A line on string theory

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A major problem with string theory is that it has never been confirmed experimentally, which is where Donner Professor of Science Cumrun Vafa and the Large Hadron Collider (LHC) come in. Photo: Stephanie Mitchell/Harvard Staff Photographer

(PhysOrg.com) -- A Harvard theoretical physicist has discussed with scientists at the Large Hadron Collider in Switzerland the possibility that they may discover a theorized "stau" particle, with a lifetime of a minute or so, that could provide the first experimental confirmation of string theory.

String theory, developed in the late 1960s and early ’70s, is a theoretical physicists’ multitool, explaining in one model all four of the universe’s main forces: gravity, electromagnetism, and the two that operate inside atomic nuclei, the strong force and the weak force.

Without string theory, physicists need two theories to explain how the universe works. General relativity explains gravity, while the other three basic forces are explained by the “standard model.” Moreover, gravity has been very difficult to reconcile with quantum theory, a problem for which string theory offers a solution.

A major problem with string theory, however, is that it has never been confirmed experimentally, which is where Donner Professor of Science Cumrun Vafa and the Large Hadron Collider (LHC) come in.

Several years of work with graduate student Jonathan Heckman, who graduated in June, and other colleagues, has led Vafa to suggest that a particle whose properties are predicted by string theory may be detectable at the energy levels produced by the LHC.

The LHC is the world’s largest particle collider, located in a 16.8-mile-long underground ring that runs from Switzerland under the border into France and back. Once it is fully operational, it should be able to smash beams of protons into each other with an energy of 14 trillion electron volts, seven times more powerful than the current highest-power collider, the Tevatron at the Fermi National Accelerator Laboratory in Illinois.

After glitches and equipment failures marred the LHC’s start last year, operators are trying again this month. In late October, scientists at CERN, the European Organization for Nuclear Research, were celebrating the first particles to enter sectors of the accelerator since it was shut down.

Operators expect a gradual ramp-up of activity, first circling beams, then creating low-power collisions, and slowly increasing the collisions’ energy. Vafa isn’t the only Harvard faculty member eagerly anticipating the LHC start-up. Harvard experimental physicists have lent a hand to build ATLAS, one of the two main detectors there. Other theoretical physicists, including Lisa Randall, the Frank Baird Jr. Professor of Science, and Howard Georgi, the Mallinckrodt Professor of Physics, also await the light that the LHC will shed on their work.

Most physicists expect the LHC will discover the elusive particle known as “Higgs,” which is the origin of mass for all known particles. One major remaining question is what else the LHC might discover.

Vafa traveled to CERN in late October to discuss with teams of scientists at the two main detectors on what else they might see. If the assumptions that he and Heckman make in the context of string theory are valid, Vafa said, the two lightest of the new particles are the gravitino and the stau. The

gravitino, however, is so weakly interactive that it is hard to produce directly, Vafa said. A stau particle, however, is easier to produce and should be semi-stable, lasting as long as a minute. And it should leave a signature track — unexplainable by any of the already-observed particles — as it streaks across the LHC's detectors.
"It would be the smoking gun for our stringy models," Vafa said.

While Vafa and Heckman's work predicts there is a good likelihood of generating a stau particle, there is also a less likely possibility that a semi-stable neutral particle will be generated. If the particle proves neutral, it won't manifest itself in a way that the LHC's detectors would see. It could still be found, but indirectly. If the particle is created and escapes the accelerator, it would manifest as missing energy and could be located as scientists tally their experimental results.

Vafa and Heckman came up with their stau conclusion by winnowing the many possibilities in string theory. One difficulty of the theory, Vafa said, is its flexibility. String theory has hundreds of variables, which he described as "dials" that physicists can turn up and down to generate innumerable possible universes.

While that is interesting to theoreticians, Vafa said, it can also muddy the theoretical search for one universe: ours.

Vafa and Heckman devised two constraints that greatly narrowed the possible string universes. First, they assumed that gravity does not have to play a role in the unification of the other three forces. And second, they assumed that one property of string theory, called supersymmetry, is present at the energy levels generated by the LHC.

If string theory is correct, our universe is made up not of particles, as has been generally taught, but of tiny vibrating strings. The different vibrations manifest themselves as the familiar particles and forces that students learn about in physics class.

In addition to string theory's ability to encompass gravity and the other forces in one framework, it can also fill a second important theoretical gap in understanding the universe, by explaining all the missing matter.

The known constellation of particles under conventional theories — electrons, quarks, neutrinos, and the like — can only account for about a sixth of the matter in the universe. The rest of it is made up of theorized "dark matter," whose form remains unknown.

Dark matter is explained in string theory by the concept of supersymmetry. Supersymmetry, which was first discovered in the context of string theory, holds that for each known particle there is a corresponding particle of different spin. At the time of the big bang, the theory says, the paired particles had similar properties such as mass and charge, but as the universe cooled off, the symmetry got broken. Now, according to the theory, in our broken-symmetry universe, the supersymmetric particles have much higher masses than their known partners. This higher mass also would explain why scientists haven't seen them yet, since particle colliders must generate more energy than they have been able to do to create them. In the stringy models of Vafa and Heckman, the gravitino, which is predicted to be about 100 times more massive than the electron, comprises the bulk of the dark matter.

With the start-up of the LHC, Vafa said, science may be on the threshold of energies needed to create new supersymmetric particles, and of gaining a new understanding of the universe.

"I think it's probably the most exciting experiment we'll see in our lifetimes," Vafa said of the LHC. "We'll be excited by whatever they find — whether or not they confirm our predictions — because it's the truth of nature, and it will teach us about the fundamental ways nature works."

More information: lhc.web.cern.ch/lhc/

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