Institute
for the Physics and Mathematics
of the Universe

September 27, 2007

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

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

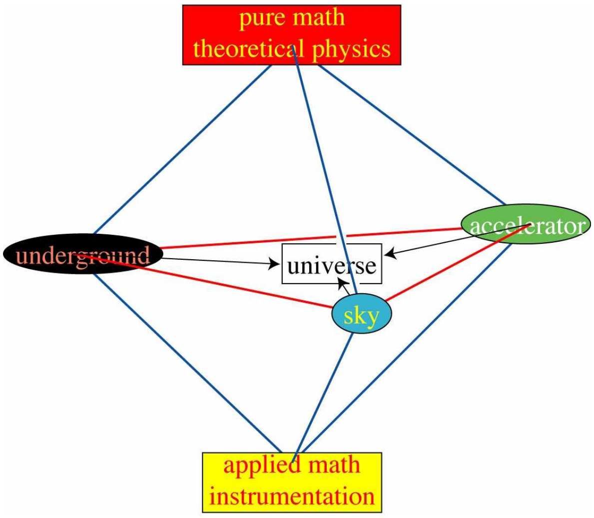
1. Introduction

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

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

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

2. Science



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

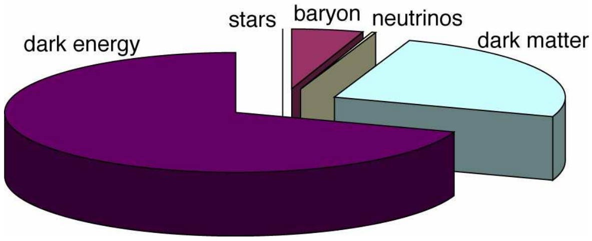
2.1 Why Physics and Mathematics?

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

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

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

2.2 The Three Experimental Approaches



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

a) Underground

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

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

b) Sky

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

c) Accelerator

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

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

2.3 Common Threads

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

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

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

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

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

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

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

3. Synergy of Mathematics and Physics

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

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

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

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

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

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

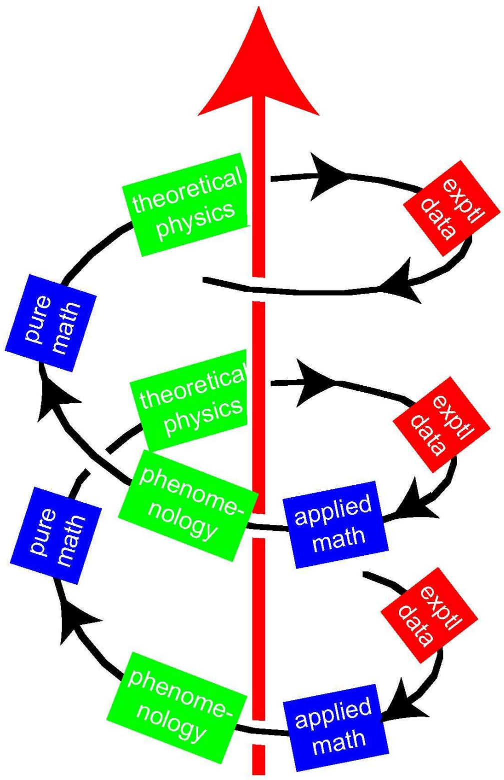
Infinite analysis is also relevant to statistics of geometrical objects. For example, techniques of conformal field theory have been used to study stochastic geometry of self-avoiding random walks – the citation of Fields Medal to Werner last year. Research in this direction may lead to new tools to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

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

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

4. Discovery scenarios and Deliverables

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



4.1 Initial Activities

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

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

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

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

4.2 Potential Deliverables

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

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

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

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

4.3 Assembled membership to achieve our goals

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

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

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

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

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

5. Management

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

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

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

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

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

6. Organization

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

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

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

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

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

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

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

7. Broader Impact

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

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

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

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

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

8. Conclusions

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