IPMU Interview
with Michael S. Turner

Interviewer: Naoshi Sugiyama

Godfather of dark energy

Sugiyama: Welcome to IPMU. You are known as the godfather of dark energy, and the person who invented the term. How did you come to this name?

Turner: Names have to be short and catchy; they have to be accurate to some degree, but not too accurate so as to make them boring.

Sugiyama: “Black hole” would be a good example then, is that right?

Turner: “Black hole” is a great example.

Sugiyama: Black holes used to be called “collapsers” and other names··· I think the name came from John Wheeler.

Michael S. Turner is Bruce V. & Diana M. Rauner Distinguished Service Professor, Departments of Astronomy and Astrophysics, and Physics, and the College; Enrico Fermi Institute; Kavli Institute for Cosmological Physics (KICP), at the University of Chicago. He is a world-renowned cosmologist, and was awarded Helen B. Warner Prize of the American Astronomical Society in 1984 and Julius Edgar Lilienfeld Prize of the American Physical Society in 1997. He was the Assistant Director for Mathematical and Physical Sciences for the US National Science Foundation in 2003 - 2006.

Turner: Yes, black hole is definitely catchy, and it is pretty accurate. I hope dark energy does as well. First of all, it’s the perfect mate to dark matter. In relativity anything that has a pressure comparable with its energy density is called energy-like, and anything that has very small pressure is called matter-like. This stuff is more like energy rather than like matter, in the sense that pressure is comparable to energy density.

Sugiyama: Well, the sign is different and it breaks its energy condition.*1

Turner: A Good name can’t be too accurate, because if you make it really accurate, the name gets longer and longer and fewer people will understand that. So “black hole” is great: it’s not inaccurate, and it is very catchy. I hope dark energy is viewed the same way.

Sugiyama: OK. What are your impressions of IPMU?

Turner: I think IPMU is a very timely idea. There is a lot of energy here and it’s attracting a lot of people from all over the

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*1: Here, the "energy condition" means the "strong energy condition" which requires that a sum of the energy density and 3 times the pressure of (a fluid of) normal matter or radiation should be positive.

world. I think IPMU will have not only big effect in Japan, but it will have a big effect beyond Japan. Because science today is so international, something that happens in Japan is not only going to change Japan, but it is also going to change the rest of the world. I am very excited about IPMU.

Sugiyama: The main purpose of IPMU is to act as a bridge among mathematicians, physicists, astronomers, and astrophysicists, and to help reveal the secrets of the universe. I am just wondering if you started your career as a particle physicist or an astrophysicist.

Turner: My career began in particle physics. I was a student at the Stanford Linear Accelerator Center (SLAC), and then I got interested in general relativity. I did my thesis in general relativity, on gravitational waves. Then, I moved on to Chicago, and I fell under the influence of Dave Schramm.*2 He said: "Astrophysics is good, Cosmology is good, Particle Physics is good; all three together is even better!" I was in the right place at the right time and most importantly, had the right mentor – David Schramm.

Sugiyama: That's right. I am curious about that period in the 1980's. I imagine it as something like a golden age of particle cosmology.

Turner: No, I don't think it was the golden age. I think it was the very beginning of what may become a Golden Age. It was the first coming together of two fields. At the time there were different views of how successful this coming together of the very big and the very small would be. Dave Schramm was very enthusiastic about bringing particle physics and cosmology together. My adviser at Stanford, Bob Wagoner,*3 who wrote the first computer code to study "Big Bang Nucleosynthesis," which is one of the pillars of early universe cosmology, was unenthusiastic about it. His advice to me was: "Do something safer, like gravitational waves."

Sugiyama: That's safer than particle cosmology …

Go-go junk bond days of early universe cosmology

Turner: At the beginning of anything new and different, it's not clear if it is going to pan out. In the 1980's it was basically a bunch of wild and very bold speculations, that if correct, would change forever both fields. However, it wasn't obvious that those wild speculations could ever be tested or further would turn out to be true. The 1980's

Naoshi Sugiyama is a principal investigator of IPMU. He is also professor of physics at the School of Science, Nagoya University.

*2: A famous cosmologist worked at the University of Chicago. His research connected cosmology, particle theory, and nuclear physics. He was born in 1945 and died tragically in 1997 in a crash of a plane he was piloting.

*3: Professor Emeritus at Stanford University. He is known for his research on strong sources of gravity such as neutron stars and black holes, and on gravitational waves.

were the go-go junk bond days of early universe cosmology. Anything went, and there were lots of very ambitious ideas – cosmic strings, textures, phase transition, monopoles, monopoles on strings, Kaluza-Klein, and axion. The two most important ideas were particle dark matter and inflation. These two ideas really caught on and helped drive the entire field of cosmology. They led to a framework for discussing the evolution of structure, known now as cold dark matter, which made specific predictions which could be tested. The observers have paid cold dark matter the highest compliment they can, which is to try to rule it out!

Sugiyama: But they didn't succeed…

Turner: Well, they did. They kept ruling it out, but CDM kept wiggling out. Finally, we have a version – CDM with dark energy or Lambda CDM[*4] – which fits all the data. The challenge now is to figure out what dark energy is, and to see if the theory continues to fit the data as the data gets better and better. I am not sure what would have happened, if data didn't start to come in the 1990's. I am certain that we would not be on the verge of a golden age if the observations had not come in the 1990's. People would have gotten tired of speculations.

Sugiyama: What are the key observations of this golden age: Sloan-like surveys, cosmic microwave background (CMB), or supernovae?

Turner: There are all kinds of observations. What really makes this a special time is the sheer number: large-scale structure, microwave background, the high red-shift universe, dark energy studies, dark matter experiments, the LHC, and you put them all together and the whole is even greater than the sum of the parts. And what all of these observations have in common, is that they all can test inflation and cold dark matter, the two big ideas that came out of 1980's. If you go back to 1980, the idea that you would ever measure the curvature of the universe seemed very remote. People were focusing on measuring the actual matter density. It's very hard to do; you really need a big, big sample of the universe here.

Sugiyama: That's right, using the number count of galaxies, things like that…

Turner: When you were at Berkeley, you might remember that Ω (density parameter of the universe) climbed almost to one, and then it started sinking, finally arriving at about 0.3.

Sugiyama: Right, I remember that one day in 1994, I think, we had a debate at a seminar at the end of the semester. Joe Silk[*5] and Marc Davis[*6]...

Turner: Flipped the coin to decide who got which side – the issue was completely up in the air.

Sugiyama: Yes, they flipped a coin. One took the flat $\Omega=1$ universe; the other had to argue for a low-density universe. That was really spectacular… But now, this fun has been denied us because all data points to the universe being low density, but flat, since we also have an unexpected player in the game in the form of dark energy.

Turner: Dark energy is such a wonderful story; the story began in 1980; those of us who believed in inflation said very carefully that it doesn't mean $\Omega_{matter} = 1$. It means you have a flat universe. But we were pinning our hopes on particle dark matter, because we already knew that if we will have enough matter to make the universe flat, that wasn't baryons, instead it had to be particle dark matter. That was already pretty exotic. And then, during the 1980's the measurements of Ω_{matter} went up, getting close to one and then falling down, and it looked in the late 1990's that the inflation was really on the ropes because Ω_{matter} was falling short of 1. As a last desperate try, we suggested that it was something like a cosmological constant.

Sugiyama: Right, but that may be the last thing to introduce…

Discovery of accelerating universe changed cosmology over night

Turner: If you look at cosmology around 1997, it was not clear where things were going to go, because you had that idea of inflation and dark matter and they worked pretty well if you took $\Omega_{matter} = 0.3$, but inflation really insists Ω is one. It looked like it was not going to be a happy ending. Then in 1998 the discovery that the universe was accelerating changed it all, essentially over night.

Sugiyama: Is that supernovae data?[*7]

Turner: Yes.

Sugiyama: They even reached the wrong conclusion in the first paper, if I remember correctly.

Turner: It is true that the first ten supernovae or so did not show signs that the universe is accelerating. And even the original discovery data from 1998 is not very strong. But instantaneously everybody said: "Aha, we have a solution. We have a universe with dark matter and dark energy and it's accelerating, because the accelerating universe and dark energy made everything fit together." Over the past ten years the evidence has become rock solid.

Sugiyama: Two years later, Boomerang CMB also proved that the geometry of the universe is flat. That is really a triumph.

Turner: Yes, 2000 was a very important year and Boomerang really settled the issue of

[*4] Lambda (Λ) means the cosmological constant which Einstein introduced to his equation of gravity.

[*5] Professor at Oxford University. He is known for his research on cosmology, galaxy formation, dark matter, and so on.

[*6] Professor at the University of California, Berkeley. He is known for his pioneering observations of the large-scale structure of the universe as well as numerical simulations for its formation.

[*7] Observations of the distances and redshifts of distant galaxies reveal if the rate of the cosmic expansion at that time was faster or slower than the present rate. This in turn tells if the cosmic expansion is decelerating or accelerating.

Public lecture by Michael Turner (see p. 19)

flatness. But 1998 was the watershed year. I will give you an example why. In April 1998, Dave Schramm was supposed to debate with Jim Peebles[*8] on whether the universe was flat and this time there wasn't going to be a coin flip. Schramm had flat and Peebles had non-flat. You know Dave Schramm died in December of 1997. The whole fall before his death he was worried about his debate with Peebles and the only thing he could see that would make a winning case for flat universe was Λ (cosmological constant). Dave kept coming to my office saying: "Any supernovae results yet?" So I think in December Dave thought that Peebles would win the debate because the supernova data had not yet been reported. Only weeks after his tragic death, the supernovae results were announced. I was asked to fill in for Dave and the debate organizers said: "You know, Jim is not really sure about what the debate topic is." I said: "I think I know what it was supposed to be: flat versus non-flat." I spoke with Jim and he said: "Yes, indeed, flat vs. not-flat is the debate topic, but I am not willing to debate not-flat anymore" The discovery of cosmic acceleration changed it all, almost overnight.

Sugiyama: Because after the data⋯

Turner: Well, the supernovae data was not decisive and you could have argued against it. But you could see the handwriting on the wall: As crazy as the whole picture was, at last everything fit in together.

Sugiyama: So right now with cold dark matter, flat geometry, and dark energy working pretty well for every single bit of data, is there no compelling reason to think about any other possibility or still we should explore alternatives?

Turner: Well, it depends on who you are. If you are what I would call an astrophysical cosmologist, somebody who is interested in reconstructing the history of the universe, then I think you would be pretty happy with the model you just described, because we know whatever the dark energy is, it is very similar to cosmological constant vacuum energy and for the purposes of understanding how the universe evolves to form structure, you know the basic cosmological model well enough for this purpose. But if you are what I would call a fundamental cosmologist and you are very interested in the fundamental features of the universe and how they came about you would want to know more.

[*8] A pioneer in Big Bang cosmology. He contributed to the discovery of cosmic microwave background radiation by theoretically predicting that it is detectable. He also contributed to the theory of structure formation through the first detailed calculations of the formation process of hydrogen atoms. Now he is Professor Emeritus at Princeton University.

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Sugiyama: "What is dark matter, what is dark energy?"

Turner: Yes, coming back to the dark matter, again, if you are an astrophysical cosmologist, I don't think you really care if it is an axion or neutralino. The key thing is that it's very cold. If you are a fundamental cosmologist, then even though the dark energy seems to behave just like a cosmological constant, if there is even 1% difference, that's a very big deal. And likewise with the dark matter, to a fundamental cosmologist the difference between an axion and neutralino is a very big deal. So, astrophysical cosmologists know enough about the fundamental model; they can do what I think is extraordinarily interesting, to reconstruct the history of how we got here, the first stars, first galaxies. But in the terms of fundamental cosmology and the birth of the universe, we are just scratching the surface.

Sugiyama: OK. So I guess you maybe belong more to the fundamentalists. I have another question for you: If dark energy is coming from the Planckian era, it is quite unlikely that we would have such small dark energy in the present day. It's not natural. So, we need an appropriate explanation for that. What is your explanation?

To be a great theorist you need big problems to solve

Turner: The scale of the dark energy – more than 30 orders-of-magnitude below the Planck scale seems to suggest that it has nothing to do with Planckian physics. That being said, we don't have a clue what it does have to do with! I think today's session really illustrated this: theorists are without good ideas about what the dark energy is. They have plenty of ideas, but none of them are compelling – they are mostly ad hoc and don't shed light on anything else. But, I think what is so wonderful about this problem is that it is a big one. It's really big one, and the solution is not at all obvious.

Sugiyama: So we have to be very happy as theorists or researchers that we can tackle such a big problem.

Turner: I think you are right. If it's an exciting time, you not only need data and smart people, but you need big problems. You know, Bill Clinton, our 42nd President, had enormous political skills, but he was President at a time when there were no big problems to solve.

Sugiyama: The new president has many problems to solve··· major problems.

Turner: I think Bill Clinton is very envious of Barack Obama for just that reason. To be a great theorist (or a great president) you have to live at a time when there are big problems to solve. But when the problems are really great,

WE KNOW MUCH
たくさんわかっている
インフレーション
超ひも
宇宙論
熱いビックバン
モデル
暗黒
エネルギー
質量を持つ
ニュートリノ
元素
加速膨張
冷たい暗黒物質
CAN WE PUT IT ALL TOGETHER?
これらを全てまとめあげる
ことができるだろうか？

全体像
THE BIG PICTURE
OUR UNIVERSE
私たちの宇宙

One of the slides shown by Michael Turner at his public lecture

there is no guarantee that it will be solved in your time window. Dark energy might be solved in 5 years, 10 years, or it may take a hundred years.

Sugiyama: Thinking about dark matter, Zwicky*9 found dark matter in the 1930's; we still don't know what it is. The same thing might happen with dark energy.

Turner: That's very true. Zwicky was the most creative astrophysicist of his time, and he speculated about what dark matter was – neutron stars, white dwarfs, black holes. Nowhere on his list was a new particle of nature. It looks like we are just about to solve the dark matter puzzle; so that would eighty years or so. Let's hope that dark energy doesn't take as long! And you never know, the solution could be just around the corner.

Sugiyama: What is our next major task? Dark energy is extremely difficult and dark matter is almost there. We have a flood of data coming. What are your thoughts on the future of cosmology?

Turner: I would even say right now that we live in extremely exciting times, where theory and observation have come together. And I think the next 10 to 15 years will determine whether or not this is a golden age in the following sense: we have some very powerful ideas, we have fantastic instruments, and whether or not this will be considered golden age will turn on "Did we solve some of the big problems? For example, did we figure out what dark matter is?; did we figure out how the universe began?; did we figure out dark energy?; did we figure out the origin of ordinary matter, baryogenesis?; did we finish the story of the formation of stars and galaxy?"

Sugiyama: It sounds like a major leap to new knowledge, a new understanding of the universe…

Turner: What's really exciting is that one of the founding principles of the IPMU is; it's not just the astronomy, it's not just particle physics, it's not just mathematics. They are all tied together and so a jump in any one of them, will likely be a jump in all three together.

Sugiyama: Please come back again to IPMU to see what happens…

Turner: I certainly want to come back. You and your colleagues created something very special. And I look forward to watching how IPMU changes science around the world.

Sugiyama: Thank you very much.

*9: A famous astronomer (1898-1974) worked at California Institute of Technology. He is known for many brilliant achievements; for example, extensive observations focusing on the relation between supernovae and neutron stars, finding the method to determine the distance to far-off galaxies by using supernovae, and the discovery of the existence of dark matter.