Science & Technology

The String is the Thing

Brian Greene unravels the fabric of the universe.

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One doesn't expect to see a theoretical physicist on the *Late Show with David Letterman*. But there sat Brian Greene, Columbia professor of mathematics and of physics, last March. His hair was graying around the temples, which accentuated a passing resemblance to Richard Gere, and he was at ease in front of the audience and the studio’s bright lights; his gestures were theatrical but precise. He was promoting his second book, *The Fabric of the Cosmos: Space,Time, and the Texture of Reality*. He was sincere when explaining his work in string theory, an ambitious attempt to unite the clashing domains of gravity and quantum physics. Letterman listened intently, and then asked,“So, how is my life better for this?” Greene responded earnestly that the theory has the potential to peer back before the Big Bang and explain how the universe began.“I think that would really alert us to our own place in the cosmos in a deep way.” “Does your head ache all the time?” Letterman asked.The scientist giggled. Greene was on television that night not merely to serve as Letterman’s foil, but to communicate his passion. He has gone to great lengths to make modern physics accessible to ordinary people and to help them understand how it alters our conventional notions of reality.When he talks about his chosen field, he sounds spiritual.“Science is a full-body experience,” Greene, 42, says.“It makes the heart beat fast when a result is working well. I’ve long since felt the public has a misconception about science: that it’s something that only makes use of the mind. But it really touches the soul when you reveal deep truths about the universe.” Television is one method Greene has used to spread those deep truths. His appearance on the *Late Show* was actually his second. His first was in fall 2003 when the PBS program *NOVA* aired *The Elegant Universe*, a documentary based on his first book of the same name.“He’s a wonderful writer, a wonderful talker," says Paula Apsell, *NOVA's* senior executive producer."When he's explaining something to you, it feels really clear." The show won a Peabody Award for broadcast excellence.

It doesn't hurt that string theory seems tailor made to capture the public imagination. The fundamental picture the theory presents is deceptively simple. If you could put a subatomic particle under an ultra-powerful microscope and magnify it billions and billions of times, you would find that it is actually a two-dimensional vibrating filament, or string. "A violin string is not a bad picture to have in mind," Greene says. Strings can vibrate in different ways, and each kind of vibration — every note, if you will — corresponds to a different particle.The theory presupposes that the infinitesimally small strings wriggle in and out of dimensions of space that we can't see. Proponents say string theory could give physicists a single fundamental description of the universe from its inception.

Greene first spoke on string theory to the public in 1996 at a conference in Aspen, Colorado. Encouraged by his audience's desire to learn more but unable to refer them to a popular book on the subject, he began work on his own. Three years later *The Elegant Universe* was complete."I was very impressed by it," says Greene's colleague and friend, David Morrison of Duke University. "It was really quite remarkable in its ability to convey rather abstract physical concepts to lay audiences." Those lay audiences apparently agreed. "The first weekend *The Elegant Universe* was in stores, it completely sold out," Greene recalls. "And it went to number one on Amazon for three days." The book became a national best seller, selling more than one million copies, and was a finalist for the Pulitzer Prize. Prospective physics majors at Oxford regularly rank *The Elegant Universe* second to Stephen Hawking's *A Brief History of Time* as the book that most influenced them, says Graham Ross, a theoretical physicist at Oxford, who advised Greene as a Rhodes Scholar. Leonard Susskind of Stanford University, one of the originators of string theory, says Greene "has a marvelous ability to use metaphor and analogy to illustrate difficult physical ideas." Greene went on tour and did a circuit of late-night shows — *Nightline*, *The Charlie Rose Show*, and *Late Night with Conan O'Brien*. "It became hard to get him on the phone," says Morrison. Greene downplays his celebrity."I really view physics as the celebrity that people have newly discovered," he says. "I take pleasure in helping people understand the world around them a little bit more deeply.The greatest gratification I have is when a six-, seven-, or eight-year-old writes to me, and they've seen the program, and they're so excited, and they want to maybe go into science and physics."

Untangling the Universe

String theory weds general relativity, Einstein's theory of gravity, with quantum physics. Einstein's theory describes the universe's shape as a whole. It says the universe is made of a smooth and continuous fabric-like entity called "spacetime." In The Fabric of the Cosmos, Greene describes spacetime as a loaf of bread; its length represents time's passing and its height and width represent space's extent. In effect, observers moving at different speeds "slice" the same loaf of bread at different angles, carving out different amounts of duration and extent — and thus disagree about the passage of time and the dimensions of objects. General relativity says that the loaf is rubbery. Massive objects such as the sun warp and curve spacetime as a bowling ball would bend a trampoline. Less massive objects follow these warpings; thus the orbit of the planets, the bending of light by the sun, and the falling of apples. "It's as if matter and energy imprint a network of chutes and valleys along which objects are guided by the invisible hand of the spacetime fabric," Greene writes in Fabric. But Einstein's theory breaks down when matter is packed together cheek by jowl and gravity becomes extremely strong, such as inside black holes or before the Big Bang, which kicked off our universe.

Quantum physics, on the other hand, describes particles of matter. *In The Elegant Universe*, Greene illustrates the theory by imagining two space travelers who stop at a mysterious bar for drinks. When the drinks arrive, they observe to their astonishment that the ice cubes in the glasses are rattling around of their own accord, like energetic bumper cars. In the smaller of the two glasses, the ice rattles faster, and one of the ice cubes bizarrely teleports through the side of the glass and falls to the floor. The story is designed to demonstrate Werner Heisenberg's "uncertainty principle," which dictates that small particles have no definite position in space, and the smaller the region confining them, the more indefinite their position. But mathematically and conceptually, quantum physics butts heads with general relativity.When physicists try to apply the uncertainty principle to general relativity, spacetime becomes infinitely jittery, which makes no sense.

String theory, if proved right, brings quantum physics and general relativity together. Strings inherently obey quantum physics.Their vibrations, the ones that give rise to different particles, are like the rattlings of the ice cubes in the quantum bar. These vibrations can accommodate a huge number of particles, including all the known particles and the graviton, a hypothetical particle that transmits the tug of gravity. So all of the forces are present, all come from the same stuff, and all obey the laws of quantum physics.

Origins of Physicist

Greene’s upbringing offers a hint of his trajectory. He grew up in Manhattan, and his family was enterprising and creative if not academic. His mother managed a veterinarian’s office and his father was a composer and had a minor hit in the 1960s with “Turn Around,” recorded by Harry Belafonte. Alan Greene never finished high school, but he had a great fondness for science and math and taught his son to multiply at a young age. By four or five Greene was solving enormous multiplication problems involving up to 30-digit numbers, written out by his father on construction paper.

When he was 12, in 1975, he had exhausted the high school mathematics curriculum, so his teacher at I.S. 44 on West 77th Street suggested he look for a math tutor at Columbia. With his 14-year-old sister along for moral support, he poked into offices in the computer science and math departments, handing uninterested researchers a note from his teacher requesting help for a precocious kid.The Greene siblings finally found a PhD candidate, Neil Bellinson, to tutor Greene in subjects such as advanced geometry and the theory of numbers, at no expense. “He didn’t have to teach me,” says Greene. “He didn’t get anything out of it beyond the joy of someone younger being initiated into this wondrous world.”

He first discovered and fell in love with physics at Stuyvesant High School in downtown Manhattan, famous for nurturing prodigies.“It became clear that the math I’d spent so much time thinking about and enjoying could actually be used to do something,” he says.“When that realization hit me, it was like a thunderbolt.” In 1980 he entered Harvard at age 17 and was drawn to Einstein’s theory of general relativity. He bought a textbook on the subject and carried it around campus.“It was beyond me, but I just wanted it near me,” he says. “I had this burning urge to learn Einstein’s theory.”

For decades physicists have been trying to unify gravity with the three other forces in the universe: electromagnetism and the strong and weak nuclear forces, which keep the nuclei of atoms together. Einstein struggled for 30 years to fuse general relativity and electromagnetism, to no avail. Gravity refuses to cooperate because the other forces all obey quantum rules. After graduating from Harvard, Greene went as a Rhodes Scholar to Oxford, where he got his first chance to work on the unification problem.

String theory, a weird idea that would combine the forces, had been floating around for about a decade. It had been plagued by mathematical inconsistencies until the year of Greene's arrival at Oxford, when two pioneers finally showed that this esoteric scheme had a shot at describing the real world. Greene and his adviser, Graham Ross, set to work."It was a grand opportunity to perhaps work on the theory that Einstein himself was looking for but never found,"Greene says."That was a temptation none of us could, or even would, think about resisting."

String theory requires space to have 9 or 10 dimensions — more than the 3 that we can easily observe.The 6 or 7 dimensions that we can't observe are "curled up" and too small to see. If that seems difficult to imagine, think of the way that a clothes-line looks one-dimensional from far enough away. If you never got close enough to the line, you might never know it had thickness. Similarly, unless you were the size of the strings in string theory, you would never be able to wiggle around in these hypothetical extra dimensions. Physicists are willing to bother with such a strange idea because their current theories leave tantalizing gaps in our understanding of the universe. String theory is one of the most mathematically daunting fields in physics, but Greene's facility with numbers helped him achieve a prominent place among its younger practitioners. He and two other students constructed a model describing how the extra dimensions of string theory might get curled up in such a way to produce known particle physics."It failed in the details, but it was the first one of its time to get close," says Ross. (All other string theory models have so far failed to match precisely the known particles, too — something critics of string theory point to.) The attempt brought Greene and his classmates recognition. "They'd sort of gone from scratch to world leaders," Ross says.

At Oxford, Greene began taking intensive acting classes. "I really enjoyed having my mind go in a very different place than it generally is when I'm doing my own work," he says. "I used to go to these three-hour acting classes and after I left, it'd be like, 'Wow, I was just in a completely different universe than I ordinarily am,' and I love that.”

Theater was common at Oxford, but his other qualities set Greene apart even from the highly talented crowd at the school, says Ross. “It was clear that Brian was unusual,” he recalls.“He was very, very smart and he had an ability to communicate. He was always a very charismatic character.”

After Oxford, Greene, then 23, returned to Harvard as a postdoctoral fellow. There he began making his biggest scientific contributions so far. As he thought about the extra dimensions of string theory, he found himself convinced of a surprising conjecture by other theorists. In general relativity, every spacetime geometry, or shape, is unique. Each one corresponds to a different network of the “chutes and valleys.” In 1990, shortly before he took a position at Cornell University, Greene helped prove that string theory’s extra dimensions could be curled up in two geometrically distinct ways but still yield the same physics.The relationship between the two distinct but equivalent shapes is called “mirror symmetry” (although the pairs of extra dimensions are not literally mirror images of each other).“Mirror symmetry remains a deep mathematical mystery,” says John Morgan, chair of Columbia’s mathematics department.The beauty of the symmetry is that it sometimes allows very difficult calculations to be recast in an easier form by switching to an equivalent version of a problem. In an example of such a switch, Greene and two colleagues, Paul Aspinwall and David Morrison, both of Duke, discovered that the extra dimensions of string theory could rip and reseal without causing catastrophic problems for the theory. Part of the extra dimensions of space can become pinched off as if it were a ball of dough or clay being pulled in different directions. It starts looking like a dumbbell and then rips in the middle. But just after it rips, a new sphere grows from the ripped spot and seals it.There is no rip in the mirror description, and the process is consistent with known physics.

Impressed, Columbia’s mathematics department lured Greene from Cornell in 1996, right before his second career as popular science expositor took off. At first he had no desire to return home to New York City. “It just didn’t strike me as a quiet enough place to sit and think,” he says. But he was dating an aspiring actress who wanted to move there. Although he and the actress split up, he has since married Tracy Day, a television producer he met doing a segment for ABC News. Their son, Alec, was born early last year. Manhattan also offers numerous opportunities for Greene to indulge his taste for what he calls “nontraditional” approaches to education. Consider “Strings and Strings,” his collaboration with the Emerson String Quartet, which was performed in 2000 as part of the Works and Process series at the Guggenheim Museum. Greene and the quartet took turns in a seamless physics-music dialogue: Greene would speak briefly about string theory, segueing into metaphorical language that the quartet would then expand upon by playing a few minutes of music designed to capture an aspect of the science. The Canadian director Robert Lepage is working with Greene to expand “Strings and Strings” into a “theatrical piece with a narrative backbone that will intertwine physics and music, with the core being the way they interface with time,” says Greene. Tentatively scheduled for Lincoln Center’s 2008 season, it will be part of a massive science-for-the-public gathering now being developed by the Science Festival Foundation — a nonprofit company founded by Greene and his wife. The festival will bring together cutting-edge scientists from around the world for a week of panel discussions, lectures, and debates at a number of universities, including Columbia, throughout the city. Cultural institutions will hold music, dance, and other types of performances, with all of the works emphasizing a scientific connection. Greene still finds time for work, too.

His interests have swung back and forth between the more mathematical side of string theory, such as the work that led him to mirror symmetry, and research more grounded in observation and known physics. He cofounded the University’s Institute for Strings, Cosmology, and Astroparticle Physics (ISCAP) in 2000, reflecting his current interests in applying string theory to the origin of the universe and finding consequences of the theory that could be observed with telescopes. Lately, he has been studying whether strings could have left an impression on the microwave radiation that fills the universe. The universe expanded rapidly in its early moments, which might have blown up the signatures of strings — like writing on a balloon as it’s being inflated — resulting in tiny temperature variations across the cosmos that might be detectable.While Greene views this possibility as a long shot, a successful outcome would provide the first experimental support for string theory. Greene draws on other ways of thinking as well.

He dabbled in Buddhism as an undergraduate. In the introduction to Fabric, he tells of the lasting impression left on him by the existentialist philosopher Albert Camus’s book The Myth of Sisyphus, which he pulled down from his father’s bookcase as a teenager. “I think it’s exciting,” he says, “that so many of us, in so many different ways, seek the true nature of reality.”

Whither String Theory?

String theorists have to be persevering. Despite making great progress in understanding the theory, they have yet to devise an ironclad way of testing it.The trouble stems from string theory’s extra dimensions, which can twist themselves together into a huge variety of shapes, each of which results in particles having slightly different masses, charges, and other properties. Nothing in the theory tells physicists which shape to choose. Even some string theorists have begun to abandon the idea of selecting one shape for the extra dimensions, arguing that the different dimensional contortions are equally realized in a larger “multiverse.”

Critics such as Peter Woit, a physicist in Columbia’s mathematics department, dwell on this point, complaining that the theory has virtually monopolized particle physics for two decades, with nothing to show. “The models they are working with just aren’t connected to the real world,” said Woit in a recent interview in Discover magazine.“There’s an ongoing discussion now almost at the level of philosophy of science: Is this even a science?”

Both camps have given up too early for Greene’s taste.The lack of a unique prediction may be a result of physicists’ poor understanding of the theory, he says. Quantum mechanics, which deals with molecules and atoms, took 30 years to formulate. “What we’re trying to do now is extend the reach of theory to things 100 billion billion times smaller” — and potentially that much further removed from experimental contact. “We’re on our own searching in mathematical realms for physical truth.”

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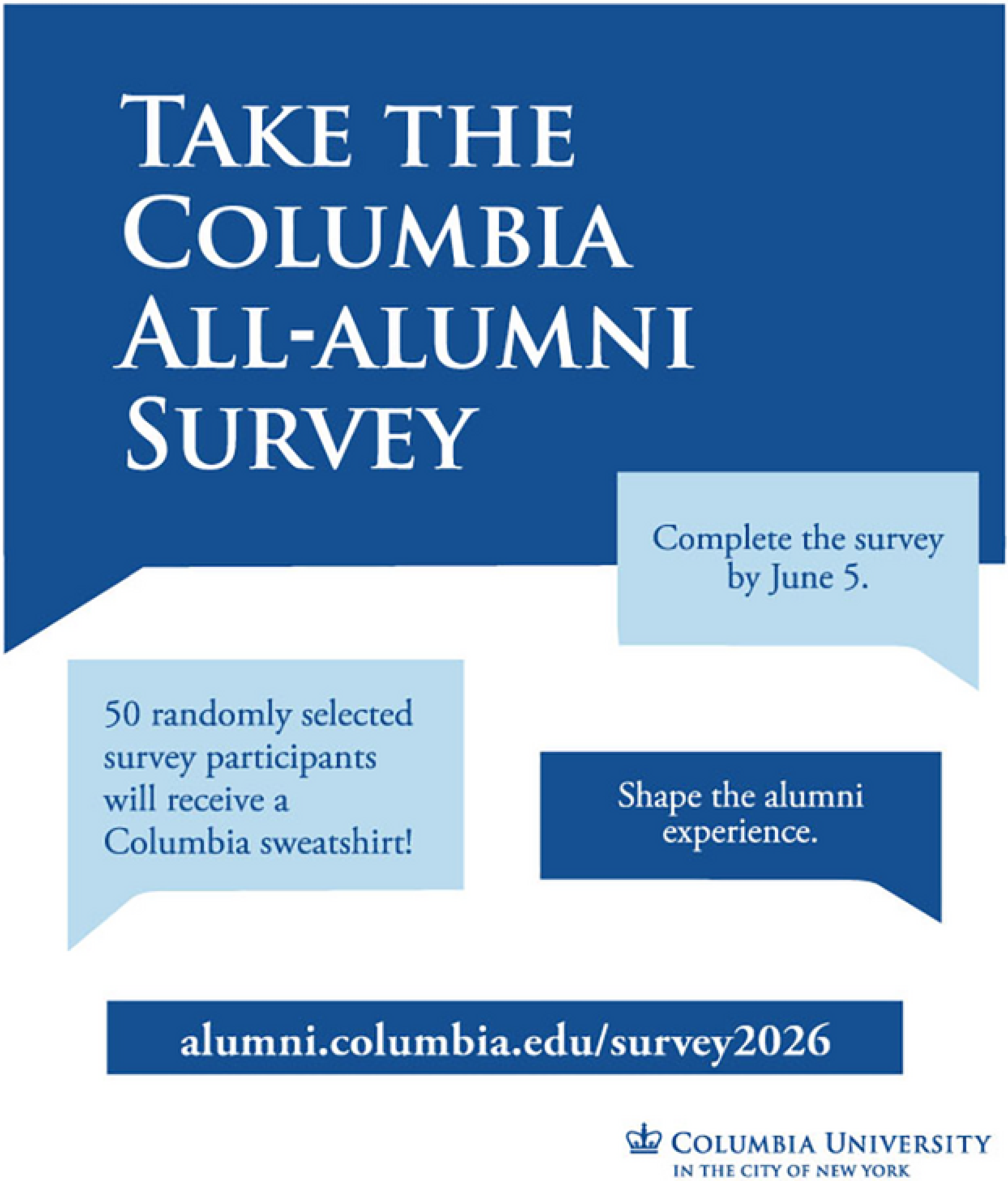

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