INTERVIEW WITH PROFESSOR HITOSHI MURAYAMA: SUPERSYMMETRY

By: Sabrina Berger, Juwon Kim, Yana Petri, Kevin Nuckolls

Professor Hitoshi Murayama is the MacAdams Professor of Physics at the University of California, Berkeley. He is also the director of the Kavli Institute for the Physics and Mathematics of the Universe at the University of Tokyo. His research interests include the investigation of dark matter, grand unification, neutrino physics, and physics beyond the standard model, including Supersymmetry.

BSJ: Can you start off by describing your background? How did you get into theoretical particle physics?

Professor Murayama: Well, I was born in Japan, lived in Germany for four years during my childhood, went back to Japan, and eventually got a degree from the University of Tokyo. I found my way to Berkeley as a post-doc up here at the lab, and then acquired a faculty position here.

I don't know exactly the story about getting interested in science. But I was a very curious child, for sure. I was the kind of child who kept asking questions to my parents and so on. My dad was a researcher who worked for Hitachi. He was doing research on semiconductors for the company. He didn't have a PhD, but he had a Masters degree. My memory is, of course, hazy from those days, but I do remember that he answered many of those naïve questions I had at that time, so that's probably how I got interested. That's also how I learned that many questions have answers, which is actually not an obvious thing for many children, I'm afraid. If they're not inquisitive enough, or if their parents or teachers aren't resourceful enough, then many of their questions just go answered. That doesn't nurture curiosity. I was lucky enough to be in that kind of position, I guess.

I was also a very sick child. I had a very bad case of asthma as a child, so I missed many school days. I stayed home quite a bit, so I had to find something to do while I was at home. So, I turned the TV on, the soap operas were not interesting for kids, so I ended up turning my TV to educational channels. Back in those days, in Japan, the educational programs were actually pretty good. Some of them were really sort of story-based. There was one story I particularly remember talking about how infinite series can converge. The story was about a guy in ancient Edo in the 17th century who was trying to buy tofu. So, he brings his bowl, and gets one piece of tofu, but wanted some extra. So, he gives many compliments to the tofu shop owner to please him. He keeps praising until, eventually, he got another half piece of tofu. So he continues to praise until the tofu owner gives him half of the rest, and half of the rest, and so on. This guy in the story thought, "Eventually, I'll have a huge amount of tofu, enough tofu for the rest of my life." But, in the end, he only gets two pieces of tofu. So, that was the story, and it intrigued me.

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Another program I remember was a physics program about a little booth, where some man is making some food, and there was a nice aroma. Then comes this strange looking guy who comes close to the booth, smells it, and goes home. He does this everyday, so the owner got fed up with this guy, and eventually gives him an invoice saying, "You've been smelling my food everyday without paying. You owe me 100 dollars." The rest of the show is spent checking the legitimacy of this request. They first try to figure out what exactly it is that we are smelling. So they tried blocking the smell off with a thick slab of glass, such that you can see it, but not smell it. This meant that something was actually coming towards you, that could be blocked by the glass. This is how the show unfolds until, eventually, they figure out that there are some particles that come off the food on the grill, propagate through the air, and enter our noses, which explains how we smell things. Of course, I don't know any legal issues regarding the smelling of someone's food.

So these shows were very fascinating to me. I think I was in 2nd grade or something when I saw them, so I talked to my dad and told him "This series thing is kind of interesting." He then bought me a bunch of math books, which I started to read. I studied all the way up to calculus when I was a third grader. I got really, really into it. That's basically how I spent my elementary school days.

For middle school, I moved to Germany, and all of a sudden became very healthy. So, I pretty much lost all interest in those things I had been studying and just wanted to play outside, like soccer and volleyball. I was much more into the outdoors activities now that I could do them. I then got into music, so when I got into college, I became serious about the double bass and got pretty good at it. I was making money off of it as people hired me. Naturally, I considered a career in music until people told me that it was awfully difficult to making a living out of music. But, I always had a sort of interest in physics, remembering those days when I was a kid watching the educational programs on TV. Many of the questions I had asked when I was little were like "Why is the sky blue?" or "Why is it dark at night?" Those questions had to do with physics, astronomy, and some chemistry. Those ideas remained in my mind, so when I got into college, I decided to major in physics. I was studying physics at a minimal level. I wasn't too serious about it, but when I thought about going to graduate school, I thought "Okay, maybe this is the way to go." So, I got into graduate school in physics and wanted to explore the most basic, fundamental thing, which, in my mind at the time, was particle physics. This was because I knew that everything eventually breaks down to tiny pieces, like quarks, atoms, electrons, and other particles. I thought that, in understanding these things, we could maybe understand everything. It was very naïve of me to think this as a senior in college, but that's what I wanted to do.

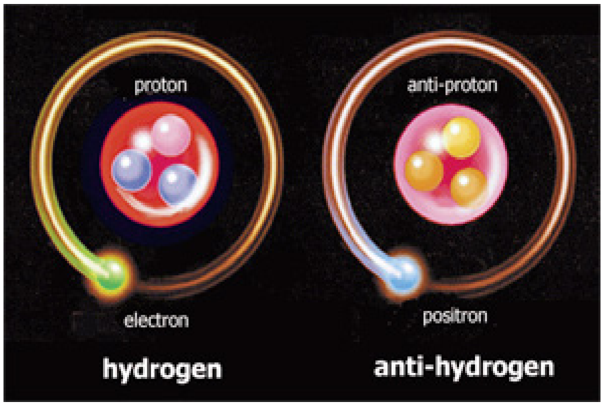
When I got into graduate school, I wasn't careful enough in choosing the school that was active in my area of interest. I was at the University of Tokyo, so, without thinking, I just applied to University of Tokyo's grad school, which was a really bad idea. No one was active in this area to supervise me, so I was kind of left alone. I ended up seeking people outside the university in the field. Unfortunately, this area was not that active at the time, so not many people were working on it. Eventually, I found somebody at an institute that was 200 miles away. I begged him to please teach me, and finally found him when he was just about to move for a short-term position in England. He said, "Sure, I can do that, but only after I come back from England." So, I lost another two years of grad school. After he came back, I reminded him of his promise, to which he said "I remember I promised, but just teaching one students is a waste of time, so why don't you assemble at least 7 students for me to teach?" I literally went around the country, to cities like Hiroshima and Kyoto, finding students interested in the subject until, eventually, he agreed to teach us.

That was the first time I really got started with learning the subject. The University of Tokyo system is kind of brutal in saying that you have to graduate in the period of five years, no matter what. Given that I only had one year left, it was really tough. I worked incredibly hard, writing a piece of software that's still being used today to compute elementary processes in particle physics. With that, of course, I did a bunch of calculations myself, put together a thesis, and nearly failed. One of the issues with my thesis was that people working on theoretical physics and experimental physics were decoupled from one another. What I was working on was smack in the middle, doing simulations of experiments, but it wasn't very mathematical or theoretical. So, the thesis committee got into a huge debate because they didn't know what side my work would be classified as. In the end, I passed, but was shocked that what I was doing did not seem to be appreciated. I got a degree, so that was great, but it was the message I received that caused me to rethink my career path. That's when I decided to move to another country. So, I applied to the US and was lucky enough to get a post-doc position at LBNL.

Berkeley is really great. After I came here, I kept hearing about the legendary people from Berkeley, one being Louis Alvarez. He is a Nobel Laureate who got the Nobel prize for discovering many particles in the 60's. However, his most famous paper is the theory that dinosaurs became extinct due to an asteroid impact. These subjects don't seem to have anything to do with one another, but that's just Berkeley's style. You just jump in to whatever excites you, disregard what you're an expert in, and just do whatever you want to do. Another Nobel laureate in Physics, George Smoot, got the Nobel Prize by looking at the baby picture of the universe, yet his background also had no implications of this. I was very interested in this intellectual freedom that Berkeley offered, so I really wanted to stay here. I'm really happy about that.

BSJ: How would you explain the basic principles of Supersymmetry to people outside of your field?

Professor Murayama: Well, I think there are two ways of explaining it. One is that it's another version of antimatter. What we've learned really goes back to the 1930's, when every piece of matter or particle we have (electron, proton, quarks) has an antimatter counterpart. Matter and antimatter are actually not very different from each other. So if you just happen to meet a person made of antimatter, you wouldn't recognize it as so. But, the minute you shake hands with that person, you would blow up! That's because when matter and antimatter meet, they annihilate, and turn into a huge amount of energy. So that's antimatter.

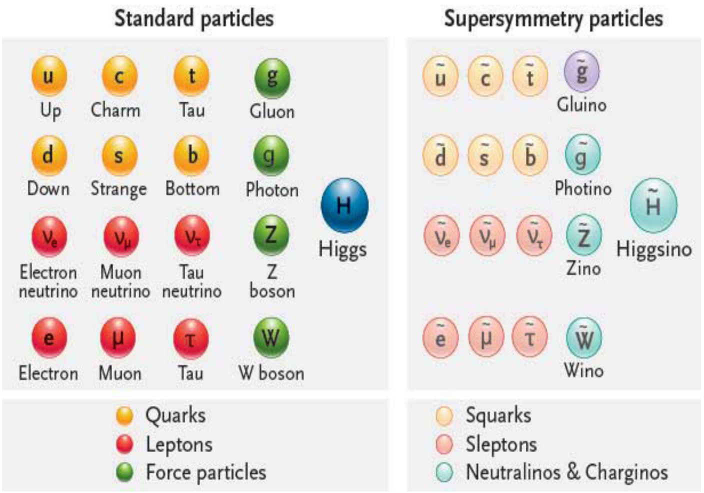


So, we now have double the number of particles with matter and antimatter. The idea is to double the number again, and for the same reason. The reason we need to have antimatter is to make the energy of elemental particles fairly stable. Consider an electron. Using, let's say, freshman physics, you have learned about electromagnetism, so you know that if an electron has a negative charge, it repels itself. How do you keep the electron together then? If you think of an electron as a tiny ball with electric charge inside, then you have to put a lot of pressure on that ball to keep it tiny. The amount of pressure that you provide requires energy, which is actually something like at least ten thousand times bigger than the energy that the electron itself has. That's strange, right? You need to provide that much energy to keep the electron tiny, but ultimately, the electron is far lighter than that. Remember that mass is the same thing as energy, according to Einstein. This was actually a very important puzzle. It turned out that the minute you consider antimatter, there exists another process that will help you squeeze the charge of the electron into a tiny ball, but a lot more easily than before, so that it does not cost so much energy anymore.

Now, you can also apply the same idea to the recently discovered Higgs boson, which was a big deal two years ago. This boson is filling up the entire Universe – it is here, it is densely packed everywhere - and it repels itself, just like the electron does. Then, we're faced with the same problem: if you would like to keep this boson as tiny as it is, then you have to put in huge amounts of energy to squeeze it to be that small, but the Higgs boson does not seem to have this kind of energy. So, where did this energy come from? We use the ideas of Supersymmetry and double the number of particles. Every particle has a partner, each with a strange name: the photon has a partner called the photino, the gluon has a partner called the gluino, and the electron has a partner called the selectron. Once you accept this extra partner, then the previously unaccountable energies become okay again. So that's one explanation.

The other one is the idea of extra dimensions. So, we live in three-dimensional space, but there are ideas that our space is not actually three-dimensional, but maybe nine-dimensional. This is what string theorists tell us. The extra six dimensions are curled up in a very tiny size so that we don't actually see them, but they do exist. At least, that's the idea.

In Supersymmetry, we have yet another type of extra dimensions. Ordinary extra dimensions, even though that already sounds extraordinary enough, can be described by numbers. Think of an intersection. We can decide to meet at 5th Avenue and 3rd Street on the 7th floor of a building. This is all described in a coordinate system,



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described by a set of numbers. But, Supersymmetry is an extra dimension, whose coordinates are numbers, but they don't commute with each other. When you have two numbers and change their order, you get an extra minus sign. It's a weird kind of number. It's a dimension nonetheless. So, another way to describe Supersymmetry is a structure of new dimensions in space. When a particle goes into that weird dimension, it comes back as a partner. An electron enters, a selectron exits. A photon enters, a photino exits. So, that's the results of this new dimension of space. It's a quantum dimension of space.

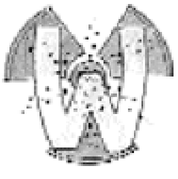
BSJ: How or why did you choose to pursue Supersymmetry over other models in particle physics?

Professor Murayama: I didn't necessarily choose it over the other theories out there; it just seems to be the best understood and the most viable. Mathematically, Supersymmetry is quite beautiful. Its ideas have been useful in many developments in recent mathematics, like in understanding topology of four-dimensional spaces, or even six-dimensional spaces. It turns out that Supersymmetry has a very rich mathematical structure. It seems to help with the idea of why particles don't have as much energy as we think they should. It also helps us understand an even bigger version of the Supersymmetry's grand implications.

We have identified at least four different forces in Nature – electromagnetism, strong force, weak force, and gravity. There is a possibility that all of these forces actually come from a single force at the beginning of the Universe. They may have separated as time went on, progressing to the way we see four different forces now. That idea also requires Supersymmetry to make it consistent with the data we currently have. It also provides a candidate for something called the dark matter theory. Dark matter is everywhere and is, in some sense, the mother of stars and galaxies, which were made thanks to dark matter. When the Universe started, it was a very bland, boring place, totally smooth and looked exactly the same everywhere. But, eventually, the Universe managed to create these bumpy structures that are stars and galaxies, or else we would not be here. So, how did the Universe become so bumpy? For the answer to this question, we turn to dark matter. We can't see this dark matter, but we know where it is, we know it exists. Dark matter has enough gravitational pull to assemble things together just by pulling them using the gravitational force. Where dark matter is a little bit more dense, it pulls stuff in to become more dense. As the gravitational force becomes stronger, it can pull in even more, and become even denser. Eventually, the universe forms these clumps of densely-packed dark matter. Those clumps draw ordinary atoms in, which scatter against each other, emit light, cool down, and eventually collapse into stars and galaxies. That's the best theory we have.


gravity


strong force


weak force


electromagnetism

Unfortunately, we still don't know what it is yet. However, Supersymmetry gives us a candidate of this dark matter particle, so it is also quite useful in that way.

BSJ: In several of your papers, we read about the hierarchy problem. We wanted to ask you about the ways Supersymmetry can attempt to resolve this problem.

Professor Murayama: This relates back to what I mentioned about the energy of the particles. The hierarchy problem is the problem that the Higgs boson, which we now know weighs under 25 GeV, or gigaelectron volts, could have also been at the highest scale possible, 1018 GeV, which is the highest energy scale we could ever imagine. Because we know that the Higgs boson is much lighter, so something must be protecting it. Initially, the idea with the electron was that something is indeed protecting it, so it can be much lighter than it would be alone. But, because of the presence of antimatter, with antimatter actually cancelling part of this dark energy, the electron can remain light. In the case of Higgs boson, again, if you consider it alone, it's mass tends towards the highest possible energy scale, so we know something should be protecting it from remaining at this huge mass and energy. Something must be cancelling its self-repelling force, so we use the ideas of Supersymmetry. That's how the Higgs boson can stay as light as we have discovered, we think. This is one of the greatest influences Supersymmetry has in helping us understand these tiny particles.

BSJ: What is the relationship between Supersymmetry and String Theory? How can they be used to further our understanding of dark matter?

Professor Murayama: String Theory is a theory that all particles we see are actually not points, despite what we used to think. They are actually these extended rubber bands, which have many branches. Obviously, these rubber bands have to be small enough so that we can perceive them as points. So, they are tiny, tiny strings,

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but are extended and have a finite size. People think that this might really help us unify gravity with the other forces that we know in nature, so that they ultimately come from a single force, which I mentioned earlier. So, why does this extra size help? Well, think back to the very beginning of the Universe. We know that the Universe was getting bigger and speeding up as it did so. Thus, the Universe should have been much smaller before. If you just keep going further back in time, eventually, the universe reduces to a single point. Here’s where we don’t know what is going on, because the entire energy of the Universe collapses to a point, the density inside this point is infinite. Whenever physicists see infinity, we throw up all hands, for we don’t know what to do with it. The laws of physics as we know them just break down. We struggle to study the question of how exactly the Universe got started because we don’t know how to handle this infinity.

But, just imagine that the Universe was, instead, made of these tiny strings, not elementary particles. Then, as we try to squeeze the Universe down to a point, it gets stuck, because the strings inside have finite size. This gives us hope that once we understand String Theory, we can successfully avoid this infinity. We can probably understand how the Universe got started without getting into this issue of infinities, which is the way that String Theory helps resolve this problem. When people started to build String Theory, they quickly discover that we would need the ideas of Supersymmetry in addition to the tiny string to make the theory mathematically consistent. So, that’s where the idea came from. Bruno Zumino, from our department, who unfortunately passed away last year, and Julius Wess, who also passed away a couple of years ago in Germany, were the people who wanted to implement the idea of Supersymmetry in a kind of theory we could deal with, calculate with, and use to make predictions. Since 1994, the idea of Supersymmetry really took off as it was combined with everything we now understand about particle physics. We now have this new theory, with which we can make predictions about what kind of signals we are supposed to see at the Large Hadron collider, some experiments in cosmology, cosmic ray experiments, and so on. This is the frame that can combine many other theories together into a single theory. Of course, we have not seen evidence of it yet; it remains undiscovered, but at least it is something we can think about, deal with, look for, and study.

In connection with dark matter, we’ve mentioned that Supersymmetry predicts the partners for every single particle we have in the Standard Model. There is a good reason to think that photons is one (among the whole host of supersymmetric particles) that is stable, does not decay, is electrically neutral, and weakly interacting. It is actually one of the best candidates for dark matter particles. There are people in this department who have pioneered an experiment done underground, looking for a signal for dark matter. Of course, again, we have not found it yet, but we are getting into the range of precision where you might expect a signal, so that’s quite exciting.

BSJ: Also, in one of your papers, you mentioned the conflict between naturalness and Supersymmetry. Could you first explain this philosophy of naturalness, and then explain some of the conflicting concepts we see between Supersymmetry and naturalness?

Professor Murayama: Naturalness is the idea that we have this Universe with lots of physics. Most of physics has many intrinsic numbers in it: the speed of light, the mass of electron, electric charges, the mass of the proton, strength of the weak interaction. We describe physics using what we call the fundamental constants. Suppose, now, that you play the role of God and are thinking about making a universe. You have to choose these fundamental constants to set up a universe, but you don’t have any particular reasons to choose one number over the other. If you create a universe where these fundamental constants are just a tiny bit different from what we have in this universe, would that result in a totally different universe? Would there be life? Would there be people? Would there be stars? When this other universe, which has slightly different fundamental constants, looks pretty much the same as ours, then that gives you some sense of stability in our universe. This universe is sort of “natural” in relation to the stability we see. If you tweak things around a little bit and yield a totally different universe, then we think this kind of universe is “unnatural”, because you need to choose these constants extremely precisely so that we can live in this universe and have stars and galaxies and so on so. That’s the concept of naturalness.

Of course, naturalness is not completely scientific because we can probably never observe if there are other universes at all, but maybe they don’t exist. It may just be totally ludicrous to think about changing these fundamental constants around. Maybe there is a way to actually derive these fundamental constants from some principles. Maybe they are supposed to be exactly the way they are. There's always a philosophical debate about this subject.

This problem I mentioned about the mass of the electron or the mass of the Higgs boson relates nicely to this idea. If you change things by just a tiny bit, at the order of 10-36, the Higgs boson would be much more massive. It doesn't seem to be natural in that sense. So, here lies our problem.

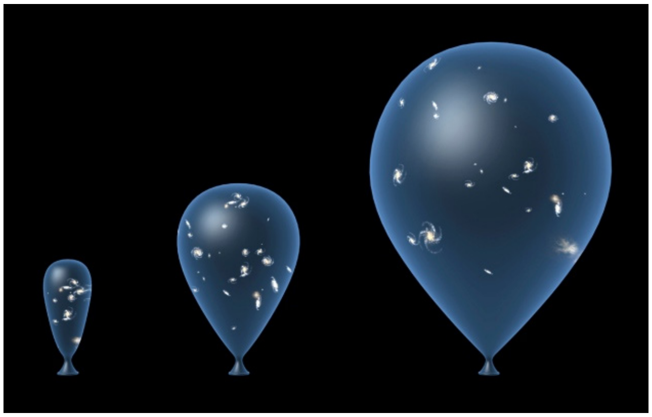
BSJ: In trying to test these notions of naturalness and other constants, do theorists just take current constants that they know, tweak them slightly, and just see how other physical processes work out?

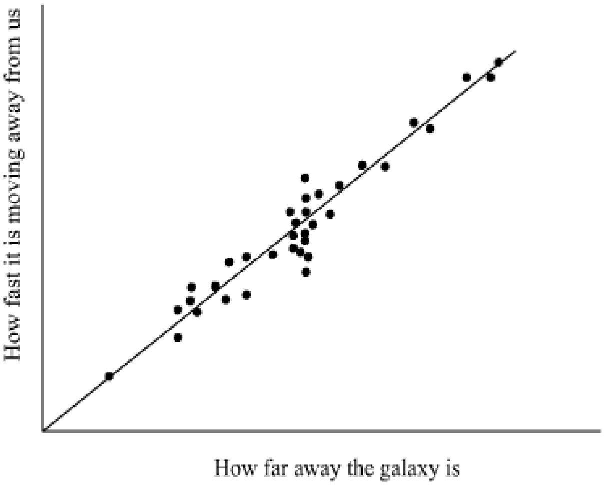
Professor Murayama: Yes, exactly. In doing so, though, we see that most things are not that sensitive to change. For example, if you change the mass of the electron, say make it twice as big, atoms become twice as small. This doesn't really seem to change things very much. In contrast, the difference between the mass of the proton and neutron is more sensitive. The mass difference between the proton and the neutron is only about 0.15%, so they are extremely close in mass. If you make the neutron 2% heavier than it is now, then all the neutrons in your body very quickly decay into protons which are lighter. Then, because the neutrons act as the glue for binding the nucleus together, these nuclei can no longer stay together. Thus, the protons (again like charges repel) would all of sudden blow apart, so you wouldn't exist. If it's the other way around, in which the proton is less than 2 % heavier than the neutron, then protons decay into the neutrons, causing nuclei to become electrically neutral.

Then, there would not be any atoms. There would not be any periodic table or chemistry. There wouldn't be any humans. This case is a little more sensitive than the case of the mass of the electron, but again only at the level of a few percent.

There are two things that seem to be, in this sense, very unnatural. One of them is the Higgs boson. If you change things around just a tiny bit, at the level of 10^-36, as I previously mentioned, the Higgs boson becomes enormously massive. It would then be stuck in the universe today, unable to move. Then, all the elementary particles would become massless, electrons in your body would fly away with the speed of light, and you'd disappear in a nanosecond. So, this tiny change would wreak such havoc in the universe, thus making this very unnatural. That's one example.

There's one other example where you are incredibly sensitive to these kind of small numbers, and that's the current acceleration of the universe. We still don't know exactly why the universe is picking up speed these days. Saul Perlmutter discovered this and got a Nobel Prize for it. It's named dark energy, which is filling the entire universe. This sort of sounds similar to the Higgs boson, and they must be related at some level. This dark energy is multiplicative in nature. If you make the universe twice as thick, the volume of the universe becomes eight times bigger and dark energy becomes eight times bigger. It keeps pushing the expansion of the universe as it gets bigger, so we see the universe accelerating at an increasing rate. Now, suppose this is true and somehow empty space has this dark energy. Because it grows with volume, there must be some constant density of energy in the empty space. But, who chose this constant? Again, I can play the role of God here, where I change this number a tiny bit and see what happens. It turns out that if I change things around only the tiniest bit, even worse than the Higgs boson, at the level of 10-120, this energy density of the universe can become hugely positive or hugely negative. If it's hugely positive, then the universe must have expanded or started when it was still very hot and dense. Then, as things start to accelerate right away, everything splits apart and there's no time left for stars and galaxies to form. On the other hand, when it gets driven to this huge negative number, as the universe gets started it actually decelerates so quickly because dark energy is negative. It stops right away, starts to collapse, and leaves no time for any stars or galaxies to form. The way the universe is today seems to be very sensitive to this dark energy, or whatever it is that decides this energy density of the empty space.





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If you require that the amount of dark energy has to be as such to be able to build galaxies and stars eventually, then you can predict that the amount of dark energy today must be within about a fraction of 10 of what's all discovered. The number we got in the end seems just right. If we change things just a tiny bit, we wouldn't be here, so we say again that it seems very unnatural. From what I know, these two numbers are the only numbers in physics I know of that seem so sensitive to tiny variations and seems so unnatural to us.

BSJ: When pursuing your research in your career in particle theory, a lot of your work is highly collaborative with the high energy experimentalists. I was wondering if you could explain how your relationship with various experimentalists, especially those working at the LHC, affects how you choose the work you work on?

Professor Murayama: Experimentalists are, first of all, very important. I'm kind of jealous because of what the experimentalists' ability to talk to mother nature. Theorists are sort of receiving second-hand information. We ask the experimentalists to do the experiments. They know how to talk to mother nature, so they get some answers. They then actually consult us, theorists, again and they say, "We got these answers, but they're so cryptic, so we can't make sense out of them. What do you think of mother nature's response?" That's where we come back in. I really admire them. We really need them so that we can get information about the way the universe works in the end. I very much love the idea of collaborating with them.

We, the theorists, start by giving them advice or suggestions about interesting directions to take in their work. Then, the experimentalists go ahead and build some complicated instruments to take data. Then, they bring the data back to the theorists and say, "You know I tried what you suggested, we got this answer, so what does it mean?" Then, we start the process over again. So, that's the way that science is supposed to make progress. I try to remain very close to them in my work. In practice, the way it works is that experimentalists tend to be glued inside their laboratories. We tend to be glued at our desks, working on our computers and stuff. Thus, it is actually not easy for us to meet and work together. We actually have to make a conscious effort to do so, so that we can contribute to each other's work. I am honored to be invited to many advisory committees and make suggestions on how big laboratories should be run, how the next experiments should be chosen, and what is the right way to take data. I contribute my two cents; and sometimes they listen, sometimes they don't. That's okay. That's what really sets physics apart from philosophy. Physics is really based on the data. I have nothing negative to say about philosophy by the way, but that's the difference.

BSJ: Along the same line of thought, just to clarify, although you work together, theoretical and experimental physicists have very different ways of approaching the same problem. How would you break down your abstract ideas to establish testable hypotheses that the experimentalists can work with?

Professor Murayama: One of them is to basically convert ideas to numbers. For example, let's say I have my own idea of what dark matter may be. Then, that idea itself is difficult to test. If I want my idea to be tested, then I have to come up with a set of data that could be experimentally obtained that should match that produced by my new theory. Once I've made this definite prediction, then experimentalists can work from their side of the problem. They can start to think about exactly how they can build an instrument to be able to take such data, and make sure that the instrument they build is sensitive enough to be able to accurately agree with the numbers I've come up with. Once the problem is concrete, then they are really the experts in doing work on this problem. I just need to make sure to make my abstract-sounding ideas as concrete as possible. Therefore, in the end, I just predict a couple of numbers that are supposed to come out from a very particular type of experiment and see if they agree with the numbers I predicted. Although this process typically takes a long time, I think it's the only way we can work together.

BSJ: Now, when you're coming up with these concrete numbers, do you present experimentalists with maybe a list and see what might be easiest to test?

Professor Murayama: Yes, absolutely. A list of numbers, or some plots or programs that they can also play with and see what numbers will come out that might be easiest for them to test.

BSJ: We read in one of your papers that you mentioned X-ray observations of galaxy clusters could provide support for the dark matter hypothesis. What other evidence could be used in support of supersymmetry?

Professor Murayama: Many things, in fact. For example, if dark matter is really made of this supersymmetric particle, it's supposed to fill the inside of our galaxy. These particles are very shy, and don't interact at all with matter most of the time. This is why we don't feel the wind of dark matter all the time. But, once in a while, these particles may decide to annihilate with each other, just like matter and antimatter do, and produce something that we can observe. It might be a very energetic photon, in the form of gamma rays, or maybe particle and antiparticle pairs. Then, these made particles may eventually propagate over the disk of a galaxy and fall from the sky so that we can observe them. This idea, actually, has been discussed quite a bit in the last several years. For example, with gamma rays, which again are very energetic photons which may come from this dark matter, there seems to be an indication that there are actually quite a few of these photons coming from our galactic center, which is presumably where the dark matter is most concentrated within a galaxy. So, that raises some hope.

Also, once antimatter is within a galaxy, and when it takes a sort of "random walk" through this galaxy, no one expects that this antimatter would meet up with a matter particle and annihilate. But, if you do see antimatter particles coming from space, then you should wonder where they're coming from. They couldn't have travelled very far, or else they would have all annihilated away. They must have come from fairly nearby, which, from a galactic standpoint is about a hundred thousand light-years. But, regardless, this is relatively nearby. So, we need to look for what produced these antimatter particles. There are locations in the galaxy where very energetic particles are produced, like supernova remnants. This is a, sort of, nearly dead star that had exploded at the end of its lifetime and has left these supernova remnants that are still spurring out from its core, which is slowly sizzling and fizzling out until it fully dies. But, before it is totally dead, it still spurs out these energetic particles. So, maybe, that's the location we're looking for. But, we can spot some of these, and if they're not coming from the right direction, or if they don't seem to be producing enough of them, maybe this could also be evidence that these dark matter particles inside a galaxy fairly nearby might have annihilated with each other and produced a pair of matter and antimatter. Then, that antimatter managed to survive and reach us. So, that's another piece of evidence that other people are looking for.

BSJ: This is more on a tangent to what we've been talking about until now. Many people in the field of mathematics or the field of theoretical physics who have been in the field for a long time build a rather intangible sense of intuition. This intuition allows these people to essentially look at a problem that they'd like to answer and gauge not only the difficulty of a problem, but also the complexity of the solution it might yield. So, we were wondering if you might be able to talk a little bit about how you first interact with a problem and determine its solvability and how you approach an initial solution.

Professor Murayama: Well, my approach is pretty simple. I will usually work on a problem for a while until I hit a brick wall. Then, I just, well, leave it and start working on something else. Then, if I hit a brick wall again, then I leave it and start something else. I end up taking this random walk between problems. Now, once in a while,

A ghostly ring of dark matter.

I manage to break through this brick wall and come up with an answer. That's how I make progress.

Then, I remember the problems that I've left behind and decide to spend a little more time on one again. So, I go back to that one and, surprisingly, even though I had been doing something totally different for a while, somehow, my brain matures and improves. I can then, sometimes, get through the brick wall I had hit before. I'm actually not a very patient guy, so I'm not very persistent in really working hard on a particular problem for years and years. So, I tend to jump around, which has served me pretty well because the field also has many directions and is quite fluid in directions others may be taking. So, I'm okay with this.

Of course, in the end, I'd like to solve really, really hard problems. So, for some reason, jumping around and talking to many people really helps. Berkeley's a great place with so many wonderful people. I'm not patient enough to read every single paper that appears in arXiv, every single textbook on the matter, but talking to people seems to allow me to learn things much more quickly. There really are so many people to talk to in Berkeley, so that's the way that I end up learning and making breakthroughs. I don't recommend this to students. You are supposed to solve your homework problems, but that's my style.

BSJ: Now, before you hit that first brick wall, though, many of these problems are quite abstract and hold many different approaches towards a possible solution. So, how do you first come to an initial path to trying to solve some of these problems?

Professor Murayama: Well, that's an interesting question. That, of course, is determined on a case-by-case basis. So, I would say that if the problem is already familiar enough to me, meaning that I already have enough information in my brain to think on my own and try to stitch together these pieces of information to come up with at solution to a problem, then I tend to spend only a few days or a couple of weeks on the problem. Then, I can sometimes see if I'm making any progress. If not, then I stop. If the problem I want to work on is sufficiently unfamiliar to me, then I have to start reading materials on the subject and familiarize myself with the problem. This includes learning about the many techniques other people have used to solve similar problems. Then, I start talking to people and attending lectures. That may take a few months. Then, after talking to many people, I will at least get some sense of what has been done already and what is still a big problem. Then, I have to eventually decide whether or not I want to pursue the problem. So, it varies.

BSJ: So, we have read about your position as the Director of the Kavli Institute for the Physics and Mathematics of the Universe. Could you comment on the philosophy behind such and institution and the role it plays in your research field?

> "Berkeley's a great place with so many wonderful people. I'm not patient enough to read every single paper that appears in arXiv, every single textbook on the matter, but talking to people seems to allow me to learn things much more quickly."

Professor Murayama: So, there are a lot of things in common between Berkeley and that institute. It's just a different organization. So, when I founded this institute, I had this idea that, if we could just break the walls down between different departments and disciplines, what are some helpful combinations of disciplines that would allow for us to make the most efficient progress? What I saw was, especially for people working in string theory, a much more advanced mathematical theory of physics, they interact with mathematicians. They have to because they need advanced mathematics. Mathematicians also want to learn from the string theorists to gain inspiration for some of their work. So, that actually works out to be a very good combination to have.

The kind of thing that I do is much more experiment-oriented, so I love to have experimentalists nearby. A lot of other things that I have a lot of connections to astrophysics and astronomy, so it's also good to have them around. So, in the end, the idea was to have this collection of disciplines meet, which normally, in a university setting such as Berkeley, are divided in different buildings. If you have an institute where everyone is together, everyone sees each other everyday, then you tend to come across some breakthroughs that would not have been discovered by these people, individually. So that's the way this institute was designed.

It's a different structure. Being in a traditional department of course has some advantages by allowing people to pursue fields at a deeper level within a discipline. You have enough expertise from different people within the same area, so it's easy to talk with each other. It's also a lot easier to train students if you're within a particular discipline, for once you go outside the border of a discipline and want to be more interdisciplinary, it's hard to figure out what degrees students would earn. That sort of mundane issue is also important. It's also had to figure out what journal they should publish in. It really isn't clear. So, for students, it's probably a lot more comfortable and easier to be in this structure containing more traditional departments because everything else is currently structured that way. So, there are pros and cons. What I hope for is that when I'm over there at the institute, I interact with people from different areas and, as a result, I actually became in charge of building an new telescope, which I've never done before. I don't think that I'm good at it, but I can still organize the group of collaborators that will be working on this. It's an $80 million project, for which I had to raise funds, which I'm also pretty good at. So, I can play my role towards a very different goal from what I used to do. So, that was an opportunity that I don't think I would have ever had if I were just a physics professor in the physics department here at Berkeley. It comes with this extra cost, in that I should spend some extra time and learn how to talk to people in different disciplines, which can sometime be a bit confusing. You'd be amazed, once you get more specialized and go to graduate school for a particular discipline, that it becomes much more difficult to talk to people from other disciplines because every discipline cares about how precisely you make statements. The precision means different things in different fields. The word we use to describe precision is different from one field to another. So, just communicating is rather challenging. It's like someone who speaks French and someone who speaks Chinese trying to talk to one another. Theoretical physicists talking to mathematicians is like that, actually. We speak very different languages.

BSJ: You were talking about constructing this telescope in the future, but what are some future steps and directions you plan to take with your research?

Professor Murayama: Let's see. So, I've been relatively random in what I do; I jump around. I also participate some underground experiments studying neutrinos. Unfortunately, that particular experiment was not one of the ones that got a Nobel Prize this year, which I believe it deserved, but it didn't.

As I said, I tend to be relatively random, so I don't really know. But, I can imagine that, now that I'm trying to build this instrument for the telescope, I'm sure I'd like to use it to take data of my own and analyze it. So, that's one direction I could certainly imagine. Some other things I've been doing with postdocs and students have gone off in very different directions in mathematics, which I was not familiar with. I used to use a lot more geometrical techniques, but these new techniques tend to be much more algebraic. I knew very little about it when I started, but now I know quite a bit. We believe we actually made a very important breakthrough just yesterday, so I'm very happy about this. Well, certainly, this new technique I just learned seems to be very versatile and should be applicable to more problems than the problem we have just managed to solve. So, that's the way I choose to grow my horizon. Sometimes, I hit a jackpot. I try to pursue it a bit further until I hit another brick wall. This is another way to grow in my research and has been the way that I have done so. I don't really know what I'm going to be doing, but at least I see some particular directions that seem rather fruitful, which I hadn't imagined before, but seems to be coming out very nicely.

BSJ: Thank you very much for your time.

Professor Murayama: No problem. Thanks for having me.

IMAGE SOURCES

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