References and Notes

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PHYSICS

Bringing Hidden Dimensions into View

James D. Wells

A scientific revolution is in the making. Particle detectors, electrical wire, magnets, and people are coming in sealed trains to Geneva, Switzerland, for the planned 2007 start of the Large Hadron Collider at the European Laboratory for Particle Physics (CERN). Experimental physicists are writing computer programs, testing equipment, and arranging housing. They await the collision of protons at extraordinarily high energies—higher than humans have ever achieved before. They are curious. They know from mathematical analysis that something new must develop beyond what we know today, otherwise scattering probabilities among known particles at these high energies will be nonsensical. But what precisely will happen? Although no one knows for sure, experiments should tell.

Theoretical physicists await the experiments with equal anticipation. In preparation for this revolution, some theorists calculate the predictions of standard-model particle interactions at ever higher precision in order to compare them with the new experiments. "Standard model" is the lackluster title given to the sum of current particle physics knowledge, which includes the properties of known elementary particles (electrons, quarks, etc.) and the forces that determine their interactions.

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Warped Passages
Unraveling the Mysteries of the Universe's Hidden Dimensions / Unravelling the Universe's Hidden Dimensions

by Lisa Randall

Ecco, New York, 2005. 512 pp. $27.95, C$37.95. ISBN 0-06-053108-8. / Allen Lane, London. £25, C$40. ISBN 0-713-99699-4.

Other theorists speculate on what the high-energy frontier has in store for us. They identify problems with our current understanding of the basic laws of nature and posit solutions for those problems. Lisa Randall, a professor of physics at Harvard, is among the very top of these theorists. It is a treat for readers at all levels to have one of the leading experts write a book about what she's been up to. In *Warped Passages*, Randall does not disappoint.

The book's main focus—the source of its title and what will surely stay with its readers the longest—is not so much the important problem in physics that Randall addresses but rather her proposed solution. In this case, the solution is the hypothesized existence of extra dimensions of space. These dimensions are not your parents' dimensions. They are tiny and warped. Their existence is not intuitive, and Randall explores nearly every possible way to explain the idea, employing everything from a garden hose to classic children's literature in this pursuit. Most of the connections she makes are clever and work well.

Why extra dimensions? An idea gains respect only when it holds promise of solving an important problem. In this case, the extra warped dimensions may solve the hierarchy problem: Why is the scale of known elementary particles (i.e., their masses and interaction strengths) so different from the scale of Newton's gravitational constant?

Within the particle physics community, there is almost universal acceptance of the severity of the hierarchy problem. All the arguments come in the hypothesized explanations. Most theoretical explanations for the problem have been killed off by additional unwanted predictions. A particularly difficult iatrogenic illness is the prevalence of one type of particle (say, a muon) decaying into another type of particle (electron) more often than experiment says is allowed. And since experiment is axiomatic to all good physicists, the offending theories are put to rest quickly. There are no obvious showstoppers of this sort in Randall's theory, which is remarkable given the radical nature of the idea.

The particle physics community has a long history of exploring the various interesting properties of extra dimensions, stretching back to at least the 1920s. Albert Einstein is just one of the many illustrious physicists who have been enamored with the idea. The modern frenzy grew out of a 1998 paper by Nima Arkani-Hamed, Savas Dimopoulos, and Gia Dvali, who showed that invoking extra dimensions enabled recasting the hierarchy problem, from one of quantum corrections of particle masses to that of geometry of extra-dimensional space (*1*). Any new ways to attack the hierarchy problem are always welcome, and their clever insights set many theorists scrambling to go deeper.

One difficulty is that the geometry problem started to look just as intractable as the old problems. A year later, in a pair of remarkable papers (*2*, *3*), Randall and her collaborator Raman Sundrum showed that the geometry problems of warped extra dimensions, as opposed to standard or "flat" extra dimensions, are not as problematic. Soon after, Walter Goldberger and Mark Wise showed that the warped extra dimensions could be stabilized by natural particle physics models (*4*). Randall beautifully describes this theoretical odyssey, emphasizing the physics but also sprinkling it with a personal touch.

Of course, with new ideas come new questions and challenges, and the Randall-Sundrum approach is no exception. For example, many theorists wonder how this approach can tune the cosmological constant (a background energy density permeating the universe) to the tiny value observed by experiment. That is a fair criticism, but not necessarily lethal. The Randall-Sundrum idea may well overcome all objections based on cosmological constant arguments once people understand better what the true issues are regarding that notoriously difficult problem. In any case, if Randall's ideas are relevant to the hierarchy problem, there is a good chance of finding evidence for it at the Large Hadron Collider.

The main competitor to extra dimensions—one probably having more adherents and practitioners—is supersymmetry. That theory posits that for each particle there is a superpartner. The pair work together to tame quantum corrections of particle masses and thus stabilize the hierarchy of scales. If it has direct relevance to the hierarchy problem, supersymmetry will also be tested experimentally at the Large Hadron Collider. To make things even more interesting, Randall explains why supersymmetry and warped extra dimensions are not mutually exclusive hypotheses, which creates the possibility that both radical ideas could be protagonists in the hierarchy story.

Randall likes to emphasize that her theories are testable. It is a high achievement for a theoretical physicist to tackle a hard problem, come up with an ingenious solution, and realize that it is testable beyond ex post facto predictions within a short period of time. *Warped Passages* recounts such an achievement. Experiment will cast its supreme judgments shortly.

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