Interview with Katsuhiko Sato

Interviewer: Naoshi Sugiyama

World Plans for the Next-Generation Ground-Based Large Telescopes

Sugiyama: Professor Sato, thank you very much for your time today.

Sato: I also thank you for traveling from Nagoya.

Sugiyama: I hear that you just came back from the general assembly of the International Astronomical Union (IAU) in Beijing. Did you hear any new or interesting talks?

Sato: Since we live in the Internet age, we hardly encounter sudden new stories. But I re-affirmed that large projects are progressing at various places all over the world. I felt it is very favorable situation for the field of astronomy.

Sugiyama: I see. People are discussing several large projects in Japan as well. As the President of the National Institute of Natural Sciences (NINS), you must be in a position to push for the Thirty Meter Telescope (TMT) and a future plan of the Subaru telescope, in the field of astronomy, for instance. Today, I would like to ask you about such things.

Sato: Well, the first thing is the ALMA telescope. They plan to hold an inauguration ceremony in March of next year. But a very important thing is to request funding for the operational budget each year in the form of special expenses. The Subaru telescope is important, of course. It is producing excellent results, and getting strong support from the public, especially by providing nice astronomical images. Yet, I believe the TMT project, which the National Astronomical Observatory of Japan (NAOJ) plans to join presently, is very important as

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we move to an era of large telescopes of 30 meters and 40 meters. Telescopes of this class, such as the GMT (Giant Magellan Telescope) and the ELT (Extremely Large Telescope), are planned in the world.

Sugiyama: The GMT is US-based and the ELT is European-based plans, I think.

Sato: That's right. For the GMT, they are already polishing one or two mirrors. I got the impression that they are making good progress.

Sugiyama: You mentioned about the Subaru telescope. Kavli IPMU is currently promoting the SuMIRe project toward uncovering the nature of dark energy, which is one of the biggest mysteries in cosmology.

Sato: The Subaru telescope provides a good exercise for research which will be done at the TMT. Also, as large telescopes like the TMT are going to be main players, I think that research using the Subaru should make good use of characteristics or merits of a 10-meter class telescope. Personally, I know the SuMIRe project well, and I think it is a wonderful project utilizing Subaru's characteristic features. As President of NINS, I should not interfere in the projects of the respective institutes affiliated to the NINS, but I think the new Director of the NAOJ, Professor Masahiko Hayashi is managing NAOJ, thinking similarly to me. As he was the previous Director of the Subaru Telescope, I think he also knows the SuMIRe project well.

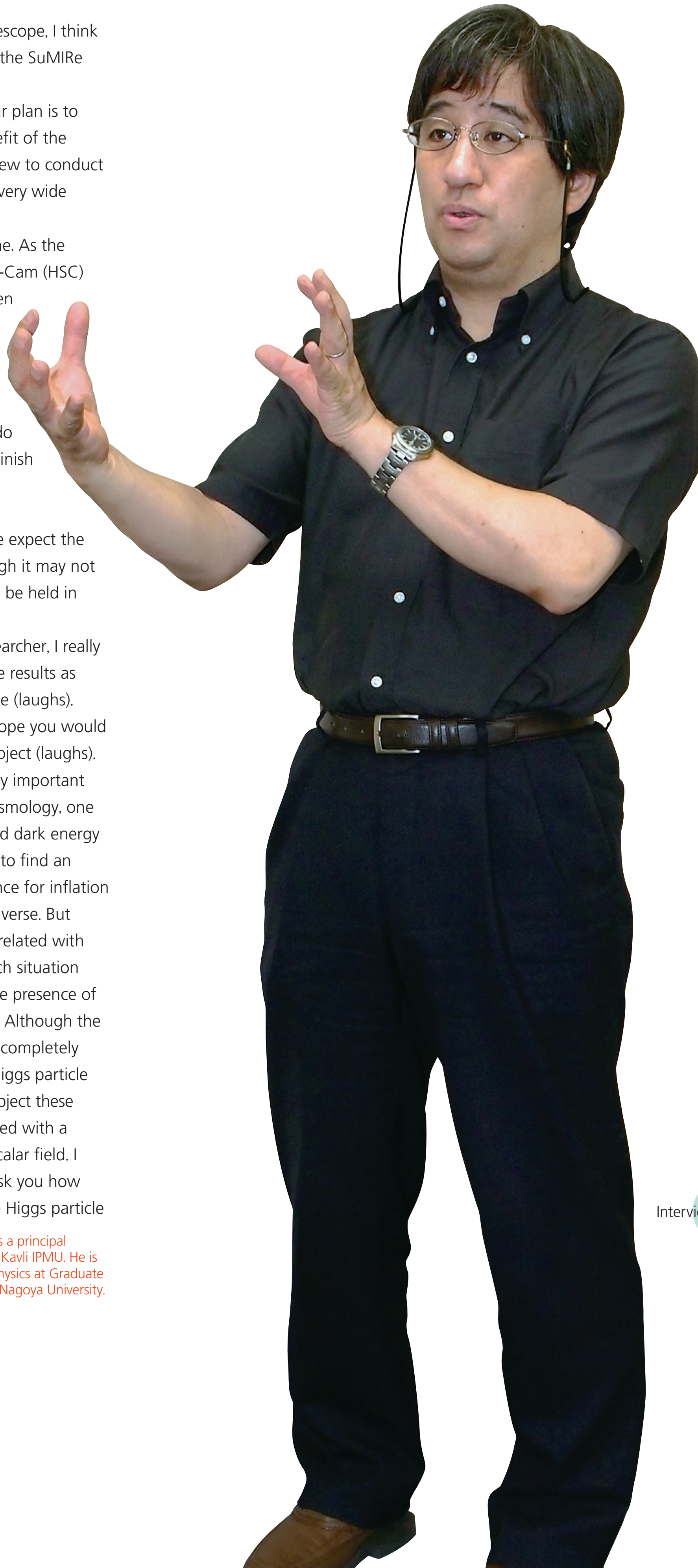
Sugiyama: Our plan is to utilize the benefit of the wide field of view to conduct surveys over a very wide region.

Sato: That's fine. As the Hyper Suprime-Cam (HSC) has already been completed, I am looking forward to hearing the results. When do you expect to finish the PFS with multi-fibers?

Sugiyama: We expect the first light, though it may not be full-scale, to be held in 2014 or so.

Sato: As a researcher, I really hope to see the results as soon as possible (laughs).

Sugiyama: I hope you would support our project (laughs). Among the very important problems in cosmology, one is to understand dark energy and another is to find an ultimate evidence for inflation of the early universe. But they might be related with each other. Such situation can occur in the presence of the scalar field. Although the energy scale is completely different, the Higgs particle that is a hot subject these days is associated with a fundamental scalar field. I would like to ask you how you related the Higgs particle



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to cosmology when you proposed inflation for the first time.

Connecting the Higgs Field with Cosmology

Sato: It started when I was studying the Weinberg-Salam theory for supernova research during my Kyoto years. Back then, neutrino physics was not yet understood well, but Maskawa-san advised me that I should study the Weinberg-Salam theory. I was not familiar with that theory, so I then studied hard and applied it to supernovae. "Neutrinos are trapped inside the core of a supernova through neutral-current interactions" is my another important work.

Sugiyama: Yes, that is a very important work. I somehow thought that there are two separate mountains in your research, one is that of the early universe and cosmology and the other is that of the supernova explosions and high-energy astronomy. Are you saying that these two mountains are actually connected by the Weinberg-Salam theory, or elementary particle physics?

Sato: Yes, they are really connected to each other rather smoothly. When I became a graduate student, I wanted to study the early universe. But cosmology was not doing very well in those days. After the discovery of 3K cosmic background radiation, many problems had been solved. It seemed that very little was left in cosmology for graduate students to work on. In such an atmosphere, I began to work on neutron stars and supernovae partly having been influenced by the stay of Professor Hans Bethe in Kyoto as a guest of Professor Yukawa. By studying the Weinberg-Salam theory, suggested by Maskawa-san, while working on the supernovae, I not only learned neutrino physics, but I also realized that a phase transition can occur in the early universe because this theory is based on spontaneous symmetry breaking which is, for us, equivalent to the occurrence of a phase transition associated with the change of temperature.

Sugiyama: That's great. You collaborated with a Nobel laureate, Hans Bethe, when you were a graduate student.

Sato: Yes, that was my first paper (laughs).

Sugiyama: That's very impressive! You came across neutron stars because of the collaboration with Professor Hans Bethe, and you came across the Weinberg-Salam theory because of talking with Maskawa-san. You received guidance from the two Nobel laureates when you were a graduate student. What an incredible atmosphere!

Sato: Yes, indeed. I should be thankful to a good atmosphere of Kyoto in those days, where I was able to talk freely with such distinguished people, though I was just a graduate student. Of course, Maskawa-san was a junior staff member back then.

Sugiyama: Surely he was young back then.

Sato: One important thing was that we had ample opportunity to talk freely with professors and junior staff members at nearby offices.

Sugiyama: I agree.

Sato: Those were the days, indeed. Back then, there was the so-called Research Planning Committee in Kyoto. Those who were elected by vote formed a cabinet of the Department of Physics II. Anyone, even graduate student, became a committee member once he/she was elected. I was elected, and so was Maskawa-san. Anyway, we knew each other for the most part, graduate students and staff, within the Department of Physics II. I knew the names and faces of almost all people in the particle physics and nuclear physics groups, and I was able to make contact with anyone personally. It has been my method of research to deal with nuclear physics, particle physics, and astrophysics simultaneously. I was really able to work in that way, and I fully enjoyed the merit of Kyoto's atmosphere in those days. Though I was a graduate student, I was able to have extensive discussions with professors and even with distinguished professors without hesitation (laughs). That atmosphere was really great. I remember a conversation with Maskawa-san. He proudly said, "I recently wrote a paper in which I claim there are three generations of quarks." So I said, "Are you aware of what your boss is saying? He is arguing the infinite strata."

Sugiyama: That must be Professor Sakata, I guess.

Sato: I said a joke, "No need to stick to just three. There must be infinite generations." I was making fun. Anyway we were able to enjoy casually talking. To tell the truth, before going into cosmology I wrote a paper claiming that the phase transition of the Weinberg-Salam theory should occur even inside a high density object, neutron star. Broken symmetry would be restored by the fermion-Higgs interactions. But I made an important assumption that the mass of Higgs boson is very small. At that time, I was regarding it as a few hundred MeV, at most.

Sugiyama: That is a few hundredths of the present value.

Sato: Yes, I could make such an assumption in those days because the Higgs mass was completely unknown and also in many papers discussion was made with rather small Higgs mass. So I proposed that the fermion fields restore the symmetry. Around that time I became acquainted with Linde because he was working on similar problems such as restoration of the symmetry by the fermion fields and by raising temperature. This was in the 1970s. I sent my papers to him, and he wrote to me, "I worked such and such problems," with his Lebedev Institute's preprints.

Sugiyama: It was a difficult time for people living in the Soviet Union to travel abroad, wasn't it?

Sato: That's right. Of course he was not able to go abroad. Sending letters back and forth took one month or so. Time was moving rather slowly in those days. Later but still during the Soviet Union times, Linde visited us. He was saying with a very cheerful voice, "I mostly work at home. I only go to the Lebedev Institute when I have to check references. Then I return home and do all my research there." He had to report to the Soviet Union Embassy every day on what he had done. But, as he was not so important a person nobody came along with him, and he was saying anything he wanted to say. As he was a very energetic person, I was lucky to get acquainted with him.

Professor Hayashi's Astro-Nuclear Physics Group Was Exciting

Sugiyama: So Kyoto had a very good atmosphere, and you met a lot of people there.

Sato: Yes, indeed.

Sugiyama: I want to hear more about Kyoto of those days. You belonged to Professor Chushiro Hayashi's astro-nuclear physics group. That group produced a lot of excellent people, covering almost all Japanese astrophysics theorists if we talk about not only his direct disciples but also disciples of his original disciples and so on. Somehow, I myself am his second-generation disciple.

Sato: I suppose so.

Sugiyama: What do you think was a key to the success?

Sato: I think it was very significant that Professor Hayashi laid out a simple principle, that is, you have to work every phenomenon from the basic physical processes. We were intensively trained with this principle and through colloquia held in the group. He insisted that we had to work on elementary processes starting from basic equations rather than learning many phenomenological facts. I think that was great. When we look into astronomical phenomena, data analyses may have a bigger impact on the field as a whole, but in those days Professor Hayashi's approach had great influence. We were trained in colloquia which started at noon every Saturday and looked interminable.

Sugiyama: Did they last till midnight?

Sato: Well, sometimes. We had to spend a lot of time in preparation for colloquia because we were interrupted whenever Professor Hayashi had questions. Reporters had to choose their themes as early as half a year before the colloquia and start preparation. Otherwise they were sure to end up stalled during the talk.

Sugiyama: (laughs)

Sato: We had to do an exhaustive survey of the related references. Otherwise we were sure to be scolded by him, "You have not checked even such things?" We were really trained intensively. When I moved to the University of Tokyo, I wanted to do the same thing. But as the colloquium went on one hour or two, even graduate students would begin to complain that they were busy and had something else to do. As times had changed, I dared not do that.

Sugiyama: It's really difficult to do now. We have to watch out for things like academic harassment. But I can understand that very deep discussion and building up from basic physical processes were key elements. Did you also have good communication?

Sato: Well, it was probably specific to the Department of Physics II, where we were able to hold discussions freely not only with people in the respective research groups but also with nuclear physicists and particle physics, or with experimentalists and theorists, because we knew each other. I think that was really great.

Sugiyama: I see. You incubated the inflation theory in such environment. Was it prior to your departure to Copenhagen as a visiting scientist?

Sato: Yes, it was only about three months before my departure to Copenhagen. Back then I was working not only on the Weinberg-Salam theory but also on problems such as the phase transition based on the Grand Unified Theories, phase transition inside matter, and possibilities to set limits on the Higgs particle from cosmology. It sounds crazy now, but I was also working on the possibility that the Higgs particles existed in the cosmic microwave background, and their decay changed the spectrum of the 3K background radiation. From this argument, I wrote a few papers by setting a limit on the lifetime of the Higgs particle and also by setting limits from the evolution of stars, assuming that Higgs particles come out of stars. Recently this approach has become a standard technique when particle theorists try to propose new particles.

Sugiyama: Yes, indeed.

Sato: A new particle called the tau-particle was also discovered around that time. It was called a heavy lepton in those days. I worked together with Makoto Kobayashi on setting limits to the neutrino mass and lifetime. We submitted our paper three or four days after the famous paper by Lee and Weinberg. But our paper discussed a possibility for their decay. The famous Lee-Weinberg paper, on the other hand, only set a limit on the mass, but not the lifetime. I'd like to stress this point because this was a joint work with Kobayashi-san.

Sugiyama: Here again, you worked with a Nobel Laureate. You had such a luxurious research life.

Sato: It was great that I was able to work with Kobayashi-san. Though I couldn' t do detailed calculations, he wrote various diagrams for neutrino decay and made calculations. Apart from cosmology, Kobayashi-san checked various parameter limits from the particle-physics experiments of those days. We then wrote a paper by combining theoretically allowed regions and limits from cosmology.

Sugiyama: Was it around the time when you became an assistant professor?

Sato: Yes, around that time I became an assistant professor. Of course, Kobayashi-san was an assistant professor.

Post-Graduate Days

Sugiyama: Speaking of appointment to assistant professor, you spent about five years as a postdoctoral fellow before that. It must have been a difficult time for you. Would you mind telling us about it before going back to the topic of inflation?

Sato: Well, it was about four years (laughs). When I think back, there were more postdocs compared to graduate students in the astro-nuclear physics group, though the level of the group was high enough. It was good for me that I had to work hard in such a harsh period.

Sugiyama: I asked around people who were graduate students in those days (of course they are professors now) about it. They said it was a real concern for their future to see many postdocs including Sato-san and Takahara-san in the group.

Sato: Well, postdocs contribute to strengthening a research group. One reason that Professor Hayashi's group was exciting was that those people made up more than half of the group members, and they led very stimulating discussion over a wide field, allowing all the members to join them. Together with the positive atmosphere of the entire Department, it was really great.

Sugiyama: You are saying that, although it was a difficult time for young people to get jobs, those posdocs were taking the roles of assistant professors and leading the research activities in the group.

Sato: Yes. In that sense, I was also organizing an independent group. I am not sure if you knew this; I was also working on inter-stellar molecules.

Sugiyama: No, I didn't know that.

Sato: When I was in my first year as a postdoc, I organized a group to work on something new for summer school. That period coincided with the time when we built a nuclear-reaction network, namely, the nucleosynthesis network.

Sugiyama: Was it for the study of nucleosynthesis inside the supernova?

Sato: Yes. Not many people know this, but it was the first such attempt in Japan. The nucleosynthesis code which we developed had since been used by Nomoto-san and Sugimoto-san's group. An idea came to me that the code could be used for the inter-stellar molecules. If you read papers about inter-stellar molecules in those days, you will realize that the chemists pick only those reactions which they like and claim the synthesis from those chemical reactions. But I thought that there must be many reactions that destroy the synthesized molecules, and so we must consider all these effects. That was my purpose. Ms. Hiroko Suzuki played an important role at that time. She was planning to work on nucleosynthesis inside the star. So we decided to work together. Noting that the density and temperature vary in contracting inter-stellar dust, we calculated the ion-molecule reactions (one participant being an ion and the other being a neutral molecule) using a network. We published the results as a few papers. We found that the ion-molecule reactions are in fact the main route for the inter-stellar synthesis of molecules except hydrogen molecules which are produced only through surface reactions. Suzuki-san continued her research in this direction and pioneered the field of inter-stellar molecules in Japan.

Sugiyama: So, you have worked on various subjects to which your expertise in physics could be applied, not limiting yourself to a specific discipline.

Sato: Right. Furthermore, as we had good communication, we could make informal collaboration with no hesitation (laughs).

Proposing Inflation in the Early Universe

Sugiyama: While you were working on a variety of subjects, as we discussed, you were thinking how to apply the Higgs particle in the Weinberg-Salam theory to the universe.

Sato: At first I applied it to the inside of the stars, but it was obvious that a phase transition occurs at the beginning of the universe.

Sugiyama: From the energy argument, it is readily understood that it occurs at the beginning of the universe.

Sato: Yes. During my postdoc days, Professor Fumitaka Sato was asked to write an article for a popular science magazine *Shizen*, and he asked me to write something based on my work. Accordingly, I drew a plot in which the forces are drawn with temperature and time indicated on one side. As the temperature goes down, phase transitions occur and the forces branch out. I believe I drew that plot for the first time in the world. Of course, Professor Fumitaka Sato made various corrections to the manuscript.

Sugiyama: I recall that *Shizen* was published by a publishing company *Chuo Koron*, but it was discontinued many years ago. When did your article appear?

Sato: First in 1976, and then in 1978. Professor Motohiko Yoshimura's work on baryon asymmetry also appeared about the same time and, I think particle physicists were beginning to show interest in cosmology. They had not paid any attention before. When I talked about phase transition in the universe in a particle-physics workshop, I was asked immediately, "Do you really believe the spontaneous symmetry breakdown of the Higgs field?" It was sufficient for them if symmetry be broken down. They thought it was not a real phenomenon that phase transition occurs as the temperature goes up.

Sugiyama: Yes, there were arguments that it was just an expedient.

Sato: I was often scolded by senior people. They said it was just sort of a mathematical tool, just an expedient. Other people told me, "Nobody found the Higgs particle. Weinberg-Salam? They discuss things assuming a fictitious particle. You should not study supernovae based on such an argument." It was appalling. The early 1970s was such time. A change of mood occurred when the neutral current was discovered. To my pleasant surprise, the Gargamelle experiment at CERN discovered the neutral current when I was working on supernovae. This caused the Weinberg-Salam theory to rise in value greatly.

Sugiyama: It was just around the time when your work on neutrino trapping inside the supernovae appeared. So you got definitive evidence.

Sato: Well, I was very encouraged by this experiment, especially because it just came as I was working on neutrino trapping. I strongly felt: "This is the truth." I wrote a lot of papers on cosmological limits on the Higgs particle in the early universe. As I had already noticed the phase transitions of the universe, I had also noticed that it naturally causes the branching, or evolution, of the forces. But if the story ends up with the evolution of the forces, the subsequent evolution of the universe would be just an old tale. Unless we find its trace in the present universe, it would not be interesting. As I continued working, I found that if a slightly smaller value is chosen for the Higgs mass (here again, the Higgs mass should be modified), the Higgs potential has a small peak between the symmetric state where the value of the Higgs field is 0 and the state where the symmetry is broken, because the effect from radiative corrections becomes very large. Though fine-tuning was needed, it resulted in an appropriate first-order phase transition. In the first-order phase transition, though some parts of the system have completed the transition, others have not. So, I soon realized that the universe would exponentially inflate by the vacuum energy of the Higgs field, should there be a vacuum-energy dominant, or, Higgs-energy dominant era. I built a simple model that the universe would be heated all at once to form a fire ball, as a consequence of the sudden change of states occurring in the first-order phase transition. It was in April, 1979. But when I talked about this model at a seminar of our subgroup, which I think was in May, I was severely criticized by Kodama-san.

Sugiyama: Is he now a professor at KEK?

Sato: Although I was not quite confident, I claimed "We can settle the horizon problem once and for all by this." Then Kodama-san said: "You are claiming that the universe becomes homogeneous by using a homogeneous isotropic model. That does not make sense." His criticism was: "You've derived the conclusion by postulating it. It will be worth paying attention if you conclude homogeneity starting from an anisotropic model. But it is tautology to claim homogeneity of the universe or that of 3K radiation starting from a homogeneous model." He was right. So I thought of three things based on a policy to look for any observable effect or anything useful in actual astronomy rather than putting emphasis on just the horizon problem or other philosophical problems. The first one was the fluctuations, namely, the origin of the large-scale structure of the universe.

Sugiyama: Yes, you stressed that point very much.

Those Days at the Niels Bohr Institute

Sato: That's right. So, secondly, on the survival of the so-called baryon-antibaryon symmetric (domain structure) model of the universe, and lastly, the monopole problem (as the collaboration with M.Einhorn)—in Copenhagen, I wrote three papers along these lines. At that time, it was not in favor to propose the inflation because the density parameter of the universe, Ω was determined to be 0.01. I was not able to propose the flatness of the universe, which was contradictory to the observational results.

Sugiyama: Was it 0.01?

Sato: Yes, it was 0.01 or 0.02, because it was a baryonic number.

Sugiyama: It was referring to the visible part of baryonic contribution.

Sato: That's right. So, I was not able to claim the flatness with confidence.

Sugiyama: To some extent it sounds similar to the story of Einstein who built an unnatural model of a static universe. This was because observations were quite behind theory.

Sato: A similar story–I thought that the story of creating the large-scale structure of the universe by the growth of large-scale fluctuations extending over the horizon was persuasive for a paper. So, I decided to submit that paper to *Monthly Notices of the Royal Astronomical Society (MNRAS).*

Sugiyama: It's not a journal of physics, but astronomy. You submitted your paper earlier than Guth.

Sato: I submitted this paper and another one dealing with creating the matter-anti matter symmetric universe at the beginning of February, and the last monopole paper in July. Guth submitted his paper in August. My three papers were all submitted for publication earlier than Guth, with the first two earlier by almost half a year. When I thought something useful with inflation, I was reluctant to write a paper for *MNRAS* to claim the flatness of the universe, because I was aware of its inconsistency with observations. It would have been better to submit a paper claiming it to *Physical Review* as Guth did.

Sugiyama: I see. Because of that, the motivations of your papers did not look very clear.

Sato: In retrospect, stressing the flatness would have been more popular.

Sugiyama: But, last year, when the Nobel Prize in Physics was given for the discovery of the accelerating expansion of the universe, the Nobel Committee for Physics referred to the inflation, and quoted the names of Starobinsky, Sato, and Guth. Your name was quoted second.

Sato: I was pleased with that as evidence for world recognition.

Sugiyama: That means recognition by the Nobel Committee for Physics. You completed that work in Copenhagen, which was a big turning point for your research. That's my impression.

Sato: That's right. Of course, I had had the idea but how to complete it as papers was worked out in Copenhagen. As a matter of fact, I was invited to Copenhagen as a visiting professor because my research on supernova neutrino trapping by the neutral current interactions was highly evaluated. I felt sorry to Chris Pethick who invited me, but I did nothing about supernova there. I was concentrating on the inflation.

Sugiyama: That's OK. You made a major achievement. In addition, you got to know many foreign researchers of the same generation in Copenhagen.

Sato: So many visitors, including M. Rees, M. Turner and S. Perlmutter, came to the world-famous Niels Bohr Institute. I got to know so many researchers.

Sugiyama: You built many good relationships. Then, after having returned to Kyoto, did you immediately move to The University of Tokyo?

Sato: No, I stayed at Kyoto for one year. During that time I was able to write a paper on multi-production of universes with my collaborators at Kyoto. A detailed study of the first-order phase transition shows that it does not finish everywhere all at once. If a false vacuum region surrounded by bubbles of true vacuum has a substantial size, that region is still inflating. So, the phase transition does not finish. On the other hand, looking from the regions where phase transition finished, the false vacuum region must be shrinking away. This means that the surface of the region is shrinking, but its volume is expanding. I suffered from this paradox. I returned to Kyoto in July, and found a solution to this paradox through discussion with young people at that time forming a subgroup with me, Sasaki-san, Kodama-san, and Maeda-san. We wrote a paper in September. We realized that a wormhole solves the paradox, and by assuming spherical symmetry the equation becomes smooth. So we built a model in which a spherically symmetric region of false vacuum is surrounded by small bubbles, and showed that region becomes a wormhole in a mathematically beautiful way.

Moving to the University of Tokyo

Sugiyama: Then, you moved to Tokyo and started to build your research group. You have fostered researchers who are now leading scientists in Japan. What was your policy of managing your group at Tokyo?

Sato: As I was trained by Professor Hayashi, I adopted my principle of guidance as studying from basics rather than studying phenomenology. I gave great attention to colloquia and made efforts to continue discussion. I invited Kodama-san as my first assistant professor. As he had the same philosophy as mine, I think our academic training was quite severe for graduate students. Kodama-san was particularly severe.

Sugiyama: I think so (laughs). It is evident from his complaint about inflation.

Sato: Well, his critical attitude is quite important. Without it, you cannot make scientific success. That's why I invited him to be my assistant professor. Another thing I managed to bring to Tokyo from Kyoto was an atmosphere in which even graduate students are on equal footing with staff physicists in research. I think it was also nice. We have fostered many researchers in such an atmosphere.

Sugiyama: I see. Your group has been very active, of course, but you started to be involved in administration; for instance you served as President of the Physical Society of Japan and Dean of the School of Science. How did you reconcile your standpoint as a researcher and administrator?

Sato: I certainly started to be involved in administration when I was around 50 years old. The first occasion was an application to the COE (Center of Excellence) Program as the Principal Investigator. It was approved. Honestly speaking, I had to concentrate my efforts to such things around the time when I worked on establishing the Research Center for the Early Universe. As a matter of fact, I was encouraged by Professor Kamae, Professor Orito and other senior professors at first, because, if successful, they could get valuable money for their observational research, and theory groups could buy a small supercomputer.

Sugiyama: It was successful. The center has been operated with even a net increase of a professorship.

Sato: The COE Program was a five-year program, but it was extended to seven years and we got two billion yen of support in total. With that support, Professor Orito launched a balloon to detect anti-protons (BESS Experiment), Professors Kamae and Makishima developed the X-ray detectors for the ASTRO-E satellite. In that sense, my center was very useful in strengthening the astrophysics groups in the University of Tokyo and very much contributed to raising the level of the entire university. Usually theorists present original contributions when they are rather young. That means that if they are no longer young, somehow I feel it's their duty to do some administrative work appropriate to their age. Of course, some old theorists are still active, which is great.

Sugiyama: I think you have performed your duty very well. The Japanese name of the Research Center for the Early Universe has changed now to mean the "International Research Center for the Big-Bang Universe".

Sato: At the stage of application to MEXT for establishing the center, I asked some journalists about the name of the center. Some said, "The Research Center for the Early Universe? It's too difficult to remember." So, the Japanese name of the center was decided as the International Research Center for the Big-Bang Universe. But, I was told by a professor of chemistry, "Wow! Big Bang Center? Isn't the Big Bang only a hypothesis, just a story with no reality? It's an awkward name for the center."

Sugiyama: Really? That was about ten years ago, wasn't it?

Sato: Yes, I was stupefied at hearing it.

Sugiyama: You had to say that there was plenty of evidence.

Sato: Only ten years ago, researchers in other areas still thought that the Big Bang was but a story that the Universe begun with it. It happened at the time when I asked Dean of the School of Science for starting formal discussion about establishing the center. I was stunned.

Sugiyama: So, we must make every effort to convey our knowledge to people through outreach activities.

Sato: I agree. When I became Dean of the School of Science, I started public lectures by faculty members. Till then, the atmosphere of the School of Science was: "You must work on writing papers if you have time to do things like that." However, as the fields of astronomy and astrophysics spend big money, these fields particularly need people's support. We can only expect it by conveying the fun of science to them. So, actually, many researchers in the field of astronomy are involved in outreach. The same is true for all other fields at the School of Science, I think. Therefore I thought that public lectures at the School of Science were really important, and I initiated the event twice each year. Around that time, the social atmosphere started to show a big change. So, not only because of my initiative, but also because of the trend at that time, we have been making lots of public relations efforts.

Sugiyama: I see. In the fields related to the universe in particular, doing public relations activities is rather easy, but in the elementary-particle field, it is not so easy. But therein also, the Kavli IPMU has been putting effort. There are some really good talkers, and they are involved in outreach in many places.

Sato: On the Kavli IPMU's home page, video clips are uploaded and we can see Director Murayama's various lectures. It's wonderful that Kavli IPMU has a powerful staff. At NINS we are also devoting efforts to public relations. NAOJ is very good on that point. Also, institutes for biological science at Okazaki frequently hold press conferences and host various hands-on programs for high-school students. In particular, as the National Institute for Physiological Sciences is an institute for brain science, it provides many programs in which people can even make experience on brain science. The National Institute for Fusion Science operates its booth for experiencing fusion science at the National Museum of Emerging Science and Innovation, and also holds a big outreach event once a year.

Major Science Projects Need Support from Community

Sugiyama: Basic science is often considered as inefficient in government spending. Now astronomers are pushing very big projects forward, and particle physicists may proceed to ILC after LHC. They need huge amount of money. So, it will become a very big problem how we can manage to get a social understanding of our projects.

Sato: Exactly. I agree that applied science is important and needed for industry and economy in Japan. So, it would be indispensable to set an appropriate proportion in budget between basic science and applied science. Basically, determining this proportion is an important policy. We naturally want a bit more appropriation for basic science, because, for example, a number of nice projects are going on at NINS. The Large Helical Device (LHD) at the National Institute for Fusion Science can be operated longer than tokamaks, though temperature and density are not yet comparable to those of tokamaks. But, lots of improvements have been made for LHD, and the three conditions for fusion, namely, time, density, and temperature, are steadily improved. For fusion research, only constructing the big ITER is not sufficient. What is needed is the accumulation of basic research. So, I would like to see a bit more governmental support. We, basic scientists think the present policy is a bit biased to application. So-called "Selection and Concentration" sounds nice, but it is clear that the concentration never results in good cost performance. I hope those who decide Japanese science policy, such as politicians and members of the Council for Science and Technology Policy, emphasize basic science a bit more.

Sugiyama: In that sense, we should take much account of the message from the Science Council of Japan (SCJ).

Sato: Yes, in that sense, we are very much indebted to you. SCJ's Subcommittee for Astronomy and Astrophysics of the Committee for Physics has produced an excellent future plan for large research projects in astronomy. The fact that the whole astronomical community has decided to push these projects makes a strong message to the government. It has been extended to the SCJ's discussion of future plans for large research projects in all fields.

Sugiyama: Yes, the Master Plan has been compiled. It was primarily motivated by our activities in the field of astronomy.

Sato: That's right. Now researchers in various fields understand that they really need supports from the respective community by hearing its opinions. As a result, it has become a basic way even for MEXT to decide things based on the report from the SCJ. It's a complete change. Previously, if scientists wanted to push a big project, they directly explained their plan to the MEXT officers concerned. Now, the process to approve the projects by MEXT proceeds in the following way. I am a member of the Working Group on Large-Scale Projects of the Council for Science and Technology, and this Working Group evaluates the projects recommended by the SCJ, because it is difficult for the SCJ to evaluate individual projects. Decision for approval is made based on the evaluation results. The TMT project, which I have mentioned at the beginning, was given top-priority, and its preparation as well as the Subaru's upgrade plan was authorized by the MEXT. So, its budget will be allocated in earnest starting with the next fiscal year. The budget for the Super-B Factory was also approved, though not in full. It was another project recommended by the SCJ with a bottom-up approach.

Sugiyama: So, we have to demonstrate that the plan we want to push is a good plan that is firmly supported by the community.

Sato: It is great that every community is now aware that if it wishes to push some project, support from the entire community is vital.

Hope for a Major Paradigm Shift in Physics

Sugiyama: Let me pose the final question. In the past decade or two, cosmology as well as observations developed very rapidly. Going forward, what do you expect in the fields you are involved with?

Sato: Well, let me first talk about my most familiar research topic, the supernova study. Particularly in Japan, the number of people doing simulation increased very much. When I started, I was almost only one to study core-collapse supernovae in Japan, but now the community has considerably grown up, and the Japanese contribution is getting pretty high. In that sense, we can expect world-class accomplishments.

Sugiyama: You mean successful simulations for supernovae explosion, for instance.

Sato: Exactly. Of course, our ultimate purpose is to clarify dark matter and dark energy. People say dark matter is elusive, but I hope LHC will discover it as its energy goes up. Underground experiments are also well advanced. For instance, Yoichiro Suzuki's XMASS will be upgraded to approach the absolute observation limit. In this sense, I hope we will be able to conclusively identify dark matter both experimentally and observationally in about 10 years. As for dark energy, I believe that it is related to inflation. Because of this, sometimes I say that the present dark energy-dominated universe as the manifestation of the second inflation. People now call the field responsible for inflation as *inflaton*, but the nature of inflaton should be a truly fundamental problem in particle physics, such as "What is the vacuum energy?" and "What is the energy of space?" I think a scalar field works phenomenologically, but I believe its real nature is not that simple.

Sugiyama: Possibly, we may obtain some important hints if we study the nature of the Higgs particles precisely.

Sato: I completely agree with you. Phenomenologically, the Higgs field is explained in a beautiful and simple manner in analogy to superconductivity, but I think its true mechanism is not known. The Higgs particle is said to be a fundamental particle giving mass to other particles. Though I am no particle physicist, I don't think it is truly fundamental. Rather, I believe it is only a concept produced in a phenomenological model. I think a phenomenological explanation of the occurrence of phase transition is true, but it may well be that the true mechanism should be extraordinarily huge and profound a concept, something related with the "vacuum". I think if the true nature of the Higgs particle is uncovered, it should be the time of a great paradigm shift in physics. Many years ago, L. Abbott wrote a review paper in *Scientific American* (vol. 3, no. 1 (1991) p. 78), in which he stated about the "vacuum" that "It is our challenge to repair that faulty foundation without destroying the towering edifice—the system of physics—we have built on it." I completely agree with him. Our present dream is that the towering edifice of the system of physics would never be broken, but repairing its foundation would cause a great development of physics once again. We do not quite understand how it happens, but according to the current trend, it may well be that we should look to the superstring theory. In that sense, I hope that Ooguri-san and his collaborators will make a fundamental paradigm shift happen, because they are truly world leading superstring theorists.

Sugiyama: I see. You are counting on the Kavli IPMU. Experimentally as well, it would be possible to investigate that point very precisely at the Large Hadron Collider (LHC) and, going forward, at the International Linear Collider (ILC). Though I am a bit of an outsider, too, I also wish to watch it with high hopes.

Sato: I think so, too. There should be still more wonderful developments in physics.

Sugiyama: To make that happen, we need to repair its foundation properly.

Sato: That kind of thing will probably happen within the 21st century. I would not say within 10 years, but I believe a major paradigm shift—a revolution in physics, should happen once again.

Sugiyama: Thank you very much for ending up our conversation with a very encouraging outlook for the future.