PHYSICS

How Black Holes May Get String Theory Out of a Bind

Beautiful as it is, string theory has come to seem aloof from reality. The problem: It predicts too many universes.

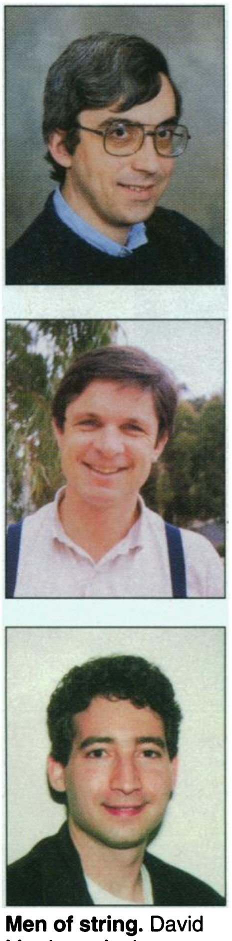
Many theoretical physicists have touted this elegant mathematical construct as the best candidate for a "theory of everything" that could embrace all the forces of nature, from those that work on the scale of atoms to the force of gravity. The theory describes all elementary particles as vibrational modes of infinitesimal strings. But there's a catch: Those strings naturally exist in 10 dimensions.

In our four-dimensional universe, string theorists say, six of those dimensions would be "compactified"—curled up so tightly in six-dimensional structures that they would be effectively invisible. Unfortunately, the 10-dimensional equations have tens of thousands of six-dimensional solutions, giving at least that many four-dimensional universes to try and match up with the real one. This plethora of solutions has not only made the theory untestable, but driven some students—hoping to work closer to reality—out of the field.

But physicists returning from a week-long meeting earlier this month at the International Center for Theoretical Physics in Trieste, Italy, say that a spurt of new work may offer a way out of the quandary. At the meeting, Andrew Strominger of the University of California, Santa Barbara, Brian Greene of Cornell University, and David Morrison of Duke University reported that when string theory takes into account the quantum effects of tiny, charged black holes packing no more mass than an elementary particle, those thousands of four-dimensional solutions may dwindle to only one. Moreover, Strominger says, the equations imply that strings and these simplest, smallest black holes—the stable endpoint to which theorists believe large astronomical black holes eventually decay—"are really two descriptions of the same thing."

"This is extremely satisfying," Strominger adds, explaining that because black holes are fundamental solutions of general relativity, Einstein's theory of gravity, string theory should embrace them naturally—but it didn't. "It was kind of irritating that you're not done classifying the elementary objects after you've understood all the ways a string can rotate and vibrate, because then you had to add on top of that these elementary black holes."

By limiting the number of solutions to the equations of string theory, the new research also raises hopes of someday relating the theory to the real universe. And that, says Edward Witten of Princeton's Institute for Advanced Study, the reigning guru of string theory, makes Strominger, Morrison, and Greene's work "one of the highlights" of the field in recent years. Or as another theorist put it, not entirely in jest: "You could almost imagine graduate students going into the field again."



Men of string. David Morrison, Andrew Strominger, and Brian Greene *(top to bottom).*

The researchers didn't begin by looking for a way out of string theory's many-universe dilemma. Instead, Strominger set out to address a different problem in string theory. Under certain conditions, when the forces between particles reach a critical strength, he explains, "the equations become infinite and refuse to give you an answer."

Strominger's solution to these singularities, as they are known, builds on a series of recent results. Last year, for instance, Chris Hull of Queen Mary's College in London and Paul Townsend of Cambridge University suggested that the minuscule black holes then missing from the equations of string theory might actually play a crucial role in it. Then Nathan Seiberg of Rutgers University, along with Witten, showed that certain singularities in a less ambitious theory known as supersymmetry—an attempt to unify all the forces of nature except gravity—vanish if the theory includes a theoretical particle that becomes massless exactly when the equations become inconsistent.

Strominger wondered whether the mini black holes might play the same role in string theory. Last February, he included them in the equations and found that the black holes became massless at the precise moment when the equations unraveled in the singularities. The result was that the singularities then vanished and the equations became consistent again. "Another way of saying it," says Strominger, "is that the singularities were there because we were ignoring the quantum effects of the elementary black hole states."

What's more, he says, the fact that the black holes became massless seemed to indicate that some kind of phase transition might be occurring—a dramatic change in the properties of string theory akin to the transition from liquid water to ice. In the simple situation Strominger was working on, "the phase transition gets on the edge of happening but doesn't really fly." The question was what would happen to the theory if it did take off.

Strominger soon found out. He wrote up his work in late April in a paper entitled "Massless Black Holes and Conifolds in String Theory" and sent it via Internet to http://xxx.lanl.gov/, the electronic archives at Los Alamos National Laboratory where physicists post preprints. At Cornell the next morning Greene and Morrison, who was visiting at the time, read Strominger's preprint. They spent the next few hours discussing the work with him by e-mail, and the three theorists quickly realized, says Greene, that a simple generalization of Strominger's result "would lead to some dramatic new physical consequences." Within a few days the three had worked out the implications.

In string theory as it was known until this flurry of e-mails, the six extra dimensions of the 10-dimensional theory curl up into structures known as Calabi-Yau spaces, which are the ones that regrettably seem to come in tens of thousands of possible configurations. Now Greene, Morrison, and Strominger have shown that during the phase transition, the Calabi-Yau spaces would evolve into one another, and at the same time black holes would become strings and vice versa. These transformations not only imply that black holes and strings are two different descriptions of the same fundamental object, but also that there may not be tens of thousands of four-dimensional solutions to the equations after all.

"Prior to this work," explains Greene, "we would have had no way of even comparing different Calabi-Yau compactifications. They were like isolated island universes. ... Now we have that possibility. Since they're all connected to one another, we can hope eventually to follow the evolution of the universe [mathematically] and watch it select one particular Calabi-Yau."

That, says Strominger, will be a "small step—one of very, very many still required" toward a testable theory of everything. He adds that once such a theory is in hand, "it will then be a question of whether the theory predicts the right everything."

–**Gary Taubes**