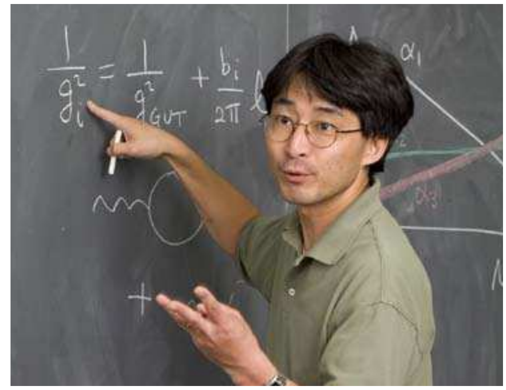

What do we want to do at this new Institute?

Hitoshi Murayama

Research Area: Theoretical Physics

Director of IPMU

Childlike Curiosity

Researchers are just like young kids at heart. I bet you looked up at the starry sky in your childhood, wondered how vast the Universe was, and had an overwhelming feeling of how small you were. "How big is the Universe?" "Did it have a beginning?" "What are the stars made of, why do they shine?" We research scientists are still pursuing these simple questions from our childhood.

One thing that really impressed me when I started to study physics is that many such simple questions had answers. Our predecessors had worked so hard to solve them. As I went on to study further, I got addicted to this feeling of "Aha!"

Why does the Sun shine?

Let us take this question, what are the stars made of, why do they shine? Nobody has been to a star and taken samples, not to mention getting inside one to find out the mechanism that powers it. But we can study the "color" of a star in great detail, and compare it to the "color" of light emitted from all kinds of atoms and molecules studied in the laboratory. This way, we found out what the stars are made of without ever taking samples from them. It turned out that stars, including the Sun, are mostly made of hydrogen. You see it happens quite often in science that we have to study objects we can't touch directly. OK, then, why does the hydrogen shine?

The clue was in the famous equation suggested by Einstein: $E=mc^2$. It says that the mass *(m)* of an object is actually a kind of energy *(E)*. This led to the idea that the Sun shines by converting its mass to energy. If so, the Sun is shedding a whopping four million tons of mass every second. But how do we

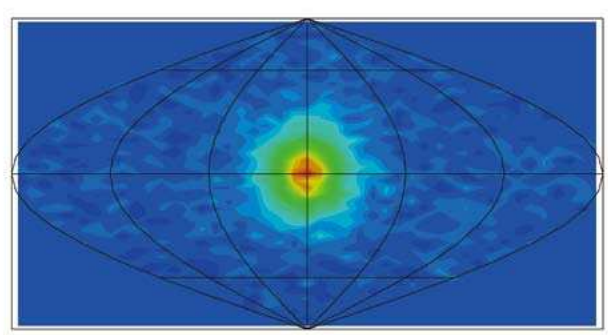

Figure: 1 The definitive evidence that the Sun is producing neutrinos from its core. This is a picture of the Sun's core taken three thousand feet underground in pitch darkness by Super-Kamiokande.

know if this idea is right? Actually, when the hydrogen's mass turns to energy, ghostly neutrinos are born as byproducts. We succeeded in capturing some of these neutrinos in Japan's Super-Kamiokande experiment, giving the definitive evidence that this theory is true. This way, we used observations with both light and neutrinos, in combination with Einstein's relativity and theory of quantum fields, and could figure out what is going on inside a star without ever touching it.

Big Bang

It is well known that the Universe started with a huge explosion called Big Bang. Nobody went back to see the beginning of the Universe, but we learned this by discovering the "fossil" of this explosion. Bright light that came out from this explosion is still moving around in our present dark space. It is just that the light got stretched by the expansion of the Universe and became microwaves that we can't see instead of visible light. It is the same kind of energy used in microwave ovens. This "fossil" is extremely interesting because it knows very well the shape, size, age, and the energy content of the Universe. Now in the new millennium, advances in technology and artificial satellites have made it possible to study it in great detail, and we began to learn amazing facts about the universe. For example, the universe is 13.7 billion years old, and its shape is "flat."

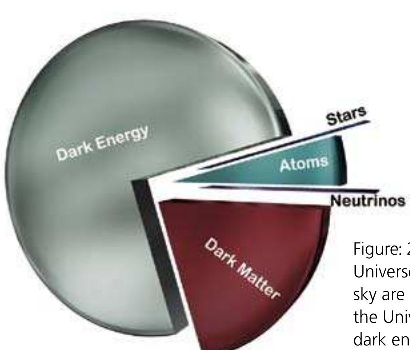

Figure: 2 Energy content of the Universe. Stars we see in the sky are a tiny fraction. Much of the Universe is dark matter and dark energy whose true identity is a complete mystery.

New questions

As I went on to study further, I was also surprised by how little we knew. I often felt, "*We don't have an answer to a simple question like that*?" I explained how we came to know what the stars are made of, but we still don't know at all what the Universe is made of! Using the "fossil" microwaves I have mentioned already, in combination with many other observations and theoretical considerations in the last decade, we learned that the kind of objects we know, namely atoms, make up less than 5% of the Universe. Another 20% is "dark matter" we don't know, and the remaining 75% is "dark energy" we have no idea about. Both of them have names, but their true identity is a complete mystery.

What we do at this Institute

At the Institute for the Physics and Mathematics of the Universe (IPMU), we pursue simple questions like "*How did the Universe begin*?" "*What is it made of*?" "*How did we come to exist*?" We cannot repeat the beginning of the universe, or see what is "dark." These are all very difficult questions to answer. This is why we are trying to gather top notch researchers from various disciplines (astronomy, particle physics, and mathematics) and use many different methodologies to attack the problems together. At the same time, these are questions common to all human kind, and we need to gather researchers from all over the world. We chose English to be the official language because of this even though IPMU is in Japan. It is also important to promote young minds that are flexible and not tied to a particular subfield so that we can create new ways of looking at things.

For example, the beginning of the Universe is said to be a "singularity" where all known laws of nature break down. First of all, we need to use Einstein's theory of relativity because of its incredibly strong gravity. At the same time, we need to use quantum field theory, another pillar of modern physics, because of its equally incredible energy. But we get nonsense predictions when we try to use both theories together, such as that the Universe cannot grow bigger than a millionth billionth billionth billionth inch. In actual fact, the Universe is wider than ten billion light years, and clearly the theories are totally wrong when used together.

The best candidate theory to solve this nonsense is called string theory (also called superstring theory). String theory combines both relativity and quantum fields, while it can do calculations without getting into contradictions like the one I have just mentioned. But it is technically very difficult to carry out explicit calculations with string theory because it says photons (particles of light) and electrons are actually a tiny little string like a rubber band, not as simple as a point. That is why we have to use very advanced mathematics. On the other hand, new areas of mathematics have developed recently because mathematicians have been inspired by string theory. This way, physics and mathematics make progress with the help of each other. In the traditional structure of departments at universities, it is not easy for mathematicians and physicists to meet and work together. IPMU will create an environment where mathematicians and physicists bump into each other all the time by sharing the same space. This is how we wish to attack naive but big questions like the beginning of the universe.

In a similar way, astronomy and particle physics have been exact opposites and have not had much in common, because astronomers study big objects like stars and galaxies in the sky, while particle physicists break up objects into their smallest parts to understand how they work. But now that it is clear that our Milky Way galaxy is filled with dark matter based on precise astronomical observations, it has come to be thought that dark matter is made of elementary particles born and left over from the time when the Universe was less than a billionth of a second old. It is clear that we need to go over the traditional structure of the universities and work together among multiple disciplines to address the question of what the Universe is made of. For example, we are pursuing a project to build a new device underground in the Kamioka mine to directly capture dark matter particles in our galaxy. At the same time, the world's largest particle accelerator, called LHC, will start taking data later this year, and it aims at creating dark matter particles in the laboratory. We will work hard to extract as much information as possible from the enormous and complex data set from the LHC. In addition, we are developing projects to observe many millions of galaxies in the Universe to understand the properties of dark energy better. Our strategy at IPMU is to approach mysteries of the universe by putting together data from astronomical observations and laboratory experiments, combined with theoretical physics and mathematics.

Conclusion

It is only about half a year since IPMU was established, but we are already seeing researchers in varied disciplines joining us from all over the world, particularly young researchers . I'm looking forward to seeing the fruits of IPMU in the next ten years solve some of the questions I've had since my childhood.

The launch of the IPMU

Hiroaki Aihara

Deputy Derector of IPMU

I am an experimental particle physicist. My interests range from the search for new elementary particles using accelerators to dark energy survey using telescopes.

Science is intriguing, but studying science is more intriguing. However, the pinnacle is to study the universe using mathematical and physical approaches. This simple mindset is the driving force behind IPMU, and is possibly the most important factor for attracting world-class researchers to IPMU. At IPMU, we conduct enthralling research, regardless of nationality, sex, and age. All that is necessary to be a part of IPMU is a devotion to science and a constant drive for exploration. We fully believe that such a research environment will naturally cultivate outstanding achievements and new discoveries. Whether IPMU develops into a truly world-renowned center depends on how seriously we take this mindset and our resolve to advance science.

The research topics to be pursued at IPMU are very challenging, and may not lead to immediate results. It is possible that twenty or thirty years will pass before we obtain significant results. However, we intend to persevere with our research objectives until we learn the true identity of dark energy and dark matter, fully understand the grand unified theory, and unlock the mystery of neutrinos. To reach our goals, we will employ all our current knowledge and technology, and develop new ones, if necessary. Moreover, we intend to combine the wisdom of people from around the globe in mathematics, physics, and astronomy, and to reach beyond the constraints of existing systems and language barriers. These ideals are the guiding principles for designing and managing the research organization called IPMU.

At IPMU, active researchers at the forefront of extremely segmentalized disciplines, including mathematics, physics, and astronomy, will come together to form one new, integrated organization. Questions that we will be answered include, "What will result from the unique approach of IPMU?" and "What breakthroughs will be made in science?" Although the approach of IPMU has many unknowns, advances in science have always involved risks. Thus, we believe that IPMU is an ideal environment for young, ambitious researchers, who are willing to expand their horizons, regardless of their original country of origin. Moreover, we strongly believe that young students in Japan no longer have the option of remaining indifferent toward science. Young Japanese students are extremely fortunate to have the rare opportunity for personal fulfillment by studying extremely interesting science, and perhaps changing the world through their endeavors at IPMU. Be ambitious, young people! We invite you to join us and become an engine for future science at IPMU.

A model for new research in Japan

My research interests are neutrino mass, dark matter and proton decay. Over the next few years I will particularly look for dark matter using a liquid xenon detector.

Yoichiro Suzuki

Deputy Derector of IPMU

Our knowledge of the Universe has increased tremendously in the last decade and we now know that more than 95% of its substances are made of so-called dark energy and dark matter, though we do not know what they really are. The main subjects of the experimental groups of IPMU are to study dark energy and dark matter.

Although the neutrino mass shares only a tiny fraction of the substances of the Universe, the smallness of their masses, together with proton decay −another subject at IPMU− could provide clues to a unified theory of elementary particles, which would be an ultimate tool for studying the early Universe.

We will pursue those studies with the collaboration of the existing observatories. The study of dark energy will collaborate with the Subaru telescope. At the Kamioka Satellite of IPMU we will collaborate with Kamioka Observatory, the Institute for Cosmic Ray Research, the University of Tokyo and the Neutrino Science Center of Tohoku University, and then aim to make a significant jump in the area of observational particle experiments. IPMU is designed not only to provide common bases for the experiment, but also to bring scientists together. I hope that IPMU will provide a good environment to get experimentalists and theorists together and hold fruitful discussions.

I will move to Kamioka after April and concentrate on research. The study of neutrino mass will enter a new era in a next few years with the T2K experiment, the second phase long baseline neutrino oscillation experiment from Tokai to Kamioka. Another immediate interest is to look for dark matter through direct interactions. The construction of the liquid xenon detector, which has the best sensitivity in the world, has already started and I expect that we will obtain new results to unveil dark matter in 5 years. I hope that we can also make a significant step forward to designing a realistic next generation proton decay and neutrino detector while we are conducting the above experiments.

This institute is established independent from any other department at the University. We must work our way up from the bottom. We need to establish a suitable personnel selection system, a world competitive salary system and a management organization to match the leadership of the director. These are difficult tasks, but worth doing.