Exclusive Interview:

Harvard Theoretical Physicist

Lisa Randall

By Jennifer Gao and Limor Spector

Harvard Professor of Physics Lisa Randall's work on the fundamental nature of particles, the Standard Model observables, supersymmetry, and other aspects of particle physics has earned her widespread recognition in the field of theoretical physics, including most recently the Klopsted Award, presented by the American Association of Physics Teachers in 2006. She recently spoke to the Harvard Science Review about her research and her recent book, Warped Passages: Unraveling The Mysteries of The Universe's Hidden Dimensions*, which was named a New York Times notable book of 2005.*

Harvard Science Review: The Harvard Science Review targets audiences from a variety of backgrounds, including humanities and science concentrators. For students unfamiliar with theoretical physics, could you give a brief description of what particle physics, string theory, and theoretical physics is all about?

Lisa Randall: Particle physics is based on the idea that at a fundamental level, everything is composed of elementary particles. That is, if you keep digging deeper [into the internal structure of visible matter], you find that things are composite: an atom has neutrons, protons, electrons. Of course, at a deeper level, even protons and neutrons have quarks. But at some level you think you've reached the smallest ingredient, which is the particle. And we're trying to understand physics at the most fundamental level and understand what everything is made up of and what the fundamental ingredients and interactions are. That's what our goal is. String theory is the idea that particles aren't the most fundamental – that instead, strings are the most fundamental matter, and particles are the oscillation modes of these fundamental oscillating strings. The reason that people have proposed this might be the case – we don't know if it's the case – is that in standard particle physics, we don't fully understand gravity. We don't know how to combine together quantum mechanics and gravity at all distances. At large distances, we can use Einstein's theory of general relativity; we understand how that works. Quantum mechanics just doesn't play a big role [at these large distances]. At atomic distances, we use quantum mechanics, and relativity doesn't play a big role. But there are distances, far beyond what we can see experimentally, where the theories become incompatible, and that tells us theoretically that there should be something else – and the proposed solution is string theory. Theoretical particle physics is trying to understand what is really going on at these deeper levels, what underlies what we see.

HSR: Can you describe the basic research you're conducting and interested in?

LR: I'm interested in a couple of different directions [of research]. Most recently, my research focuses on extra dimensions of space and the implications of extra dimensions in space, should they exist in the universe. Basically, we're trying to understand fundamental particles and their interactions, what gives mass to fundamental particles, why gravity is as weak as it is. We're trying to understand cosmological issues, how the universe came to be what it is. And those could all tie in with this physics of extra dimensions of space. In particular, I'm trying to see whether there are experimental consequences to some of these theories I've worked on, especially for particle physics accelerator experiments, in which particles get accelerated to high energies and collide together to make new particles. Also I'm thinking about possible [experimental consequences] for gravity wave detectors, which are going to be better and better in the future. We can see gravitational signals from the sky that tell us things like if there was a phase transition in the early universe. We're also thinking about what black holes would look like in the sorts of higher-dimensional theories that interest me at the moment. That's the direction I'm going in now, trying to flesh out some of these theories better as well as their experimental consequences to find out if they're really right—that is, if the universe is as we propose.

HSR: Your new book is entitled *Warped Passages: Unraveling the Mysteries of The Universe's Hidden Dimensions*. What are warped passages, hidden dimensions, and how do these two concepts correlate with each other?

LR: Passages was a word I made up to refer to extra dimensions of space. Dimensions are independent directions of space. The number of dimensions is the number of quantities you would need to pinpoint an object in space. We don't really have a name for them once we get beyond the third dimension, so I called them passages. "Warped" has to do with the spacetime geometry that I've worked with, and it's actually what we've found to be the solution to Einstein's theory of general relativity in the particular context in which we studied it. In other words, we had a setup of objects in higher dimensions and we found that the solution was highly warped. Basically, it was really dramatically curved —and in ways that have very interesting consequences. The title is derived from the research in the technical sense of the word "warped." It's not just a Star Trek term. It's actually called "warped," the type of geometry we found. But I was also sort of punning a little bit, because it's my first book – so I called it "Warped Passages" [laughs], which most people seem to miss. It [the word "warped"] also helps to describe the way people arrive at physics results, both in doing it and understanding it. You don't necessarily go straight there, you take some warped routes, so "warped" has many meanings.

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Hidden dimensions… we're really talking about the idea of hidden dimensions of space, the idea that there is a sense of space beyond that which we see. You can understand it in many different ways; probably the best way is the way Edwin A. Abbott in the late 19th century understood it. He asked the question, "Suppose you had two dimensional creatures. For them, two dimensions are analogous to our three dimensions—that was all they saw and experienced. So how would they conceptualize a third dimension?" For them, a third dimension would be an extra [unseen] dimension. So, for example, if you imagine what they see when a sphere passed through their two-dimensional world, you would see that a sphere would look like a series of disks that increased in size and then decreased in size. But the two dimensional creatures wouldn't be able to put it together and say they saw a

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sphere—except mathematically. They wouldn’t be able to envision it—but they could do it in their imagination, or in words, or with math. In the same way, we don’t necessarily perceive extra dimensions, but they could exist. We don’t know for sure if they do exist, but they could exist. For example, if a hypersphere passed through our universe, it would look like a series of spheres that increased in size and decreased in size. And again, it’s hard to visualize, but we can still imagine it and understand it mathematically. The idea is that there really might be dimensions of space beyond those that we see. The warping [comes as a] consequence to Einstein’s theory of general relativity: if there is energy in these extra dimensions, it can warp space, curve space, in very dramatic ways which turn out to have very interesting implications. They can help us understand the weakness of gravity relative to other forces in our universe. Another revolutionary thing we found was that warping could explain why extra dimensions are hidden.

HSR: Nima Arkani-Hamed, a theoretical physics professor at Harvard University, has stated that you are most well-known for your research on the concept of branes. What are branes, and what relevance do they have to current high-energy theoretical physics research? How and why have they become, as he says, part of the current lexicon?

LR: I’ve actually worked on a lot of different aspects of particle physics. Most recently, I’ve worked on extra dimensions and branes. Branes are lower dimension objects. The word comes from “membranes,” since they’re membrane-like objects in a higher dimensional space. The idea is that there could be extra dimensions [in the universe], but not everything [in it] necessarily experiences or travels in those extra dimensions. They could be stuck on lower dimensional surfaces called branes. A good analogy might be a bead on a wire: a bead on a wire can travel, but only in the one dimension of the wire, even though it might be on a two-dimensional table in a three-dimensional room. In the same way, we might be stuck on branes so that the stuff we’re made of, our universe, is stuck on a three-dimensional brane—even though there might be more [dimensions]. Gravity would still [have to] travel [and operate] through all these dimensions; [it would still have to be] spread throughout those dimensions. But we and the stuff we’re made of and the galaxy and universe in which we live might be stuck on a lower dimensional object called a brane.

HSR: Are there other aspects of your work you want to highlight?

LR: We [Randall and collaborator Raman Sundrum] found a couple of radically new consequences of warped geometry. One was quite dramatic, because since the 1920s, people thought that extra dimensions, if they existed, would have to be extremely tiny – curled up to a minuscule size, or as was later postulated, bound up between branes. We found you could actually have an infinite extra dimension – something people thought was impossible. In 1999, my collaborator Raman Sundrum and I discovered that. And that was quite a radical observation. People who worked on general relativity—on gravity—hadn’t realized this was a possibility, so I think this was quite a dramatic result that might have implications for how extra dimensions hide in our universe. The other thing we found is that if you have these really warped extra dimensions, they can actually explain the weakness of gravity, which is a huge puzzle from the viewpoint of particle physics. Particle physicists would naively predict that gravity is about the same strength as the other forces we know about (electromagnetism and the weak and strong nuclear forces), yet in reality it is many orders of magnitudes weaker in strength. The question is, "Why is that?" In warped spacetime, we showed that you end up with a very natural explanation. Gravity is essentially concentrated somewhere else, and we're experiencing the tail end of gravity. We see exponentially weaker gravity than we would if we were in the region where gravity was highly concentrated.

HSR: In the popularization of physics research in previous years, much of the focus has been on the Standard Model, a model that physicists almost universally consider to be flawed and yet has held up remarkably well to experimental testing. Can you explain what the Standard Model is? If your research is correct, how will it, if at all, impact the Standard Model?

LR: First of all, I should explain what "flawed" means, because this is an especially important point for non-scientists to get straight, as a lot of science debates are about this. We have theories we call "effective theories." They work up to certain distances, certain energies, and they work just fine. It's the same way Newton's laws work. I don't need to know general relativity to successfully apply Newton's laws. I don't even need to know quantum mechanics. These "effective theories" may not be the most fundamental, or the most complete descriptions [of physical phenomena]. But they're a good description on the scales in which we use them. The Standard Model falls into that category. It works extremely well—it's been tested to a percent precision at the scale at which we measure things. But it's considered flawed because it does not address this issue of the weakness of gravity. And particularly what it doesn't address is why masses aren't much bigger than the theory seems to predict. To make the Standard Model give the right answers, we have to do something like a [mathematical] fudge, something we call "fine tuning". [It's] a parameter that's put into [the theory to achieve] sixteen digits of precision. We know that isn't—or we believe that isn't—really what's going on, so what we're trying to do is extend the Standard Model. It's not that the Standard Model will be wrong, but it's probably part of a bigger, richer theory, and we're trying to find what that richer theory is. So my research will have an impact, if it's correct, in showing how the Standard Model is embedded in a larger theory, be it extra dimensions of space or some other theory.

HSR: So what exactly is the Standard Model then?

LR: The Standard Model of particle physics describes the most basic matters of elements that we know and their interactions. It describes particles like electrons and quarks and also the four forces we know about—it really concentrates on non-gravitational forces: electromagnetism, and the weak and strong nuclear forces.

HSR: To what extent do you see your work as being a natural progression from the already accepted aspects of physics, and to what extent does your work lead physics in an entirely new direction?

LR: Basically, it does build on old physics ideas. In fact, half my book is really building up the old physics, which I think is an important thing to do. It's important for people to know not only what is non-speculative, but also to know how our current research builds on and is a logical extension of what is known from before. It's also the reason why what we're talking about isn't science fiction, because we're using scientific theories we know to be correct, like general relativity. We're using it in a different context—namely, when there's extra dimensions of space—and we're finding very bizarre new phenomena, like this infinite extra dimension idea, but it's [still based upon] known physical laws. I think in [the way in which it's applied] won't necessarily predict new laws of physics, but it will predict new scenarios in which we should be using it, if it is correct. Physics would be a bigger, richer stage in which to apply those sorts of laws.

HSR: Where do you see theoretical physics in 10 or 20 years?

LR: That's a really great question. Looking to the past, I would be hesitant to do that [predict its direction] because people so often get it wrong. One of the really exciting things is that the Large Hadron Collider (LHC) is going to turn on. It's a large particle accelerator which achieves about seven times the energies we've achieved at the Tevatron, an existing particle accelerator at Fermi Lab. So experimenters will collide together protons at enormously high energies. And basically [the data that comes from that is] going to set the direction. When we find that out [what happens in the LHC], we'll have a much better idea of where things are headed.

HSR: What led you to choose physics?

LR: I like math a lot, but I didn't really see myself as a mathematician. I just thought the questions were too abstract. I ended up doing really abstract physics stuff, but I like the idea of doing something [that ties back] to the world, to something that we see. I like the games and puzzles aspect of it. I just enjoy problem solving. I deeply like consistency, the idea that things fit together; I like the idea that a universe can fit together in a coherent whole. And when I see it's not [doing that in our theories], I like addressing that and seeing why it isn't and if we can solve it.

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