to a more prestigious positions: Simon Fellow at Berkeley, CITA Fellow at Toronto, tenure-track positions at Iowa State, IFIC Valecia, NISER India, São Paolo, Vienna Tech. We had few students graduating so far, but they moved to postdoc positions at Caltech (later Fermilab), CERN, Arizona, Princeton, IPMU, Wuhan Institute of Physics and Mathematics.

4-2. Satellites and partner institutions

<Initial plan>
i) Satellites (Make entry for each satellite.)

Institution (1)
IPMU Kamioka Satellite

The institute establishes a satellite at Kamioka 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 Kamioka Observatoy, ICRR, University of Tokyo and Professor Kunio Inoue of Research Center of Neutrino Science, Tohoku University, will be stationed at the satellite and we will have researches jointly appointed from neutrino group.

-Role

-Personnel composition and structure

-Collaborative framework

<Collaboration to date>
i) Satellites (Make entry for each satellite.)

Institution (1)
"IPMU Kamioka Satellite"

-Role
As an initial plan, we started "IPMU Kamioka Satellite" and have been strengthening its structure and collaborative frame wok. Since then, a proper definition of "Satellite" was shown to us from the MEXT office in charge of the WPI program. According to the new definition, our Kamioka Satellite, which is closely related to ICRR, a part of the host institution, does not satisfy the criteria for Satellite. However, since we have been frequently using this name in the past, we state its role and collaborative framework below.

Two major neutrino experiments, Super-Kamiokande and KamLAND, are running and XMASS experiment has started in Kamioka. IPMU has been focusing on observation of supernova relic neutrinos using Super-Kamiokande, detection of neutrinoless double beta decay using KamLand and direct search for dark matter at XMASS. The Kamioka Satellite provides a base for the IPMU researchers working on these projects.

-Personnel composition and structure
ICRR team under the principal investigators M. Nakahata and Y. Suzuki consists of 4 associate professors, 1 project associate professor, 7 assistant professors, 4 project assistant professors, and 2 postdocs. RCNS

team under the principal investigator K. Inoue consists of 2 associate professors, 3 assistant professors, and 4 postdocs. IPMU team consists of professor M. Vagins (head) and 1 postdoc working on supernova relic neutrino, 1 associate professor (K. Martens) and 1 postdoc working on XMASS, and 1 postdoc working on neutrinoless double beta decay.

-Collaborative framework

All members of "Kamioka Satellite" work closely with collaborators of ongoing Super-Kamiokande and KamLand experiments. IPMU's main goals, however, are the investigation of supernova relic neutrinos and neutrinoless double beta decay at these two neutrino detectors. These projects require further R&D, and the IPMU team works closely with the collaborators. IPMU closely works on XMASS experiment.

Institution (2)

IPMU Berkeley Satellite

-Role

IPMU Berkeley Satellite was established on Berkeley campus in December 2009 based on a comprehensive academic exchange agreement which was signed by the University of Tokyo and University of California Berkeley. It provides a framework for conducting collaboration between IPMU and Berkeley physics department in a wide range of fields involving particle physics, cosmology and mathematics. Initial activity is taking place in the field of particle theory involving string theory and phenomenology. Further expansion into the collaboration in Sloan Digital Sky Survey is being discussed at the Berkeley satellite. It also makes easier for us to find candidates for IPMU staff in the US.

-Personnel composition and structure

Director Hitoshi Murayama spends a half of his time at the satellite during his stay at Berkeley which is 30% a year, and supervises overall activity with the help of two Research Directors, Tsutomu Yanagida of IPMU and Lawrence Hall of Berkeley. The team consists of 4 other faculty members, 5 postdoctoral fellows and 10 students.

-Collaborative framework

They collaborate with Yanagida's group and Nojiri's group in particle phenomenology, with Ooguri's group in string theory.

ii) Partner institutions (Make entry for each satellite.) Institution (1) IHES(Institut des Hautes Etudes Scientifiques), France (for mathematics) -Role -Personnel composition and structure -Collaborative framework Institution (2) Yukawa Institute for Theoretical Physics, Kyoto University (for mathematics and theoretical physics) -Role	ii)Partner institutions (Make enter for each satellite) Institution (1) IHES (Institut des Hautes Etudes Scientifiques) -Role IHES is one of the world top-level institutes of mathematics and works closely with physics. We strengthen the connection between mathematics and physics through our exchange. -Personnel composition and structure Professor Jean Pierre Bourguignon (Director) and professor Maxim Kontsevich (Fields Medalist) collaborate with IPMU staff. -Collaborative framework J.P. Bourguignon collaborates with H. Ooguri and K. Saito on new developments in mathematics which are closely related to physics. M. Kontsevich collaborates with A. Bondal, K. Saito and other IPMU mathematicians. Institution (2) Yukawa Institute for Theoretical Physics, Kyoto University -Role YITP has a long standing tradition as a superior institution of theoretical

-Personnel composition and structure -Collaborative framework	physics and mathematical physics. Collaboration with them is beneficial to IPMU, particularly in the areas of string theory and quantum field theory. -Personnel composition and structure The group consists of professor Tohru Eguchi (Director) and associate professor Ken'ichi Izawa. -Collaborative framework A close collaboration between T. Eguchi and H. Ooguri, and between K. Izawa and T. Yanagida, are pursued through their joint appointments and frequent visits to IPMU.
Institution (3) Department of Physics, Kyoto University (for neutrino physics) -Role -Personnel composition and structure -Collaborative framework	Institution (3) Department of Physics, Kyoto University -Role The team works with the Super-Kamiokande experiment for the measurements of neutrino oscillation. They put main emphasis on T2K experiment. -Personnel composition and structure The team consists of associate professor T. Nakaya (head), 1 assistant professor, and 2 postdocs. -Collaborative framework Kyoto team primarily works on the neutrino beam line at JPARC and the T2K front detector, while IPMU team primarily works on Super-Kamiokande detector itself. Since all three of these elements have to work well for precise neutrino oscillation measurements, their close collaboration is important.
Institution (4) Department of Mathematics, Kyoto University (for mathematicians) -Role -Personnel composition and structure -Collaborative framework	Institution (4) Department of Mathematics, Kyoto University This department wished to stay in the role of collaboration at individual levels rather than institutional scale, so that we removed it from the partner institutions in 2007.

Institution (5) High Energy Accelerator Research Organization (KEK) (for neutrino physics) -Role -Personnel composition and structure -Collaborative framework	Institution (5) High Energy Accelerator Research Organization (KEK) -Role A team of theorists at KEK examines new data of LHC experiments from theoretical perspectives of the standard model (Higgs particle), physics beyond the standard model (SUSY particles and dark matter), and higher dimensional theories (black hole and extra dimensions). -Personnel composition and structure The team lead by principal investigator, M. Nojiri, consists of 1 postdoc and 2 students. -Collaborative framework In analyzing the LHC data, KEK team put emphasis on the standard model and supersymmetric theories, while IPMU team tries to see the data from more cosmological standpoints. The two approaches are complementary and beneficial to both sides.
Institution (6) National Astronomical Observatory in Japan (NAOJ) (for dark energy survey and astronomy) -Role -Personnel composition and structure -Collaborative framework	Institution (6) National Astronomical Observatory of Japan (NAOJ) -Role Observations using Subaru telescope have produced many interesting results in recent years. IPMU researchers have been working closely with NAOJ staff and making important contributions in the study of dark matter using gravitational lensing and the study of supernovae. NAOJ is stepping forward and forming collaboration with IPMU for the construction of next generation camera and spectrometer to investigate dark energy. -Personnel composition and structure NAOJ team is lead by professor Hideki Takami and consists of 4 associate professors, 4 assistant professors, and 2 postdocs. -Collaborative framework NAOJ and IPMU collaborate on building a next generation camera and spectrometer, HyperSuprimeCam (HSC) and PrimeFocusSpectrograph (PFS), primarily for investigating dark energy.

Institution (7) Department of Astrophysical Sciences, Princeton University, USA (for dark energy survey and astronomy) -Role -Personnel composition and structure -Collaborative framework	Institution (7) Department of Astrophysical Sciences, Princeton University -Role Princeton team played a leadership role in the historic WMAP project. Their leader and principal investigator, David Spergel, is a world leader of the dark matter search and telescope design. This team brings various expertise to the construction of HSC and PFS as well their operation. -Personnel composition and structure The team consists of D. Spergel and 3 other professors, one assistant professor, and 3 postdocs. -Collaborative framework They collaborate with the teams lead by H. Aihara and H. Karoji for building HSC camera and PFS spectrometer, and subsequent data analysis for the dark energy investigation.
Institution (8) Department of Astrophysical Sciences, University of California, USA (for theoretical physics) -Role -Personnel composition and structure -Collaborative framework	Institution (8) Department of Astrophysical Sciences, University of California All collaborative research activities with this group was shifted to IPMU Berkeley satellite in 2009.
	Institution (9) Research Center for Neutrino Science, Tohoku University -Role This institution was added to the participating institutions from the beginning. As a member of the IPMU Kamioka Satellite, they continue ongoing study of reactor neutrinos and geo-neutrinos at KamLand. At the same time, they collaborate with IPMU on the detection of neutrinoless double beta decay. -Personnel composition and structure The team lead by principal investigator Kunio Inoue consists of 2 associate professors, 3 assistant professors, and 4 postdocs.

	-Collaborative framework They collaborate with IPMU and investigate a possible transformation of KamLand into a huge neutrinoless double beta decay detector.

<Future Policy and Concrete Plans>

There is a plan to add two partner institutions, but no new satellites.

i) Satellites (Make entry for each satellite.)

Institution (1)

IPMU Kamioka Satellite

See 4-2. i). No major changes are planned.

Institution (2)

IPMU Berkeley Satellite

See 4.2. i). No major changes are planned.

There is no plan to add new satellites.

ii) Partner institutions (Make entry for each satellite.)

Institution (1)

IHES (Institut des Hautes Etudes Scientifiques)

See 4-2. ii). No major changes are planned.

Institution (2)

Yukawa Institute for Theoretical Physics, Kyoto University

See 4-2. ii). No major changes are planned.

Institution (3)

Department of Physics, Kyoto University

See 4-2. ii). No major changes are planned.

Institution (4)

See 4-2. ii).

Institution (5)

High Energy Accelerator Research Organization (KEK)

See 4-2. ii). No major changes are planned.

Institution (6)
National Astronomical Observatory of Japan (NAOJ)
See 4-2. ii). No major changes are planned.

Institution (7)
Department of Astrophysical Sciences, Princeton University
See 4-2. ii). No major changes are planned.

Institution (8)
See 4-2. ii)

Institution (9)
Research Center for Neutrino Science, Tohoku University
See 4-2. ii). No major changes are planned.

Institution (10) new addition is planned
Division of Physics, Mathematics, and Astronomy, California Institute of Technology

-Role
Collaboration in the areas of observational astronomy, string theory, and mathematics

-Personnel composition and structure
Hirosi Ooguri (PI), Richard Ellis, and their postdocs and students

-Collaborative framework
Hirosi Ooguri continues to play the role of PI, and belongs to both Departments of Physics and Mathematics. Richard Ellis is a key member of the PimeFocusSpectrograph collaboration.

Institution (11) new addition is planned
AstroParticule et Cosmologie (APC), Université Paris 7

-Role
General scientific exchanges in theoretical particle physics, cosmology, underground experiments, and astronomy

-Personnel composition and structure
Pierre Binétruy (APC director), Stavros Katsanevas (PI), George Smoot (IPMU member)

-Collaborative framework

Stavros Katsanevas continues to play the role of PI, and leads the research program at APC. The director Pierre Binétruy is a theoretical physicist who works on unified theories, string theory, particle physics, and cosmology and collaborates with our members. George Smoot will join IPMU membership in the near future.

5. Summary of center's research environment

<Initial plan>

1) Environment in which researchers can devote themselves to their research

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.

2) Startup research funding

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 postdoctolal fellows hired by the Institute.

3) 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

<Progress to date>

1) Environment in which researchers can devote themselves to their research

The number of administrative staff is 36, of which 25 are in the category of research support staff and hired directly by IPMU as contrast to the 11 staff belonging to the administrative bureau of the University. Out of 36, 3 are with particle physics background, and they serve to make communication between the scientific staff and administrative staff smoother. Administrative staff as a whole forms a strong team to handle a wide range of tasks both in administrative and research support and, in particular, relieve paper work loads from the scientific staff. Since 2009. Physics department, graduate school of mathematical sciences, and ICRR each received fund for hiring one assistant professor to substitute their PI's teaching. In addition, the university hired one associate professor in physics department to ease heavy burden of H. Aihara as IPMU's deputy director, and provided one professor position at IPMU to further strengthen its research activity.

2) Startup research funding

All postdoctoral fellows receive annual research fund of 500,000 yen from IPMU. Researcher at or above assistant professor rank receive startup fund according to their needs.

3) Postdoctoral positions through open international solicitations

We advertised for opening positions in Physics Today, CERN Courier, American Mathematical Society Magazine, American Astronomical Society Magazine, and in English IPMU homepage. We also sent the

of the field, both in Japan and abroad, to solicit outstanding candidates.	advertisements to numerous places worldwide via emails.
4) Administrative personnel who can facilitate the use of English in the work process	4) 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.	Among the 36 administrative and research support staff, 20 are bilingual. We set up a system to handle all of work-related communication in English. We have been constantly improving the IPMU website which contains information ranging from seminar notices to daily living. The same website is also used for registering publications and conference talks, as well as filling paper works such as trip reports.
5) Rigorous system for evaluating research and system of merit-based compensation	5) Rigorous system for evaluating research and system of merit-based compensation
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 conferences, cross-disciplinary papers, salaries at competing institutions abroad, and leadership roles at the Institute.	We proceed as stated in the initial plan for setting the salary scales for all researchers. In order to assist the Director for evaluating the accomplishments of individual researchers, we constructed a comprehensive data base containing all relevant information of individual researchers. We think it is also important to correctly evaluate a type of activities which may not necessarily appear on such record. Our system of "mentor", in which one of the principal investigators closely follows each of young staff's performance, nicely covers this aspect.
6) Equipment and facilities, including laboratory space, appropriate to a top world-level research center	6) 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 24 hours a day, 7days a week to make impromptu discussions possible.	New IPMU building in Kashiwa Campus (5,900 square meters) became available in January 2010. IPMU Kamioka Satellite Office (500 square meters), which became available in February 2009, has been functioning as a base for IPMU researchers working at Super-Kamiokande, KamLAND and XMASS. All of the partner institutions as well as two IPMU satellites are connected via video conference system. They are used daily for seminars and discussion.
7) International research conferences or symposiums held regularly to bring world's leading researchers together	7) International research conferences or symposiums held regularly to bring world's leading researchers together

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.

FY 2007-2008: 11 meetings

Major examples (meeting title and place held)	Number of participants
Moonshiney Conference in Kashiwa, Media Hall, Kashiwa Campus	Domestic: 32 Overseas: 5
Focus Week: Quantum Black Holes Media Hall, Kashiwa Campus	Domestic: 56 Overseas: 14

FY 2009: 12 meetings

Major examples (meeting title and place held)	Number of participants
IPMU International Conference Dark Energy: "Lighting up the Darkness!" Media Hall, Kashiwa Campus	Domestic: 79 Overseas: 55
Focus Week: Condensed Matter Physics Meets High Energy Physics Lecture Hall, IPMU	Domestic: 160 Overseas: 40

FY 2010: 16 meetings

Major examples (meeting title and place held)	Number of participants
CLJ2010: from Massive Galaxy Formation to Dark Energy Media Hall, Kashiwa Campus	Domestic: 53 Overseas: 107
Horiba International Conference on Cosmology and Particle astrophysics (COSMO/CosPA 2010) Ichijo Hall and other rooms, Hongo Kampus (co-organized by IPMU and RESCEU)	Domestic: 135 Overseas: 159

<Summary of achievements to date>

The number of international conferences and workshop we hosted at IPMU were 11 in JFY 2007-2008, 12 in JFY 2009, and 16 in JFY 2010. Attendees of these meetings were typically at least 1/3 from abroad. Some were organized to enhance interdisciplinary discussion between

	physicists and mathematicians, between particle physicists and condensed matter physicists, or between specialists of different areas discussing a subject of common interest. Some of these activities have lead to continuing collaborations among traditionally different research fields and important publications.
8) Other measures, 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.	8) Other measures, if any IPMU takes its role in helping foreign researchers with life in Japan very seriously, so that they can concentrate on their research. For full-time researchers, support consists of the assistance needed to get their life in Japan started, such as foreign resident's registration, housing, and opening a bank account, as well as various needs in daily life. For visitors, it is necessary to help solve the various problems they encounter during their stay. Kashiwa International Guesthouse opened in March 2010. We continue to organize a group of volunteers who help our foreign staff for registering at the city hall, getting bank account, and looking for housing. We continue to offer free Japanese lessons to newly arriving foreign research staff and their family members. To enhance these services, starting from April 2010, IPMU has entered into a contract with JISTEC (Japan International Science and Technology Exchange Center) which provides the support on behalf of public institutions. At IPMU, JISTEC's support desk is open every Monday, Wednesday, and Friday in the Reception Office on the 2nd floor. In an emergency, IPMU researchers and visitors can telephone the JISTEC staff on duty for 24-hour assistance. To supplement the emergency telephone service of JISTEC, IPMU is also under contract with another company, AXA Assistance Japan, for 24-hour emergency assistance on the telephone.

<Future Policy and Concrete Plans>

1) Environment in which researchers can devote themselves to their research

Keeping the present level of administrative and research support staff is essential for maintaining the IPMU's research environment which is regarded as one of the best in the world. It is our policy to maintain it. For this, the director must continue his effort to receive support from the TODIAS management and to bring in outside funding. At the same time, IPMU, under the leadership of the administrative director, keeps improving the present system for assisting the researchers. This effort includes for each staff to improve their IT-related techniques, science communications, as well as their English skills.

2) Startup research funding

We try to continue the present scheme to provide each postdoc with an annual research fund of 500,000 yen and each faculty member with some amount of startup fund depending on their need. This requires finding such resources. We continue to encourage all researchers to aggressively go for finding outside funding and the administrative staff to help preparing necessary paper works.

3) Postdoctoral positions through open international solicitations

Recruiting very best young researchers regardless of their nationality is very important. Fortunately the name of IPMU became well known in the international community due to our tireless effort for announcing the openings internationally. However, more importantly, active participation of our postdocs in the international conferences and workshops, and their career development after leaving IPMU have been helping the international solicitations in great deal. We continue to encourage our postdocs to be active at international scenes.

4) Administrative personnel who can facilitate the use of English in the work process

With the present fraction of bilingual staff in the administration, we can handle most of language-related ordinary matters. In future, however, we want to grade up the English skills of our administrative staff to one step higher level of handling science communications and grant applications with minimum burden on researchers. Our policy is to encourage the staff to make good use of various language classes that are offered on campus, and to create an atmosphere in the office to educate each other on the job. We might also consider recruiting suitable personnel.

5) Rigorous system for evaluating research and system of merit-based compensation

Our future policy is the same as what we have now. Namely, we maintain database that contains publications, citations and conference talks of individual researchers as a quantitative and objective research activity record on one hand, and to judge their performance that may not appear on such database through interactions with "mentors". Salaries of researchers other than the director and PIs will be decided by the director based on this information.

6) Equipment and facilities, including laboratory space, appropriate to a top world-level research center

As described in 2-2-1, IPMU is promoting the next major astronomical imaging survey project using the 8.2m Subaru telescope on Manua Kea owned by National Astronomical Observatory of Japan (NAOJ). For this project, the new digital camera called HyperSuprimeCam (HSC) is being built with approximately 0.9 billion pixels weighing 3 tons together with the sophisticated and precise corrector lens system. Thanks to the much bigger mirror, the survey will probe much deeper into the younger Universe to extend the measurement of the expansion history back to earlier times, and determine the nature of the dark energy with the best accuracy anticipated in the next five years. The camera is being readied for the first light in the fall this year. The actual survey is expected to start in the year 2012.

Also, Director Murayama is leading an international collaboration of astronomers and instrumentalists to build the next generation multi-object spectrograph with a robotic fiber positioner that can simultaneously take spectra of thousands of galaxies at the same time. This project is called SuMIRe. Though his FIRST award of ¥3.4B is not sufficient for SuMIRe, international partners pledged to contribute resources to build the proposed multi-object spectrograph. Caltech and NASA Jet Propulsion Laboratory will contribute the robotic fiber positioner with 10 micron accuracy, Princeton and Laboratoire d'Astrophysique Marseille will build spectrographs covering 380 to 1300 nm, allowing for a continuous redshift survey of galaxies from nearby to $z \sim 6$ using OII and Lyman alpha lines. The formation of collaboration is well underway and the conceptual design will be fixed by this September.

IPMU accommodates visitors and graduate students in addition to its full-time researchers and administrative staff. The present IPMU Research Building, which has a floor area of around 6,000 m^2, is not large enough to accommodate the additional visitors IPMU wishes to invite. IPMU consequently requested a budget to construct its second building, with a floor area of about 3,000 m^2, and this was included in the Government's stimulus package in FY2009. As the Institute of Gerontology and the Information Technology Center also secured a budget to construct their own research buildings on the Kashiwa campus of the University of Tokyo, the University's Campus Planning Office took the initiative to efficiently integrate the demands for research space of the three institutions. As a consequence, construction of the Second General Research Laboratory Building, boasting a total floor area of 12,000 m^2, started in April, 2010, and has been completed at the end of April 2011. The IPMU wing of this building will be located diagonally behind the IPMU Research Building. IPMU is planning to use its new space not only as office space for visitors, but also as an Astronomical Information Center. It will function as an analysis center for the data to be obtained from the IPMU initiatives for astronomical observations as described above, and at the same time it will showcase outcomes from the IPMU's astronomical research to the public. For this purpose, the center will be located at a corner of the ground floor, with a transparent glass wall. There will be a number of large screens for data projection. People will be able to view them from outside.

7) International research conferences or symposiums held regularly to bring world's leading researchers together

Our future policy is to maintain the present level of activities in both number of meetings and its interdisciplinary nature. We have successfully started several new types of interdisciplinary meetings, between mathematicians and physicists or between particle theorists and condensed matter theorists. We continue such effort and follow through where their collaboration leads us to.

8) Other measures, if any

IPMU has started to organize "schools" for graduate students by inviting prominent researchers for lectures as well as providing them opportunities to present their own research this summer. We planned one on collider physics (Monte Carlo School) following a successful annual series in Europe, and another one on extragalactic astronomy. Unfortunately, due to the concerns about the radioactivity and blackout, we had to cancel the school on extragalactic astronomy. We will still hold the Monte Carlo School now relocated to Kyoto co-hosted by Yukawa Institute for Theoretical Physics of Kyoto University. We will continue to organize "schools" for graduate students every year.

6. Criteria and methods used to evaluate center's global standing

<Initial plan and goals at the interim evaluation>

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.

<Current assessment>

1) We require all scientific staff to register their publications resulted from IPMU activities. First they must register as an IPMU preprint on IPMU website, and update its subsequent publication status. They were also required to register presentations given at conferences and university seminars. In order to obtain citation numbers for the published papers, and also to collect those missing on the website registration, we adopt a scheme in which papers published by the IPMU members are thoroughly searched from a wide collection of commercially available journals by the research support staff. This scheme guarantees that the citation numbers are regularly updated once the papers are registered as "IPMU papers" including those from the former members. This is useful for monitoring annual variation of our global standing, as well as for following through the career development of our former members, while imposing minimal load on the researchers.

   There is a concern that the metrics based on publications, which is well acknowledged in physics and astronomy, may not be a suitable indicator for evaluating mathematics activities. We are considering an approach of peer review in mathematics.

   The number of papers published by IPMU in refereed journals was 124 in FY2007-2008, 202 in FY2009, and 236 in FY2010. We have compared our publication metrics with other similar research centers in the world. We have selected a sample of papers that were published in the refereed journals (review articles not included) since 2008 in the fields of astronomy and astrophysics, particle and fields, multidisciplinary physics, mathematics, and applied mathematics.

   We are fully aware that such comparison has to be dealt with great caution since each place has different research fields and staff composition. With this caution in mind, our average citations per article 7.6 compares with 7.3 for IAS Princeton, 8.1 for KITP Santa Barbara, 6.5 for YITP Kyoto, 9.6 for Perimeter Inst, and 4.5 for ICTP Trieste. For the number of articles with more than 50 citations, our 8 articles compares with 18 for IAS Princeton, 8 for KITP Santa Barbara, 3 for YITP Kyoto, 13 for Perimeter Inst, and 4 for ICTP Trieste

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.	2) We were visited by 540 (168 from abroad) in JFY 2007-2008, 432 (345 from abroad) in JFY 2009, and 862 (478 from abroad) in JFY 2010. We make the visitor list including near future visits public on IPMU website so that research centers of neighboring countries (Korea, China, Taiwan) can contact them and arrange their visits while staying at IPMU. The number of long-term visitors of more than one month was 14 (13 from abroad) in JFY 2007-2008, 30 (29 from abroad) in JFY 2009, and 32 (32 from abroad) in JFY 2010. This is a good indication that the collaboration between resident staff and visitors, which might have started at some point, has been developing into firm and mature levels.
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. 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.	3) So far only one paper was published in a refereed journal co-authored by mathematicians and physicists although a variety of collaborative research has been taking place between them at IPMU. Several papers in particle theory and string theory which were written by only physicists were inspired by talking to mathematicians. Also several papers written by physicists were published in mathematics journals peer reviewed by mathematicians. We do not view this fewer-than-expected co-authored papers as a lack of collaborative activities. It may be partly due to their different culture toward publications. While physicists try to publish their results as promptly as possible, mathematicians tend to wait until they build up into much more complete foundations and spend much longer time. Nevertheless, we like to continue monitoring this number because it provides an interesting difference of the two fields.

<Future Policy and Concrete Plans>

We have set up a basic but comprehensive database for publications, seminar and conference talks and visitors, which provides quantitative and objective methods for evaluating our global standing. We continue to improve ways to use it, especially for comparing IPMU with other similar institutes. We might need alternative method to evaluate mathematics activity, because the citation counts are known not to be a good measure of the impact of research. We explore an approach such as peer review for mathematics. Evaluation of cross-disciplinary collaboration, especially between mathematics and physics, needs further thinking. Monitoring just co-authored articles may not be sufficient or even may be misleading. We will explore this problem.

7. Securing competitive research funding

<Initial plan>

Grand total of competitive funding awarded to PI's over past 5 years (FY2002-2006) is $56.9M.

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)

Based on this past record, we are confident to maintain the same funding profile well into the era of this new Institute.

<Secured to date>

We secured 1980M yen in FY2007, 943M yen in FY2008, 866M yen in FY2009, and 981M yen in FY2010.

The SuMIRe (Subaru Measurement of Images and Redshifts) program was approved by the FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program for a total of 3.4B yen for 5 years starting in FY2010. We received 817M yen in FY2010. Funding profile for the rest of the period of this program is 429M yen in FY2011, 375M yen in FY2012, 932M yen in FY2013 and 645M yen in FY2014.

We were approved a total of 86M yen by the JSPS's Institutional Program for Young Researcher Overseas Visits. Funding period is for 3 years starting March 1, 2011. Funding profile is 28.9M yen in FY2010-2011, 29.3M yen in FY2012 and 27.8M yen in FY2013.

Among our 38 full-time foreign members, 11 obtained research funding from JSPS's grant-in-aid in FY 2010. This is a good sign of IPMU's globalization.

<Future Strategy>

We will keep encouraging all full-time IPMU researchers to apply for JSPS's grant-in-aid whenever application is possible. In particular, experimentalists and observational astronomers are encouraged to secure high-level research funding such as Grant-in-Aid for Specially Promoted Research and Grant-in-Aid for Scientific Research (S). IPMU administration helps researchers prepare particular application forms that are requested to fill in with Japanese words.

8. Other important measures taken to create a world premier international research center

<Initial plan>

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.

We are confident that our aggressive approach to assemble the world-leading scientists from other institutions from within Japan or from

<Measures taken to date>

On the 1st of January 2011, the University of Tokyo established the Todai Institutes for Advanced Study (TODIAS), and approved IPMU as the first member institute within this new and permanent organization on the 11th the same month. In the inauguration ceremony, the University President, Junichi Hamada stated that the TODIAS was established as a university-wide organization and comprises research institutes that can

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.

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.

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.

function as a world-leading center of knowledge, aiming to enhance the University's academic excellence as a whole and further advance its internationalization. We are extremely encouraged and determined to do our best to fulfill the expectation.

We continue to recruit a large number of non-Japanese researchers. Our administrative staff is effectively handling their relocation and setting up an excellent research environment. We have been receiving various inquiries about our approaches from other departments.

We enforce a policy of requiring all researchers to spend at least 1 month but not more than 3 months abroad as long as the fund allows. We think this is important for all researchers to cross-calibrate their activities with an international standard, and particularly for young staff to stay visible in the international community. We are working hard to secure the fund for this purpose. We had a plan to establish named distinguished professorship. Negotiation with Kavli Foundation to establish such position is still continuing.

Two proposals for the Global COE Program submitted by the IPMU principal Investigators were approved and the grants started in JFY 2008. They will continue for five years.

Weaving Science Web beyond Particle-Matter Hierarchy
by Kunio Inoue, professor of Tohoku University, as a project leader.

They propose to establish an international research and education center to strengthen the understanding in each of the subjects that form a hierarchy of matter, starting from particles to nucleus, condensed matter, all the way to the universe, and to deepen the connection among them. Through this approach, they try to develop a new frontier of science.

The leader of this project is a Principal Investigator of IPMU, and leading an effort in neutrino experiment at KamLAND. The theme for this program "Hierarchy of matter" can be considered as one aspect of the IPMU's theme "Physics and Mathematics of the Universe", and thus they are closely related to each other.

Quest for Fundamental Principles in the Universe
By Naoshi Sugiyama, professor of Nagoya University, as a project leader.

	They propose to establish an international research and education center to study, i) evolution of the universe, ii) space-time structure of the particles and universe, and iii) physics of the cosmological environment. Their research objective "Fundamental Principle in the Universe" constitutes an important part of IPMU's objective "Physics and Mathematics of the Universe".

<Future Policy and Concrete Plans>

Some of the measures proposed in the initial plan have been accomplished to date. The foundation of TODIAS and establishment of IPMU within TODIAS has been a major step for IPMU to become a permanent entity within the university. Yet, it is needed to establish the solid financial foundation to sustain the operation of IPMU beyond the period of WPI project funding. To this end, we will keep proactive to raise funding for IPMU. In particular, we will cooperate with the Office of the President to secure substantial endowments from overseas foundations.

The policy to recruit a large number of non-Japanese researchers will be continued, but at the same time we recognize the importance of nourishing young Japanese researchers. We will try to accept more JSPS postdoctoral fellows and also try to secure more external funds with which we can hire Japanese postdocs.

9. Host institution's commitment

<Initial plan>
-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.

<Progress to date>
-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.
Based on Action Scenario FOREST2015 and individual action scenario for emphasized themes, the University decided to found TODIAS in January 2011 as a university-wide organization for the pursuit of academic excellence and globalization of research environment, and established IPMU within it. This will strengthen the internationalization to go for world-top-level research, and further support IPMU. With this clear objective, the University supports IPMU with its every possible means.

-Concrete Measures (1) Competitive grants obtained by researchers participating in the project and in-kind contributions, etc. 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) System under which the center's director is able to make substantive personnel and budget allocation decisions 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) Support for the center director in coordinating with other departments at host institution when recruiting researchers, while giving reasonable regard to the educational and research activities of those departments	-Concrete Measures (1) Competitive grants obtained by researchers participating in the project and in-kind contributions, etc. The University of Tokyo has established IPMU within TODIAS that was founded in January 2011, and positioned it 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. These efforts shall be continued and strengthened further. 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) System under which the center's director is able to make substantive personnel and budget allocation decisions 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. With the start of TODIAS and appointment of its director in January 2011, ongoing strategic management by the President and the board member in charge of research will be strengthened by establishing IPMU within it. 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) Support for the center director in coordinating with other departments at host institution when recruiting researchers, while giving reasonable regard to the educational and research activities of those departments

In order to ensure that education and research activities 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.	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) Revamping host institution's internal systems to allow introducing of new management methods (e.g., English-language environment, merit-based pay, top-down decision making) unfettered by conventional modes of operation	(4) Revamping host institution's internal systems to allow introducing of new management methods (e.g., English-language environment, merit-based pay, top-down decision making) unfettered by conventional modes of operation
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.	As described above, the University of Tokyo has developed an innovative scheme to allow positioning of the IPMU which was further strengthened by establishing it within TODIAS. 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) Accommodation of center's requirements for infrastructural support (facilities, e.g., laboratory space; equipment; land, etc.)	(5) Accommodation of center's requirements for infrastructural support (facilities, e.g., laboratory space; equipment; land, etc.)
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 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 a residential facility for foreigners was already opened at the end of FY2009 near the campus and several more facilities are under discussion. Priority allocation of the residences at the opened facility has already been made for researchers invited to the IPMU from overseas and the same measure shall be taken for the future residential facilities. The

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.	University also develops a number of world-class research facilities and a research building for the IPMU has been completed at the end of 2009, financed by the university. The university further supports IPMU's requirements for infrastructures as needed.
(6) Support for other types of assistance	(6) Support for other types of assistance
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.	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 were reorganized in July 2007, where the Research Network Support Group was 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. With establishing IPMU as a part of the TODIAS organization, the University of Tokyo provides a concentrated support through the Research Network Support Group. As has been done before, the University cooperates with the IPMU staff and provides maximum support

<Future Policy and Concrete Plans>
-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.

Based on Action Scenario FOREST2015 and individual action scenario for emphasized themes, the University decided to found TODIAS in January 2011 as a university-wide organization for the pursuit of academic excellence and globalization of research environment, and established IPMU within it. This will strengthen the internationalization to go for world-top-level research, and further support IPMU. With this clear objective, the University supports IPMU with its every possible means.

-Concrete Measures
(1) Competitive grants obtained by researchers participating in the project and in-kind contributions, etc.

The University of Tokyo has established IPMU within TODIAS that was founded in January 2011, and positioned it 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. These efforts shall be continued and strengthened further. 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) System under which the center's director is able to make substantive personnel and budget allocation decisions

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. With the start of TODIAS and appointment of its director in January 2011,

ongoing strategic management by the President and the board member in charge of research will be strengthened by establishing IPMU within it. 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) Support for the center director in coordinating with other departments at host institution when recruiting researchers, while giving reasonable regard to the educational and research activities of those departments

In order to ensure that education and research activities 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) Revamping host institution's internal systems to allow introducing of new management methods (e.g., English-language environment, merit-based pay, top-down decision making) unfettered by conventional modes of operation

As described above, the University of Tokyo has developed an innovative scheme to allow positioning of the IPMU which was further strengthened by establishing it within TODIAS. 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) Accommodation of center's requirements for infrastructural support (facilities, e.g., laboratory space; equipment; land, etc.)

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 a residential facility for foreigners was already opened at the end of FY2009 near the campus and several more facilities are under discussion. Priority allocation of the residences at the opened facility has already been made for researchers invited to the IPMU from overseas and the same measure shall be taken for the future residential facilities. The University also develops a number of world-class research facilities and a research building for the IPMU has been completed at the end of 2009, financed by the university. The university further supports IPMU's requirements for infrastructures as needed.

(6) Support for other types of assistance

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 were reorganized in July 2007, where the Research Network Support Group was 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. With establishing IPMU as a part of the TODIAS organization, the University of Tokyo provides a concentrated support through the Research Network Support Group. As has been done before, the University cooperates with the IPMU staff and provides maximum support.

- What the host institution is /will do to support/sustain the operations of the center (include support activities already underway)?

1. Over the next 5 years

The University of Tokyo founded TODIAS in January 2011 as a university-wide permanent organization for the pursuit of academic excellence and globalization of research environment. TODIAS is to be comprised of research institutes, each demonstrating its function as a "world-leading center of knowledge," and IPMU was designated as the first institute of this organization. This is a critical step for IPMU to become a permanent entity within the university. In order to establish the solid financial foundation to sustain the operation of IPMU, the university cooperates with the IPMU staff and provides maximal support for IPMU's efforts to secure endowments, external funds, and donations.

Also, the university will keep carrying out reforms of the university-wide system aiming at establishing flexible and creative management of both human and financial resources. This is essential to create and sustain new, interdisciplinary research institutes such as IPMU. The university management considers it a university's challenge to provide such institutes with tenure-equivalent positions. This will have transformative effects on the human resource management system. In this context the university will make every effort to take on this challenge.

2. After the period of WPI project funding ends

The university will strengthen the plans stated above after the period of WPI project funding ends.

With more flexible and creative management of the human and financial resources, which will be instituted in the university, it can provide support for operation of IPMU using the available university resources for a limited period, in the event when IPMU cannot sustain itself with external funds only.

Also, given more flexibility in the national funding system such as to allow allocation of increased overhead to manage the university, the university's efforts to establish flexible and creative management of both human and financial resources would be accelerated and enhanced. Such a management system would enable the university to further support IPMU.

10. Efforts to improve points indicated as requiring improvement by Program Committee and results of such efforts

-Points specified as needing improvement (as noted in Item 3 "Points that need improvement" in the FY2009 follow-up results)	-Efforts to improve them and results
The 2009 follow-up results specified the following points as needing improvement.	
1. Continuous leadership of the center director under double appointment with University of Tokyo and UC-Berkeley	1. The director spends a total of 85% for IPMU a year, 70% by directly taking a role as the director and 15% by doing research at IPMU Berkeley

	Satellite. He took a strong leadership in negotiating with the university president for establishing TODIAS.
2. Fruitful collaboration between theorists and experimentalists.	2. Experimentalists at IPMU are mostly in neutrino physics. Unfortunately there is no publication co-authored by theorists and experimentalist in this field. Several such publications have resulted in the field of particle phenomenology, but with experimentalists belonging to other institutions and working at LHC experiments.
3. Nourishment of young Japanese researchers.	3. At the junior faculty level, Keiichi Maeda won the 2009 Astronomical Society of Japan Young Astronomer Award for supernova study, Tadashi Takayanagi won the 2010 Yukawa-Kimura Prize for string theory, and Fuminobu Takahashi won the 2010 Physical Society of Japan Young Scientist Award for cosmology research. Masaomi Tanaka, recipient of 2009 University of Tokyo President Award as a student, is now one of our highly qualified postdoctoral fellows. IPMU is full of young and excellent staff, and their researches are well recognized worldwide.
4. Qualitative analysis of publications.	4. The number of papers published by IPMU in refereed journals was 124 in FY2007-2008, 202 in FY2009, and 236 papers in FY2010. Qualitative analysis of the publications is given in 6.1. The number of papers co-authored by mathematicians and physicists, which we thought to be a measure of the synergy between the two fields, turned out just one. Our analysis on this is described in 6.3. We will continue to improve the methods for qualitative analysis of publications.
5. Early establishment of IPMU as a new "Advanced Institute" of University of Tokyo and rendering of tenured positions.	5. Establishing of TODIAS was described in 8. Issues of tenure positions will be negotiated within a scheme of TODIAS.

11. Efforts to improve points indicated as requiring improvement in the Project Progress Verification Report and results of such efforts	
-Points specified as needing improvement (extracted from the FY2009 Project Progress Verification Report) We have extracted following points from the FY2009 Project Progress Verification Report as needing improvement.	-Efforts to improve them and results
1. Although a substantial fraction of new funding come through IPMU for experimental programs, HSC, SuMIRe, XMASS and GADZOOKS, IPMU has neither the full-time experimental PIs nor senior engineers qualified to manage or lead the engineering and project-management.	1. On April 1, 2010 IPMU has appointed Hiroshi Karoji (Prof.) as a project manager for the SuMIRe project. As the SuMIRe project is the combined effort of HSC imaging survey and the new spectroscopic survey using PrimeFocusSpectrograph to be mounted on the Subaru Telescope, Prof. Karoji also oversees IPMU's engineering responsibility for HSC. Furthermore, on April 1, 2011 IPMU has appointed Hajime Sugai (Associate Prof.) who is responsible for the engineering aspects of the PrimeFocusSpectrograph. We are planning to add a system engineer in the near future as well. At the Kamioka Satellite, since 2009 March 1 IPMU has been hiring an engineer (M. Kanazawa, who had long been working at Hitachi Kokusai Electric Co., Inc. as Chief Engineer) to assist physicists in managing engineering aspects of IPMU initiatives, XMASS and GADZOOKS.
2. The funding for the experimental programs, which comes from the Japanese Stimulus Package, is so far not very well integrated with the remaining funding envisaged from collaborating institutions and domestic community. The committee strongly recommend that IPMU organize a task force to study how similar programs in the US and Europe are organized, to discuss this issue with collaborating institutions and the relevant community, and to execute a detailed review of its programs.	2. While it is true that the funding for the SuMIRe project from other institutions has not been completely secured yet, we are making substantial progress. The Academia Sinica Institute for Astronomy and Astrophysics has approximately $5M already available allocated in their operating budget. The Brazilian group has been raising necessary funds and, given their economy, they are quite confident about obtaining approximately $5M from the state of Saõ Paolo. Official allocation of necessary personnel at Laboratoire d'Astrophysique Marseille is expected in September.
3. The committee finds that software preparation for data processing, calibration and science analysis for HSC is far behind its competitor (the Dark Energy Survey). The number of dedicated scientists, engineers and computer experts are far smaller and scientific communities (domestic	3. In order to address the committee's concern, we have been carrying out a series of Data Challenges designed to define the HSC data structure and develop the software pipelines and infrastructure to analyze them in an increasingly sophisticated fashion. The goals of the first data

astronomy, particle physics as well as international ones) are not yet mobilized.	challenge (DC1), which completed successfully in August 2010, were to process single-band, single-epoch data and produce a mosaic image and an object catalog. The second challenge (DC2) subsequently began with the following goals: (1) to process "griz multi-band data" creating a multi-band photometric catalog for a sky tile, (2) to process a 3x3 square-degree mosaic by large half-a-FOV dithering, (3) to determine astrometric solution including CCD arrangements for single-shot images, (4) to process Suprime-Cam data with the same pipeline developed for the simulated data, and (5) to design the database for science images and catalogs for end users. DC2 is scheduled to conclude in August 2011. We are planning to define the goals of DC3, which is the final DC, during the HSC collaboration meeting in August at Princeton. Throughout DC1 and DC2, the software framework, originally developed for high energy physics experiment application at KEK, has successfully been used to manage execution and parallelization of analysis pipelines. HSC data management/analysis team consists of groups of scientists from IPMU, NAOJ, Princeton and KEK. Human resources for software preparation have significantly increased since the committee's visit last year. They include 10 FTEs (4FTEs from IPMU, 2 from NAOJ, 3 from Princeton and 1 from KEK) and 2 graduate students from Department of Physics. A PI from IPMU provides oversight of the activity. Software preparation has improved since the last review and is on schedule.
4. For the theory publications, it will be essential to have statistical evidence (e.g. citations) which can be quantitatively compared with that of other leading institutes.	4. In 6.1, we have presented a comparison of our publication metrics with other leading institutes having similar research programs. To perform a similar comparison for subsamples of only theory papers, we have to remove the experimental and observational papers. But that is difficult for us to perform for the other institutes. Instead we have done the following. We find the fraction of experimental and observational papers at IPMU is 14% and its average citation number is 7.1, which is not very different from 7.6 for the entire sample. We can guess with a reasonable approximation that this tendency is the same in other institutes, and, therefore, what we presented in 6.1 is a fair comparison for theory papers.
5. It could also be helpful, for the diversification of the theory group, to hire a creative young researcher pursuing a non-string approach to quantum gravity.	5. Precisely in this direction, Associate Prof. Shinji Mukohyama and two postdocs Domenico Orlando and Susanne Reffert are working on the Hořava-Lifshitz model; see 2-2-1 (4) (b) on page 13.

6. While there is some evidence of fruitful dialog between algebraic geometry and string theory, and between string theory and cosmology, we detect no evidence for significant dialogue between mathematics and cosmology.	6. IPMU takes a step forward in this direction by hiring Marcus Werner in October this year. While he is now at Mathematics Department of Duke University as a Visiting Assistant Professor, his research interests are geometry and topology in physics, especially gravitational lensing theory, Relativity, and astrophysical tests of gravity theories.
7. On-site senior mathematicians have not reached the critical mass – not enough to achieve strong interactions with theoretical physicists.	7. IPMU makes a conscious effort to increase the number of on-site senior mathematicians. In fact, recently IPMU hired two assistant professors, Todor Milanov and Tomoyuki Abe.
8. For the continuous leadership of Murayama, we need to carefully evaluate the possible adverse effects due to his double appointment.	8. We'd appreciate your continuing monitoring.
9. The Ken-nin problems (joint appointment) mentioned in the 2008 and 2008 Verification Reports still exists. The fraction of full-time PIs at present is still small. A visible on-site scientific figurehead is needed to keep the high morale of young researchers.	9. IPMU keeps searching full-time PI's. Now we have one promising candidate who will stay at IPMU for a while before making up his mind to accept Director's offer. In relation to the need of a visible on-site scientific figurehead, IPMU External Advisory Committee recommended and Director Murayama wishes to appoint an Associate Director who is stationed on the Kashiwa campus to help him keep the best performance as the IPMU Director. Search is kept on.
10. There seems to be a certain imbalance between Japanese versus foreign postdoc hirings. Slightly more balanced scheme seems desirable. Conversely, for professors and PIs, every effort should be made to hire simply the best scientific leaders irrespective of their country of origin.	10. Through the SuMIRe Project funding, mostly Japanese researchers are hired by IPMU, following the recommendations by the Subaru Advisory Committee. This helps increase the number of Japanese postdocs, in particular. In FY2010, a professor and two postdocs were hired. For the selection of PI's and hiring faculty members, IPMU has kept on, and will keep on, seriously following this advice. In this fall, IPMU will hire new faculty member Kevin Bundy, who is currently Hubble Fellow at UC Berkeley. Also, another non-Japanese candidate for an IPMU faculty member will be interviewed.
11. Graduate student numbers (16 for around 60 potential supervisors) remain rather low. It could profitably be increased by at least a factor of 3.	11. IPMU has been steadily accepting increasingly more graduate students (9 from Physics Department and 2 from Astronomy Department; FY2010, 16 from Physics Department and 2 from Astronomy Department; FY2011, 16 from Physics Department, 4 from Astronomy Department, and 2 from Mathematics Department). Since IPMU started accepting 5-year graduate course students in FY2009, the number of students is not saturated yet. It will not be difficult to increase the number of students up to 30 or so, but further increase may require some new ideas.

12. IPMU could provide joint meeting opportunities for graduate and undergraduate students in mathematics, physics, and cosmology, fostering communication between these fields at an early age.	12. Graduate students at IPMU can attend all the seminars, and also they enjoy every-day tea time which all IPMU members join. On these occasions they can easily communicate with researchers and students in other fields. On the other hand, according to our understanding of the WPI policy, it is not allowed for the WPI centers to educate undergraduate students. If this restriction should be relaxed, we would be happy to provide opportunities to undergraduate students in mathematics, physics, and cosmology, so that they can make communication between these fields.

12. Project Expenditures
- Fill out the below expenditure tables in order of FY 2007, 2008, 2009, 2010.
- When converting foreign to yen, give the exchange rate used.

FY2007 (the exchange rate used:JPY/USD=120)

Cost Items	Details	Costs (10,000 dollars)
Personnel	Center director and Administrative director	15
	Principal investigators (no. of persons):11	59
	Other researchers (no. of persons):6	8
	Research support staff (no. of persons):2	2
	Administrative staff (no. of persons):16	26
	Total	110
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):7	4
	Cost of dispatching scientists (no. of persons):	0
	Research startup cost (no. of persons):3	22
	Cost of satellite organizations (no. of satellite organizations):	0
	Cost of international symposiums (no. of symposiums):1	7
	Rental fees for facilities	5
	Cost of consumables	18
	Cost of utilities	1

Ten thousand dollars

WPI grant		459
Costs of establishing and maintaining facilities in FY 2007		51
Temporary Building (Number of facilities: ,300m²)	Costs paid:	51
Cost of equipment procured in FY 2007		124
Liguid Nitrogen plant Number of units: 1set	Costs paid:	8
Semiconductor Detector Number of units: 1set	Costs paid:	4
Arbitrary Waveform Generator Number of units: 1set	Costs paid:	4
TV Conference System Number of units: 2set	Costs paid:	6
S.K. Water Pump Number of units: 1set	Costs paid:	7
Entrance Security System Number of units: 1set	Costs paid:	23
Others		72

	Other costs	183
	Total	240
Travel	Domestic tra el costs	1
	Overseas travel costs	2
	Travel and accommodations cost for invited scientists (no. of domestic scientists):25 (no. of overseas scientists):61	16
	Travel cost for scientists on secondment (no. of domestic scientists):3 (no. of overseas scientists):4	3
	Total	22
Equipment	Depreciation of buildings	0
	Depreciation of equipment	4
	Totall	4
Other Research projects	Projects supported by other government subsidies, etc.	212
	Commissioned research projects, etc.	30
	Grants-in-Aid for Scientific Research, etc.	461
	Total	703
Total		1,079

FY2008 (the exchange rate used:JPY/USD=120)

Cost Items	Details	Costs (10,000 dollars)
ersonnel	Center director and Administrative director	48
	Principal investigators (no. of persons):12	140
	Other researchers (no. of persons):51	239

Ten thousand dollars

WPI grant	1,173
Costs of establishing and maintaining facilities in FY 2008	758
Research building construction Advanced payment (Number of facilities: 5,800m²) Costs paid:	608

	Research support staff (no. of persons):22	49	Temporary Building (Number of facilities: ,500m²) Costs paid: 59 New Kamioka Satellite laboratory building (Number of facilities: ,500m²) Costs paid: 91
	Administrative staff (no. of persons):10	53	
	Total	529	
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):30	37	Cost of equipment procured in FY 2008 241 Equipment of removing radon and generating air: 1set Costs paid: 52 High sensitivity gas analysis equipment: 1set Costs paid: 34 High sensitivity gamma ray detection equipment: 1set Costs paid: 42 Parallel-processing computer detection equipment: 1set Costs paid: 14 Others 99
	ost of dispatching scientists (no. of persons):	0	
	Research startup cost (no. of persons):23	10	
	Cost of satellite organizations (no. of satellite organizations):	0	
	Cost of international symposiums (no. of symposiums):7	2	
	Rental fees for facilities	14	
	Cost of consumables	74	
	Cost of utilities	4	
	Other costs	183	
	Total	324	
Travel	Domestic tr vel costs	12	
	Overseas travel costs	22	
	Travel and accommodations cost for invited scientists (no. of domestic scientists):69 (no. of overseas scientists):138	45	
	Travel cost for scientists on secondment (no. of domestic scientists):6 (no. of overseas scientists):18	15	
	Total	94	
Equipment	Depreciation of buildings	4	
	Depreciation of equipment	36	
	Total	40	
Other research projects	Projects supported by other government subsidies, etc.	511	
	Commissioned r search projects, etc.	53	

	Grants-in-Aid for Scientific Research, etc.	705
	Total	1,269
Total		2,256

FY2009 (the exchange rate used:JPY/USD=100)

i) Overall project funding

Ten thousand dollars

Cost Items	Details	Costs (10,000 dollars)
Personnel	Center director and Administrative director	40
	Principal investigators (no. of persons):10	93
	Other researchers (no. of persons):51	516
	Research support staff (no. of persons):27	100
	Administrative staff (no. of persons):10	76
	Total	825
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):34	34
	Cost of dispatching scientists (no. of persons):1	1
	Research startup cost (no. of persons):36	26
	Cost of satellite organizations (no. of satellite organizations):1	2
	Cost of international symposiums (no. of symposiums):11	7
	Rental fees for facilities	22
	Cost of consumables	218

WPI grant			2,342
Costs of establishing and maintaining facilities in FY 2009			1,169
Construction of laboratory building (5,800m²)	Costs paid:		1,169
Cost of equipment procured in FY 2009			1,031
Construction of super-wide-coverage camera for large telescope Number of units: 1unit	Costs paid:		462
Ultra-high-purity Spectrometer/purifier Number of units: 1unit	Costs paid:		405
CCD sensor Number of units: 3unit	Costs paid:		31
Mass analyzer system Number of units: 1unit	Costs paid:		9
Audio video system for new building Number of units: 2unit	Costs paid:		48
Others			76

	Cost of utilities	7
	Other costs	87
	Total	404
Travel	Domestic travel costs	11
	Ov rseas travel costs	24
	Travel and accommodations cost for invited scientists (no. of domestic scientists):23 (no. of overseas scientists):165	43
	Travel cost for scientists on secondment (no. of domestic scientists):1 (no. of overseas scientists):20	10
	Total	88
Equipment	Depreciation of buildings	12
	Depreciation of equipment	105
	Total	117
Other research projects	Projects supported by other government subsidies, etc.	646
	Commissioned research projects, e c.	33
	Grants-in-Aid for Scientific Research, etc.	731
	Total	1,410
Total		2,844

ii) Cost of Satellites and Partner institutions

Cost Items	Details	Costs (10,000 dollars)
Personnel	Principal investi ators (no. of persons):	
	Other researchers (no. of persons):5	
	Research support staff (no. of persons):	
	Administrative staff (no. of persons):	
	Total	1
Project activities		0
Travel		1

Equipment		0
Other res arch projects		0
Total		2

FY2010 (the exchange rate used:JPY/USD=100)

i) Overall project funding

Cost Items	Details	Costs (10,000 dollars)
Personnel	Center director and Administrative direc or	36
	Principal investigators (no. of persons):9	91
	Other researchers (no of persons):97	03
	Research support staff (no. of persons):25	99
	Administrative staff (no. of persons):11	77
	Total	906
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons :	25
	Cost of dispatching scientists (no. of persons):1	0
	Research startup cost (no. of persons :43	29
	Cost of satellite organizations (no. of satellite organizations):1	9
	Cost of international symposiums (no. of symposi ms):9	3
	Rental fees for facilities	8

Ten t usand dollars

WPI grant 1,350

Cost of equipment procured in FY 2010 40

Name of equipment: Network system for main building
Number of units:1 Costs paid: 4

Name of equipment: Video conference system
Number of units:1 Costs paid: 3

Othe s 33

	Cost of consumables	81
	Cost of utilities	12
	Other costs	67
	Total	2 4
Travel	Domestic travel costs	9
	Overseas travel costs	33
	Travel and accommodations cost for invited scientists (no. of domestic scientists):60 (no. of overseas scientists):143	33
	Travel cost for scientists on secondment (no. of domestic scientists):3 (no. of overseas scientists):12	5
	Total	80
Equipment	Depreciation of buildings	6
	Depreciation of equipment	167
	Total	231
Other research projects	Projects supported by other government subsidies, etc.	444
	Commissioned research projects, etc.	11
	Grants-in-Aid for Scientific Research, etc.	456
	Total	91
Total		2,362

ii) Costs of Satellites and Partner institutions

Cost Item	Details	Costs (10,000 dollars)
Personnel	Principal investigators (no. of persons):	
	Other researchers (no. of persons):5	
	Research support staff (no. of persons):	
	Administrative staff (no. of persons):	
	Total	8
Project activitie		1

T avel		0	
Equipment		0	
Other research projects		0	
Total		9	