The Beauty of Branes

Lisa Randall's thinking on higher dimensions, warped space and membranes catalyzed ideas in cosmology and physics. It might even unify all four forces of nature By MARGUERITE HOLLOWAY

It was the summer of 1998, recalls Harvard University physicist Lisa Randall, when extra dimensions finally pulled her in. Extra dimensions—beyond the four we encounter every day (three of space plus one of time)—have been an ingredient of theoretical physics for decades: mathematician Theodor Kaluza proposed a fifth in 1919, string theory requires 10 of them, M-theory needs 11. But Randall hadn't much use for them, she says, until that summer when she decided they might be helpful to supersymmetry, one of the conundrums she was pondering.

LISA RANDALL: WARPED THOUGHTS

- With Raman Sundrum, offered a way to unify gravity with other forces. Their papers RS-1 and RS-2 are among the most cited in recent physics.
- Published *Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions* to describe the excitement of physics to lay readers. It focuses on ideas, not personalities, in part to avoid scaring off women: "If you read a book about all guys, it can do that."

Randall contacted Raman Sundrum, a Boston University postdoctoral student with whom she had previously collaborated, and asked him if he would like to brainstorm about extra dimensions and membranes—"branes," as they are called for short. Branes are domains or swaths of several spatial dimensions within a higher-dimensional space. The everyday world we live in could be a three-brane, for example, and it is anyone's guess as to what dimension brane it might be embedded in. "Raman had already thought about branes and extra dimensions, and he was an obvious person to join forces with," Randall explains.

But Sundrum was a little worried. He was on his third postdoc, didn't have a job lined up and was considering leaving physics for finance. But he liked the way Randall thought and decided to set off on what might be his final physics adventure. The fruits of that collaboration, as fueled by caffeine and ice cream as by heady equations, were papers known as RS-1 and RS-2, two of the most cited in physics for the past five years.

The papers, which appeared in 1999, offered novel ways to think about gravity, branes and extra dimensions, and they suggested that the universe might have evolved differently in the beginning than it did later. "For me and a lot of people interested in cosmology and particle physics, it meant that there was this whole new set of possibilities of what could be going on in the early universe," says James Cline of McGill University. For Sundrum, now a professor at Johns Hopkins University, it meant seven job offers. "She is somebody with a marvelous instinct," he laughs.

This instinct often draws Randall to problems she knows little about. While at the renowned Stuyvesant High School in New York City, Randall decided to work on perfect versions of complex numbers called Gaussian integers for the then Westinghouse science talent search. (In perfect numbers such as 6, the fac-

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tors—in this case, 1, 2 and 3—add up to the number itself.) "The project was looking for and seeing if there were any patterns. And there aren't very many. Basically, I always do this. I don't know anything and take on a big project," she says. Nevertheless, Randall's musings on these numbers tied for first place—a fitting precedent for her subsequent mathematical forays into a host of arcane physics fields: technicolor, charged parity symmetry violation, flavor structure and baryogenesis, to mention a few.

Although they did not intend to, Randall and Sundrum ended up using extra dimensions to offer a solution to what is called the hierarchy problem. It can be framed in several ways, but the problem is essentially this: Why is gravity so puny, so many billion on billions of times weaker compared with the other forces—electromagnetism and the weak and strong nuclear forces? Discrepancy in strength makes it impossible to combine gravity with the other three forces, a unification thought to have existed during the early phase of the big bang.

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But rather than invoking supersymmetry—a popular solution that argues for the existence of as yet undetected partners to all the known particles—Randall and Sundrum posited that gravity could reside on a different brane than ours, one separated from us by a five-dimensional spacetime in which the extra dimension is 10^{-31} centimeter wide. In this RS-1 model, all forces and particles stick to our three-brane except gravity, which is concentrated on the other brane and is free to travel between them across spacetime, which is warped in a negative fashion called anti–De Sitter space. By the time it gets to us, gravity is weak; in the other brane it is strong, on a par with the three other forces.

String theorists had looked at the idea of confining all forces to a brane and having gravity leak, but they had not worked out the mechanism, says physicist Joseph Lykken of Fermilab in Batavia, Ill. Randall and Sundrum, he remarks, "changed people's thinking about this stuff entirely."

As Randall and Sundrum refined their idea, they realized that if the extra dimension of spacetime were warped in anti–De Sitter fashion, it could be infinitely large and what we observe about gravity could still be true. This model came to be known as RS-2. "Working that out was mind-blowing," Sundrum recalls. "We had reason to be dead scared. In each of these cases, there was a distinct fear of making complete fools of ourselves."

"It was counterintuitive," notes theorist Michael J. Duff of Imperial College London. "It came as a surprise even to those working in extra dimensions that even though the extra dimension is very large, we wouldn't be aware of it. Newton's law would still be an inverse square law, not an inverse cube law, which is what you might naively expect."

It took a while for many physicists to realize what Randall and Sundrum were suggesting, but the time was right for such thinking. Anti–De Sitter space was popping up in some models, branes were thriving, and in 1998 Nima Arkani-Hamed of Harvard, Georgi Dvali of New York University and Savas Dimopoulos of Stanford University (or ADD, for short) had postulated a three-brane within two large extra dimensions.

Some of the recent models, be they RS, elaborations of ADD or others, will be put to the test when the Large Hadron Collider (LHC) at CERN near Geneva fires up in 2007. "If there is any solution to the hierarchy problem, it should be revealed at the energies the LHC will explore," Randall enthuses. Evidence could include gravitons, supersymmetric partners or evanescent, tiny black holes. "Even if we don't know the answer, it should tell us what the answer is," she adds.

In typical fashion, Randall recently took on two things new to her. The first was writing a book about physics, released last month. The second was participating on a task force formed by Harvard president Lawrence Summers after his comments about women in science. She says she is nervous about the reception of the first project and dislikes talking about the second one. "I like to solve simple problems like extra dimensions in space," Randall declares. "Everyone thinks [women in science] is a simpler issue, but it is so much more complicated."

She should know: she was the first female captain of her high school math team, and even though Stuyvesant is famous for cultivating science and math whizzes, she did not find it supportive of girls. "There was one teacher who kept saying that Stuyvesant was much better when it was all boys, even though the two best students in his class were girls, and he liked us both. It was this weird cognitive mismatch," she says. Regarding Harvard and the task force, Randall is reticent: "I just want to see a whole bunch more women enter the field so these issues don't have to come up anymore."

The 43-year-old Randall is now collaborating with Andreas Karch of the University of Washington, investigating some of the cosmological implications of branes and extra dimensions. According to Randall, we may live in a three-brane, but "there are regions beyond the horizon that look really entirely different. And we haven't fully explored them yet."

If her ideas don't feel obvious to you, don't fret. You are in good company. "I often don't understand her," Karch confesses. "When she says things, they don't make sense and I first think 'she is crazy.' But I don't say anything, because she is usually right. Lisa just knows the answer." SA