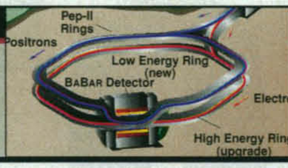

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PHYSICS

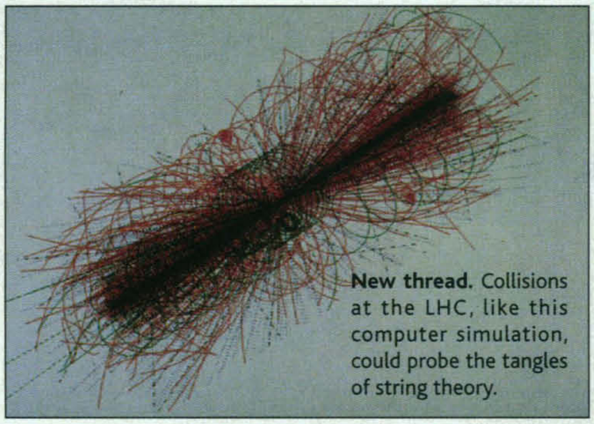
Practical Tests for an 'Untestable' Theory of Everything?

At the end of a formal dinner recently, physicist Joe Lykken leaned across the table to relay an odd bit of gossip. "There could be extra dimensions, and they might be this big!" he confided, holding his thumb and forefinger about a nickel-width apart. It was unusual behavior for a string theorist. Not because "extra dimensions" sounds outlandish—string theorists are used to dealing with multiple dimensions. But they are definitely not in the business of predicting things that can be easily tested by experiment. "When I wrote [a paper on this] I really hesitated because it's easy if you're a little loose for people to think that you're a crackpot," says Lykken, who works at Fermi National Accelerator Laboratory in Batavia, Illinois, "but the idea is on solid ground."

If it's right, then physicists may soon have their first experimental evidence that string theory—a grand "theory of everything" that attempts to tie all the known forces together in a single framework—is more than just mathematics. String theory postulates a total of 10 dimensions, seven of which are assumed to be "compactified," that is, curled up on scales of just 10^{-33} centimeters—so small as to be out of reach of any conceivable experiment. But now Lykken and several other groups are considering the possibility that a few of those dimensions could unravel a bit, opening up onto scales that precision measurements in accelerators or even on a benchtop might actually probe. The work has drawn considerable interest at physics conferences over the last month.* "Taking them seriously as [large] dimensions that can affect things is a new thing basically this year," says University of Michigan, Ann Arbor, theorist Gordon Kane. "It's really profound. It's hard to say it strongly enough."

Kane, Lykken, and others caution that the idea is so new, and indeed, so unusual, that it may have fatal flaws no one has thought of yet. Still, "I think it's very exciting," says Brian Greene, a theorist at Columbia University. It could mean that "at some accelerator in the next decade you'll see all kinds of new particles." He adds: "In my gut I think it's likely to be wrong." But if it's correct, "it would rock the foundation of physics."

And the foundation does need shaking up. Modern physics rests on two enormously successful but disconnected theories—quantum mechanics, which describes the behavior of subatomic particles, and Einstein's theory of gravity. So far no one has figured out how to tie the two together, except possibly with string theory. In this picture, matter's fundamental bits are strings that live in 10 spatial dimensions. Compactify seven of those dimensions, and those strings look like particles. As on a violin, the strings can vibrate, and crudely speaking the "notes" correspond to different everyday particles such as electrons or quarks, along with exotic particles that exist only in all 10 dimensions, such as the postulated graviton, which conveys the force of gravity.



New thread. Collisions at the LHC, like this computer simulation, could probe the tangles of string theory.

CERN

As part of this unification, string theory folds the four forces—gravity, electromagnetism, and the strong and weak forces at work inside the nucleus—into one. Proponents say that experiments have already revealed clues to this unification of forces. At high energies in accelerators, electromagnetism and the weak force turn out to be different manifestations of a single electroweak force. Other accelerator experiments have shown that the strengths of the strong and electroweak force start to converge when they are probed at increasingly high energies. When extrapolated with theoretical models, the strong and electroweak forces seem to merge at very high energy, called the GUT (grand unified theory) scale. Unfortunately, that energy is about a trillion times higher than will be reached even at the Large Hadron Collider (LHC), a massive accelerator now being built at CERN in Switzerland.

But the GUT scale, although too high for experimenters, was too low for string theorists: The theory predicted—apparently with very little wiggle room—that unification of all the forces, including gravity, would occur at an energy 20 times higher still. This puzzle spawned some of the recent work with extra, "large" dimensions. In 1996, Edward Witten at the Institute for Advanced Study in Princeton, New Jersey, and Petr Horava, now at the California Institute of Technology (Caltech) in Pasadena, offered a way to close the gap between the string scale—the scale at which gravity should get strong enough to meet up with the other forces—and the GUT scale. The pair showed that if one of the compactified dimensions was allowed to grow a bit, the string scale slid conveniently down to the GUT scale.

Nothing dictated that the dimensions had to be any particular size, so Lykken thought, "Why stop there?" He then wrote a paper looking at toy models where the extra dimensions were even bigger, and the string scale fell 12 orders of magnitude, to a point just above the energies that had been probed by accelerators.

Lykken's paper raised a lot of eyebrows in March 1996, but neither he nor others took it too seriously. "We were taught from birth" that gravity wouldn't get strong enough to unify with other forces until very high energies, Greene recalls. And most theorists assumed that the "large" dimensions needed for low-energy unification would have already shown up in dozens of experiments. But recent work has demonstrated one way for the extra dimensions to have avoided detection. The trick is that only gravity experiences the extra dimensions, while the other forces and particles are confined to the three dimensions of the world we know.

Earlier this year, Stanford University physicists Nima Arkani-Hamed and Savas Dimopoulos, with Gia Dvali of the International Center for Theoretical Physics in Italy, showed

* International Conference on High Energy Physics, 23–29 July in Vancouver, Canada, and SUSY '98, 11–17 July in Oxford, England.

that if gravity lived in more than three dimensions, it could be very strong at short distances but would peter out into its normal, weak self at distances greater than the size of those extra dimensions. And, Arkani-Hamed points out, "gravity has only been accurately measured down to a millimeter or so." Researchers are now planning at least two tabletop experiments to see whether gravity's strength grows at smaller distances, down to a micrometer.

If the theory is correct, "it would rock the foundation of physics."
—Brian Greene

Reaction to this theory is mixed: "It's a long shot," says John Schwarz, a string theorist at Caltech. He and others suspect that an extra, "large" dimension for gravity might be inconsistent with various astrophysical measurements. The supernova explosion of 1987, for instance, should have produced gravitons that would have carried energy into the extra, "large" dimensions and cooled the star quickly. But neutrinos from the explosion came in at approximately the expected numbers and over the right time period for a star cooling in three dimensions.

Arkani-Hamed and colleagues say their theory survives this challenge if there are more than two of these "large" dimensions, or if there are two that are smaller than about 10 micrometers. The theory has survived other assaults as well. "At first I thought 'This is crap, I'm going to rule it out,' " says Stanford University physicist Scott Thomas, "but it turns out it's completely consistent with experimental data." Tom Banks, a theorist at Rutgers University in New Brunswick, New Jersey, however, says that the theory still needs to be checked against certain precision measurements made at accelerators.

A third group is also independently exploring the consequences of an additional "large" dimension, this time in a string theory picture where all particles and forces can experience it. Keith Dienes, Emilian Dudas, and Tony Gherghetta at CERN have found that allowing the electromagnetic, weak, and strong forces to leak into an extra dimension on a scale of 10^{-19} centimeters makes the three unify at a very low energy. The extra dimension is small enough that it might have escaped notice thus far. "Everyone thought [the extra dimension] would destroy the unification" and the theory, Dienes says, but add it "and bingo, the [three forces] unify almost immediately."

Combined with the work by Arkani-Hamed and colleagues, showing how gravity can be made to get strong at low energies, that opens the tantalizing possibility that unification, and hence a theory of everything, might be revealed at energies that would be probed by the LHC, Dienes says. If that's true, he adds, the LHC will show that the strength of the forces are hurrying to meet at an energy far lower than anyone had expected.

A negative verdict on this and other schemes to add new dimensions to the real world might come earlier. "It could be that next week someone will come up with a very simple argument why none of this can be true," Dienes says. "But we've been at this since the end of March, and nobody has knocked us out." Others point out that the theory might work on paper but still not be the one that runs the universe. Still, comments Juan Maldacena, a theorist at Harvard University, "in this field, any idea that is not obviously false is interesting."

–DAVID KESTENBAUM

SCIENCE APPOINTMENTS

Physicist Named Japan's Education Minister

For the first time in recent memory, Japan has a Minister of Education, Science, Sports, and Culture with hands-on experience as a researcher and educator. On 30 July, physicist Akito Arima, former president of the University of Tokyo, took the post as head of the Ministry of Education (Monbusho) in the Cabinet formed by the new prime minister, Keizo Obuchi. Monbusho oversees all the national universities as well as several dozen national research institutes.

EIJI MIYAZAWA/BLACK STAR

In the hot seat. Akito Arima will head Monbusho at a difficult time.

Arima, 67, had been president of the Institute of Physical and Chemical Research (RIKEN), outside Tokyo, since retiring from the University of Tokyo in 1993. He resigned from RIKEN earlier this year and on 12 July was elected to the upper house of Japan's Diet.

The science community is elated to have a friend in such a high place. "When he was president of the University of Tokyo, he put extraordinary effort into improving the research environment," says Yoji Totsuka, director of the university's Institute for Cosmic Ray Research. "We're hoping he can do even more in a higher position." Hirotaka Sugawara, director-general of the High-Energy Accelerator Research Organization (KEK) in Tsukuba, seconds the approval. Arima, whose specialty was nuclear physics, can be counted on "to emphasize that basic research is also important" at a time when pressure is increasing for research to be economically strategic, says Sugawara.

Arima, however, will have much more on his mind than research. The $60 billion ministry has responsibilities ranging from developing kindergarten curricula to training Olympic athletes to preserving Buddhist statues. The ministry is also at the center of a number of political storms, such as a long-running and bitter controversy over how World War II is covered in secondary school textbooks. It is also set to be merged with the Science and Technology Agency as part of an effort to make the bureaucracy leaner and more cost-efficient.

Arima could not be reached for comment. But at a joint news conference with other Cabinet members, he said he recognizes the importance of all aspects of the ministry's agenda. He puts education at the top of his list, beginning with reforms to primary and secondary school that were outlined earlier this year by a committee he chaired. "This is an extremely important issue for the public," he said.

There are, however, questions as to just how much Arima will be able to accomplish, particularly as his tenure may be limited. Pundits are predicting that the political weakness of Obuchi and his Liberal Democratic Party, which lost seats in the most recent election, will mean the new Cabinet may only hold power for a year or