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Physicists Finally Find a Way to Test Superstring Theory

By GEORGE JOHNSON

For a quarter of a century, superstring theory has promised that the universe could be understood more deeply than ever before, with all the forces unified into one, if it were seen in a startling new light -- as a kind of mathematical music played by an orchestra of tiny vibrating strings. Each note in this cosmic symphony would represent one of the many different kinds of particles that make up matter and energy.

Keith Meyers/The New York Times

Dr. Lisa Randall speaking to Dr. Raman Sundrum, superstring theorists who portray the universe as one of many bubbles floating inside a four-dimensional megaverse.

But despite heroic efforts to keep this strange vision alive, with one mathematical embellishment after another, a seemingly fatal credibility problem has remained: no one has been able to figure out how to test the idea with experiments.

To give the strings enough wiggle room to carry out their virtuoso performance, theorists have had to supplement the familiar three dimensions of space with six more -- curled up so tiny that they would be explorable only with absurdly high-powered particle accelerators the size of an entire galaxy. It's a fact of life on the subatomic realm that smaller and smaller distances take higher and higher energies to probe.

In the last few months, however, new ideas emerging from the theoretical workshops offer some hope of connecting the airy speculations to reality. Physicists are proposing a revised view in which at least one of the extra dimensions is vastly larger -- large enough perhaps to be indirectly detected with existing accelerators.

"This is a field day for the experimenters," said Dr. Joseph Lykken, a theoretical physicist at Fermi National Accelerator Laboratory in Batavia, Ill. "Now there are all these things they can look for." In fact, he ventured, it is conceivable that experimenters have already found subtle hints of other dimensions. They just have had no way of appreciating what they were seeing.

Though human brains are not wired to picture a world beyond the familiar three dimensions of space, one can begin to overcome this myopia by pretending to be antlike creatures in a two-dimensional fantasy world like the one in Edwin A. Abbott's story "Flatland." Confined to the surface of a plane, the Flatlanders can move left and right or forward or backward, but the idea of up and down is inconceivable to them.

Now suppose this two-dimensional world were rolled into a long tube. The Flatlanders could still move in only two directions -- along or around the outside surface of their soda straw universe. But if the diameter of the straw were made extremely tiny, this second, curled-up dimension would essentially disappear.

It has long been assumed that if, as required by superstring theory, our own world is accompanied by additional dimensions, they too would have to be extremely tiny, curled up smaller than what physicists call the Planck length, which is a hundred million trillion times smaller than the width of a proton.

To every point in space would be attached a vanishingly tiny six-dimensional ball.

But the price for curling up the extra dimensions and tucking them out of sight has been rendering superstring theory untestable. The subatomic realm is explored by smashing together particles with powerful accelerators and then studying the debris.

Peeking below the Planck scale would require collisons of unimaginable energies.

"For the first 25 years, the thinking has been that superstring theory is so difficult to see experimentally that you have to figure it out by its own mathematical consistency and beauty," Dr. Lykken said. "Now that's completely changed. If this new picture is true, it makes everything we've been talking about testable."

Steve Kagan for The New York Times

Dr. Joseph Lykken, a theoretical physicist at Fermi National Accelerator Laboratory in Batavia, Ill., and the lab's Mobius Strip sculpture.

But the result is a picture of reality that is no less weird than before. Imagine again the two-dimensional realm of Flatland.

Suppose now that it is surrounded by an infinitely large, three-dimensional "hyperspace." And maybe there are also other Flatlands floating around inside the third dimension -- parallel universes separated by what to these two-dimensional denizens would be an uncrossable void.

Take this vision and move up an extra dimension and you arrive at the theory that is currently causing all the intellectual commotion.

Dr. Lisa Randall of Princeton University and Dr. Raman Sundrum of Stanford University suggest that what we think of as The Universe may be just one of many islands -- three-dimensional versions of Flatland -- floating inside a surrounding megaverse with four spatial dimensions.

Each ruled by different laws of physics, the various island universes would be inaccessible to one another. But the tantalizing prospect exists that each would be able to barely sense the other's presence through the weak tug of its gravitational pull.

The idea may be easy to dismiss as absurd. But in return for a suspension of disbelief, the new theories suggest answers to some of the biggest riddles of physics. Cosmologists have inferred that as much as 90 percent of the universe must be made from invisible matter that emits or absorbs no light, that is evident only through its gravity.

But what is the source of this mysterious dark matter? Maybe it is just ordinary matter trapped on another island universe, with its gravity but not its light able to cross the fourth-dimensional divide.

Most significant of all, the new theory could be a step toward the goal of embracing all of physics with one grand picture -- a vision that unites the reigning theory of gravity, Einstein's general relativity, with the Standard Model, which describes electromagnetism and the strong and weak nuclear forces. Theorists have discovered that it is possible to bring about this merger -- on paper, anyway -- if each kind of particle making up the universe is described as a different note produced by tiny superstrings vibrating in nine-dimensional space. This picture includes matter-making particles like the proton and neutron (components of the cores of atoms) and force-carrying particles like the photon (the conveyor of light) and the graviton (the conveyor of gravity).

As the unification quest has forged ahead, physicists have found it necessary to expand superstring theory to include vibrating membranes -- called branes for short. These are not just two-dimensional surfaces, like the skin of a drum or the world of the Flatlanders. Hard as it may be to picture, there can be branes with three, four, five or more dimensions. These "surfaces" can be tiny like the strings but they can also span across light-years.

The Joy of Gravitons, Hyperspace, Branes and Brainstorms

What this additional filigree offers is a novel way to hide extra dimensions without making them extremely small. Suppose that our entire universe is a three-dimensional brane (think of it as a bubble) floating inside the four-dimensional megaverse. The reason we cannot explore the surroundings of hyperspace or even sense its existence is that the strings that make up everything in our own world are stuck solidly to the surface of the gargantuan home brane, like ants on a sheet of paper confined to move in only a limited number of directions. We cannot peer into the extra dimension because photons, the carriers of light, are also anchored solidly to our home brane.

Several people had toyed with this idea, but they kept running into an obstacle: there did not appear to be any way to get gravitons to stick to the brane. That would create a big problem: It can be shown mathematically that if gravity were allowed to roam throughout all four dimensions, it would be much stronger than the gravity experienced in this three-dimensional realm.

"This would clash with everything we've observed, from the motion of the planets to that of climbers falling off cliffs," said Dr. Steve Giddings, a theorist at the University of California at Santa Barbara. Dr. Randall and Dr. Sundrum's theoretical coup was to show that if the hyperspace was curved in just the right manner, the gravitons could be kept from escaping and becoming unreasonably strong.

With that hole plugged, the possibility arises that there are other brane worlds floating out there too, neighboring islands separated by this higher dimensional void. And that suggests how dark matter could simply be regular matter waving to us from another brane. While its photons could move only along the surface of the foreign brane, the gravitons would not be so tightly confined. They could seep across the fourth-dimensional divide. Thus we could dimly feel the matter's gravity without being able to see its light.

The theory also suggests why dark matter tends to be found in the halos around galaxies. Because of gravitational attraction, large masses on the other brane would tend to line up with large masses on our home brane. Sitting behind a galaxy in this universe, separated by the void of hyperspace, would be a dark galaxy in the other brane world. Because most of it would be occluded, its gravity would be apparent only around the edges.

Conversely, luminous matter on this brane would be dark to observers in the other universe. "We'd look mutually dark to each other," Dr. Sundrum said. "We could only talk through the gravitational force." That would require signaling

In addition to the incredulity of their colleagues, Dr. Lisa Randall of Princeton University and Dr. Raman Sundrum of Stanford University faced a big theoretical challenge in making their theory of space-time work.

They were proposing that this universe is just one of many three-dimensional bubbles (called branes) floating inside a four-dimensional hyperspace. But to explain why things from this world do not disappear into the fourth dimension, they had to be sure that all the particles in this universe were stuck solidly to the brane.

According to string theory, most particles are made from strings that are open-ended, like scraps of thread.

It was easy for theorists to anchor the two ends of these strings to the brane, keeping them from escaping and effectively sealing off the extra dimension. But gravitons, the particles that carry gravity, are thought to be generated by little vibrating loops. With no ends to stick to the surface of the brane world, they would be free to wander off into hyperspace.

This would create all kinds of problems. Gravity in the familiar three-dimensional universe obeys what is called the inverse square law. If the distance between two objects is cut in half, the strength of the attraction between them becomes four times as strong. But gravity in a four-dimensional universe would obey an inverse cube law. Halve the distance and the attraction becomes eight times as strong.

Since humans do not observe gravity this intense, some way had to be found to explain why the gravitons do not generally leave the vicinity of the brane.

Here was the theorists' answer: according to Einstein's general theory of relativity, gravity is simply warped space-time -- bends in the brane on which this universe resides. Popping up an extra dimension, suppose that the hyperspace surrounding the brane is also warped, giving rise to a more powerful kind of "metagravity."

The theorists proved that if the hyperspace curves in just the right manner, so it is shaped like a funnel (see diagram), it would somehow with gravity waves.

Unlike many of physics' far-out theories, the idea of a large extra dimension may be possible to test indirectly. Since gravitons are not so tightly confined as the other particles, sometimes they will stray into the surrounding hyperspace, becoming heavier than the ordinary variety. According to the theorists' calculations, it just may be possible to create momentarily these denizens of the fourth dimension using the Tevatron accelerator at Fermilab, where protons are slammed into antiprotons to produce energies measured in trillions of electron-volts.

Physicists would not be able to detect heavy gravitons directly -- they would immediately fly off into the higher dimension -- but their existence might be inferred. Energy going into a particle collision must equal the energy coming out. If some is missing and all other possibilities are accounted for, physicists could surmise that the energy was spirited away by the heavy gravitons, carried off into hyperspace.

In fact, it might be possible to concentrate so many heavy gravitons into a tiny volume of space that they would collapse in on themselves and create miniature black holes, those cosmic sinkholes from which nothing can escape. Experiments like this will be on the agenda when the Large Hadron Collider begins operation in five or six years at the CERN accelerator center in Geneva.

"These black holes should be quite safe," Dr. Giddings said, for they would rapidly evaporate.

The intellectual fun may be only beginning. Combining the Randall and Sundrum theory with a conjecture made a couple of years ago by a young Argentinian physicist, Dr. Juan Maldacena, yields the latest big idea: the physics governing the particles stuck to this brane might be a kind of shadow of a more fundamental physics prevailing in the surrounding megaverse.

In laser holography, a three-dimensional image is encoded onto a two-dimensional surface. Viewed at the proper angle, the third dimension seems magically to pop out. So think of each separate brane world as a hologram carrying a flattened version of the Truly Universal Laws. Each would capture the view from a slightly different perspective, resulting in different universes ruled by different laws of physics.

What denizens of this universe call the Standard Model would not be standard at all, but more like a book of local traffic laws. Viewed from the fourth dimension, however, universality would prevail. If they were clever enough, scientists on each brane world could deduce the same overarching law of gravity, the lingua franca of the megaverse.

a funnel (see diagram), it would encourage a kind of feedback effect: gravitons (carriers of the familiar, low-strength gravity) would be channeled back toward the brane, prevented from easily wandering off into the extra dimension.

"Gravity would be sucked back toward the brane by the brane's own gravitational force," Dr. Sundrum explained. That would keep it from becoming absurdly strong.

Taking the idea further, Dr. Joseph Lykken of Fermilab, Dr. Randall and Dr. Sundrum realized that such a possibility might explain what physicists call the hierarchy problem -- why gravity is so much weaker than the other forces, like electromagnetism. A magnet can pick up a paper clip even though the full force of the earth's gravity is pulling back on the other end.

Maybe, the scientists surmised, gravity only seems weak because the gravitons that produce it are concentrated in another part of hyperspace, on a different brane from our own. The region of hyperspace surrounding this "mother brane" would be warped so severely that it would suck in most of the available gravitons, keeping them to itself. If gravitons are very likely to appear in one place, they are less likely to appear in other places, an implication of a rule in quantum mechanics sometimes called "conservation of probability."

"By contrast, our brane would be a lonely backwater where gravity's effects are very diluted," Dr. Lykken explained. "Only a few stray gravitons end up on our brane, just enough to explain the very weak gravitational forces that we see."

-- George Johnson

As they await the data that will provide a reality check, the physicists on this brane are enjoying their new intellectual toy.

"We can look at any question we were previously mystified by and get a new handle on it," Dr. Lykken said. "That doesn't mean this is right, but it makes theorists very happy."
