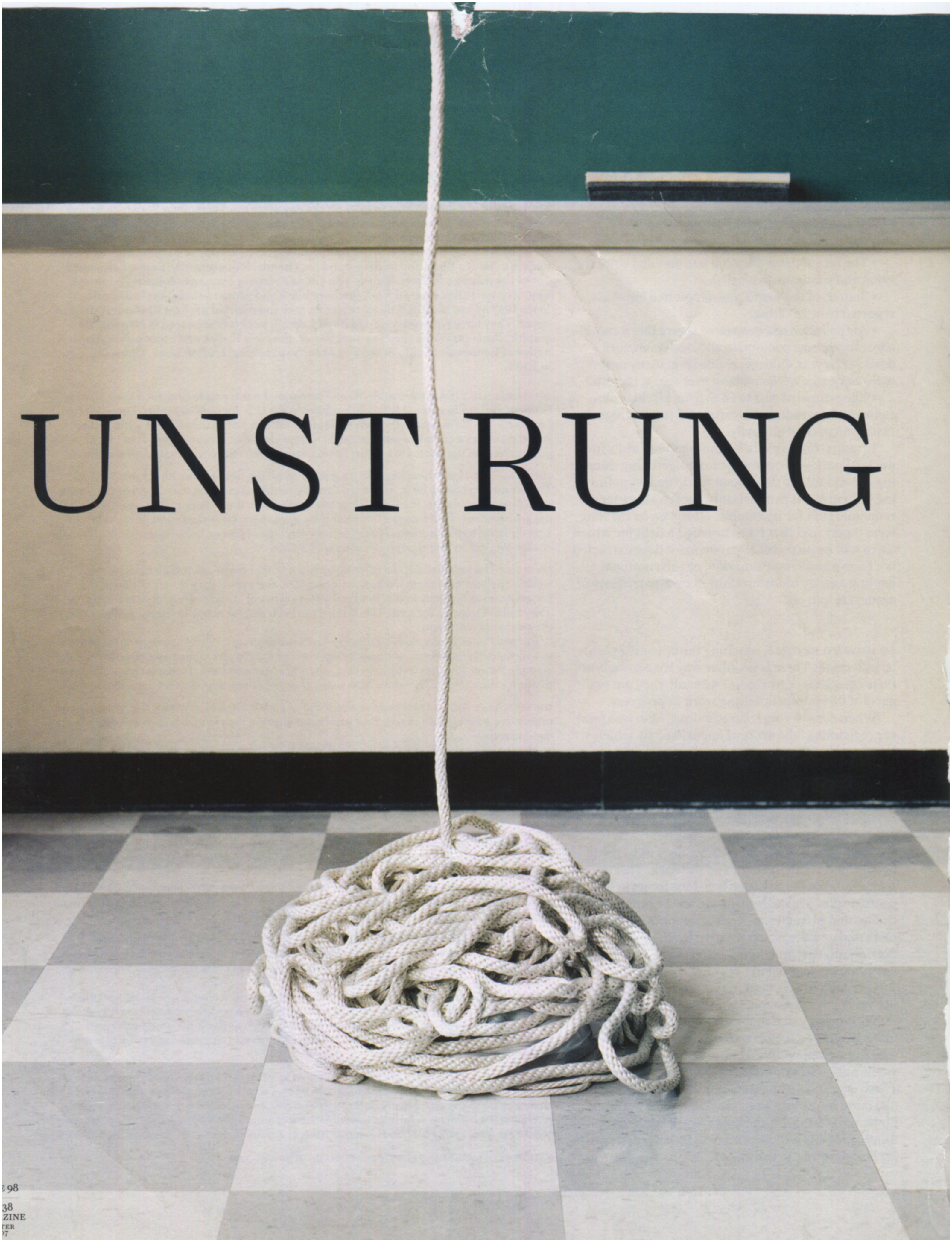
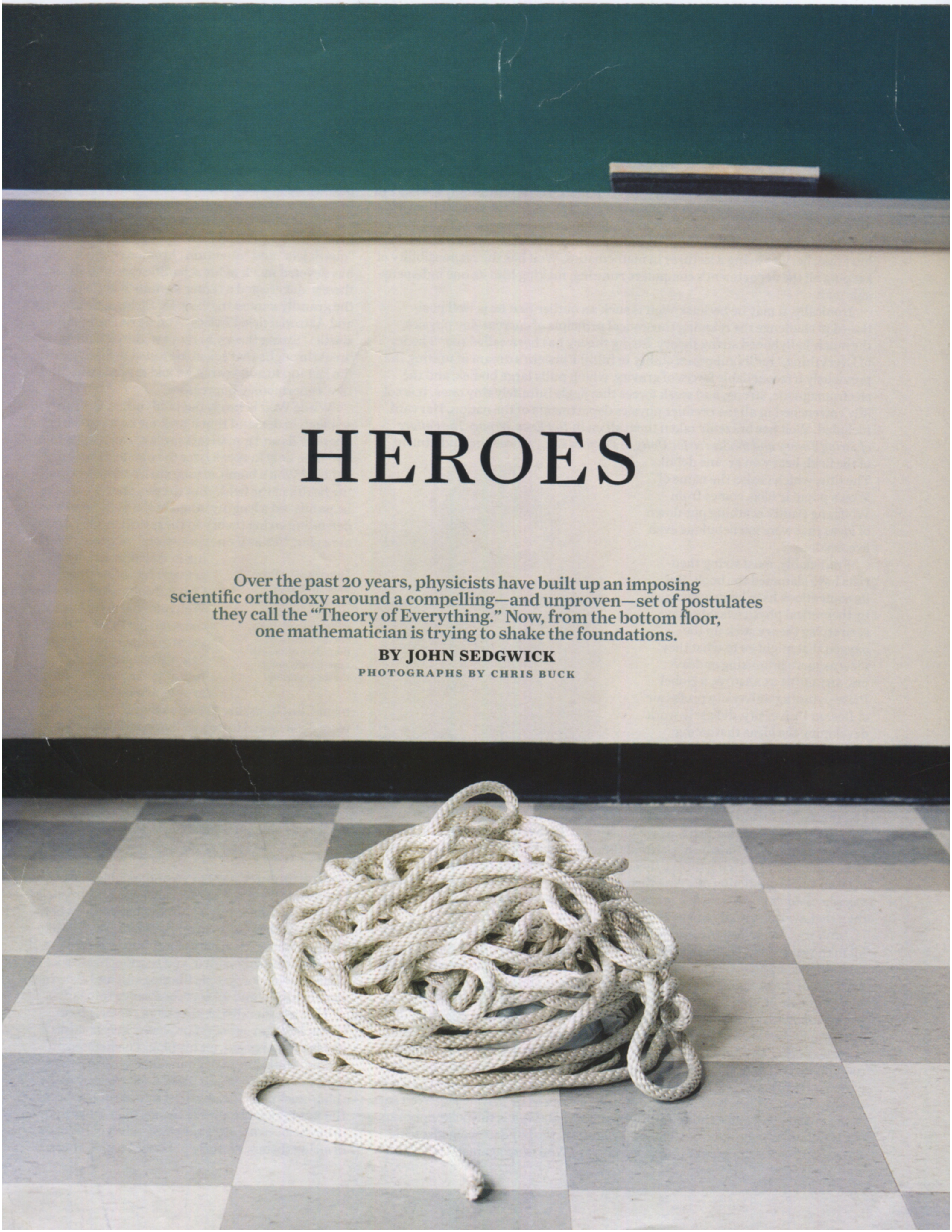
UNSTRUNG





HEROES

Over the past 20 years, physicists have built up an imposing scientific orthodoxy around a compelling—and unproven—set of postulates they call the "Theory of Everything." Now, from the bottom floor, one mathematician is trying to shake the foundations.

BY JOHN SEDGWICK

PHOTOGRAPHS BY CHRIS BUCK

THE MATHEMATICS BUILDING at Columbia University is a stately neoclassical affair designed, like much of the campus, by McKim, Mead & White in the 1890s, and it reflects a period of considerable confidence in the state of the world and academe's place in it. These are temples of learning, of truth. Inside the mathematics building, however, there is a rabbit warren of tiny offices reflecting the far more improvisational nature of the intellectual enterprise as it is practiced these days in science. **PETER WOIT**, a fortyish man with waning hair, a sheepish, post-hippie demeanor, and three degrees in physics, two of them from Harvard, occupies one of the larger ones. "It's just luck," he says with a shrug. "I happened to be hanging around when the designer was deciding on the layout." It didn't hurt that, besides being a lecturer in mathematics, Woit has the responsibility of keeping all the department's computers running, making him its one indispensable man.

Ironically, it may be because Woit is such an outlier that he is well positioned to challenge the reigning theoretical principle of current-day physics, the much-ballyhooed string theory. String theory has been called the "Theory of Everything," for its supposed ability to fulfill Einstein's dream of uniting the previously irreconcilable forces of gravity, which pulls large bodies, and the electromagnetic, strong, and weak forces that jiggle infinitely tiny ones. It is solidly entrenched in all the premier physics departments of the nation, Harvard included. Woit has brazenly taken them all on in *Not Even Wrong: The Failure of String Theory and the Search for Unity in Physical Law*, a sweeping indictment of the field, heavy on arcane detail. The title, which is also the name of Woit's popular blog, comes from Wolfgang Pauli's scathing put-down of ideas that were too nebulous even to consider.

String theorist Brian Greene: "No one successful experiment would establish that string theory is right, but neither would the failure of all such experiments prove the theory wrong."

Predictably, most string theorists have slammed the book. But its contentions have been welcomed by theoretical physicists who have seen string theory suck up the oxygen that might go to what they view as more promising endeavors. **SHELDON GLASHOW**, a Nobel Prize–winning university professor at Boston University, did early work developing the ideas that string theorists later seized upon. In 1986, he and a colleague wrote that string theory had yielded "not one verifiable prediction, nor should any soon be expected." He said he considers a big book like Woit's long overdue, because "string theory has gone exactly as we imagined." If anything, he adds, "it's even worse than it was." Adds Nobel laureate Steven Weinberg of the University of Texas, another pre–string theory theoretician: "The critics are quite right. We have no single prediction of string theory that is verified by observation. Even worse, we don't know how to use string theory to make predictions. Even worse than that, we don't really know what string theory is."

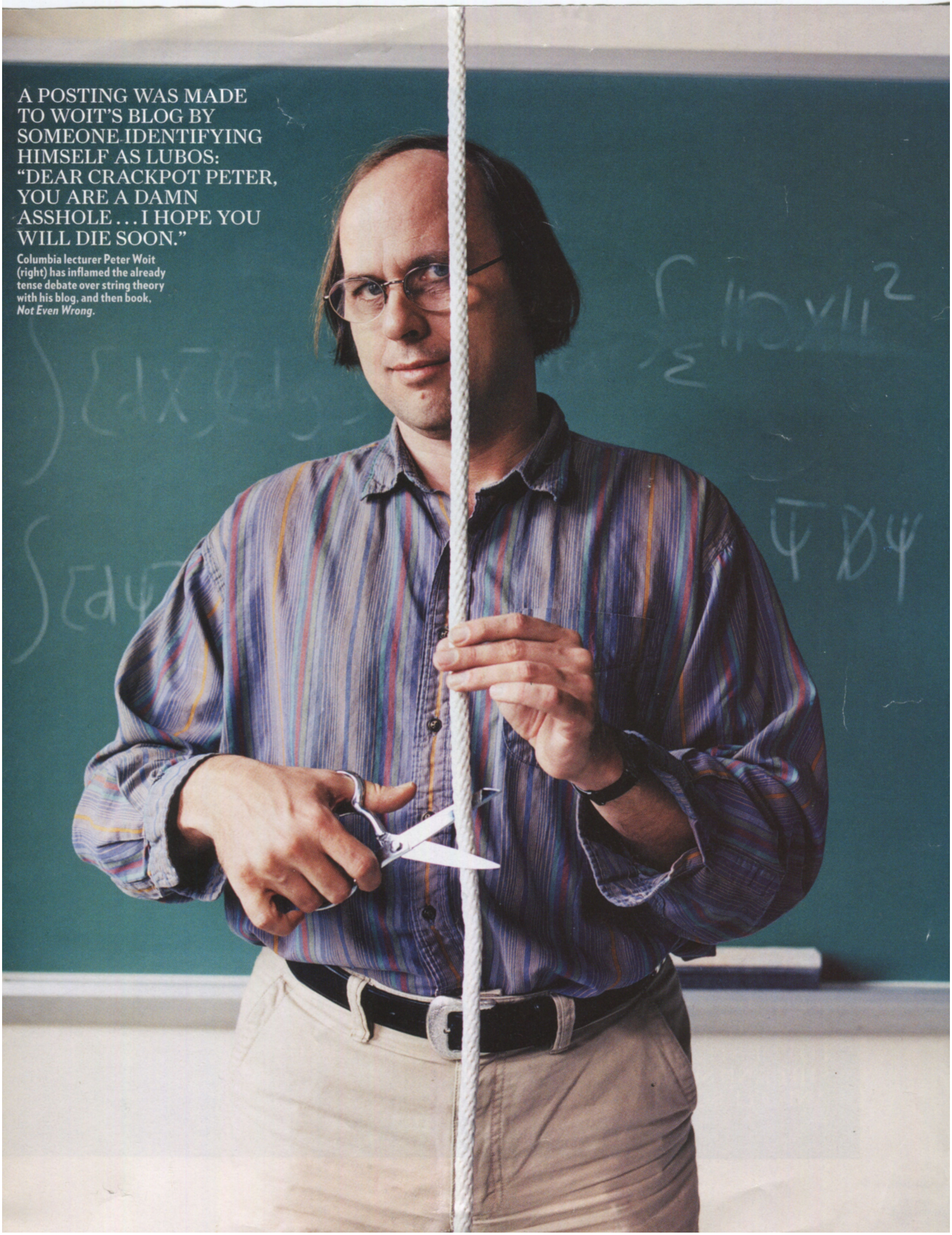
Woit was doing postdoctoral work at SUNY–Stony Brook when string theory hit in the mid-'80s. He steered clear, unwilling to commit to a field simply because higher-ups deemed it trendy, and concentrated on the mathematics of the particles of the so-called Standard Model. While the strings were all dubious conjecture, he figured the particles were undeniable, the laws governing them worked out with great precision. This has led his detractors to accuse him of sour grapes, but Woit expresses no regrets about that. His real regret, he says, is not accepting an offer to join the Bay Area startup headed by his Princeton roommate Nathan Myhrvold, which came in around the same time. The company was being snapped up by Microsoft, where Myhrvold was made chief technology officer. "When Nathan comes to visit, he flies in by private jet," Woit says.

As an outsider, and a rather unkempt one at that, Woit is the polar opposite of his Columbia colleague and fellow Harvardian, the handsome, mediagenic **BRIAN GREENE**, who exemplifies much of what Woit is up against. He holds a joint appointment in mathematics and physics and, having written the brilliant bestseller *The Elegant Universe* and starred in its three-hour version on PBS, is probably the nation's most visible proponent of string theory. Remembered as a "showman" by physics professor Arthur Jaffe at Harvard, where he performed in musicals, Greene played a cameo role in the film *Frequency* and advised fellow alum **JOHN LITHGOW** on how to salt the scientific dialogue for his TV series *3rd Rock from the Sun* with terms like "quark jets" and "quantum chromodynamics." He has devoted much of his scientific career to string theory and created a center to study it at Columbia—the grandly named Institute for Strings, Cosmology and Astroparticle Physics. And he remains enthusiastic. "String theory harbors within it many of the breakthroughs that scientists toiled to discover over the last 100 to 200 years," he told me recently, "and that's enormously impressive."

While Woit is rarely out of his office, Greene is so much in demand that it took me nearly a dozen phone calls and e-mail messages to catch up to him, and then only to speak over the phone. He calmly defused Woit's bomb, saying such a view "shows the health of the field." But the day after we spoke, he published a lengthy op-ed in the *New York Times*, defending string theory in the lyrical terms he is famous for. "It's as if one composer," he wrote, "working in isolation, produced the greatest hits of Beethoven, Count Basie and the Beatles." Well into the piece, he did concede that "a small but vocal group of critics" has complained the theory has yet to "make predictions that are confirmed by experiment." But he assured readers that string theorists were determined to do just that possibly as soon as next year, when the Large Hadron Collider, the most powerful particle accelerator ever, comes online at CERN in Geneva. Although Woit was "way down the academic food chain," as the science writer John Horgan put it, Greene registered his critique. "That op-ed was obviously a rebuttal," Horgan told me.

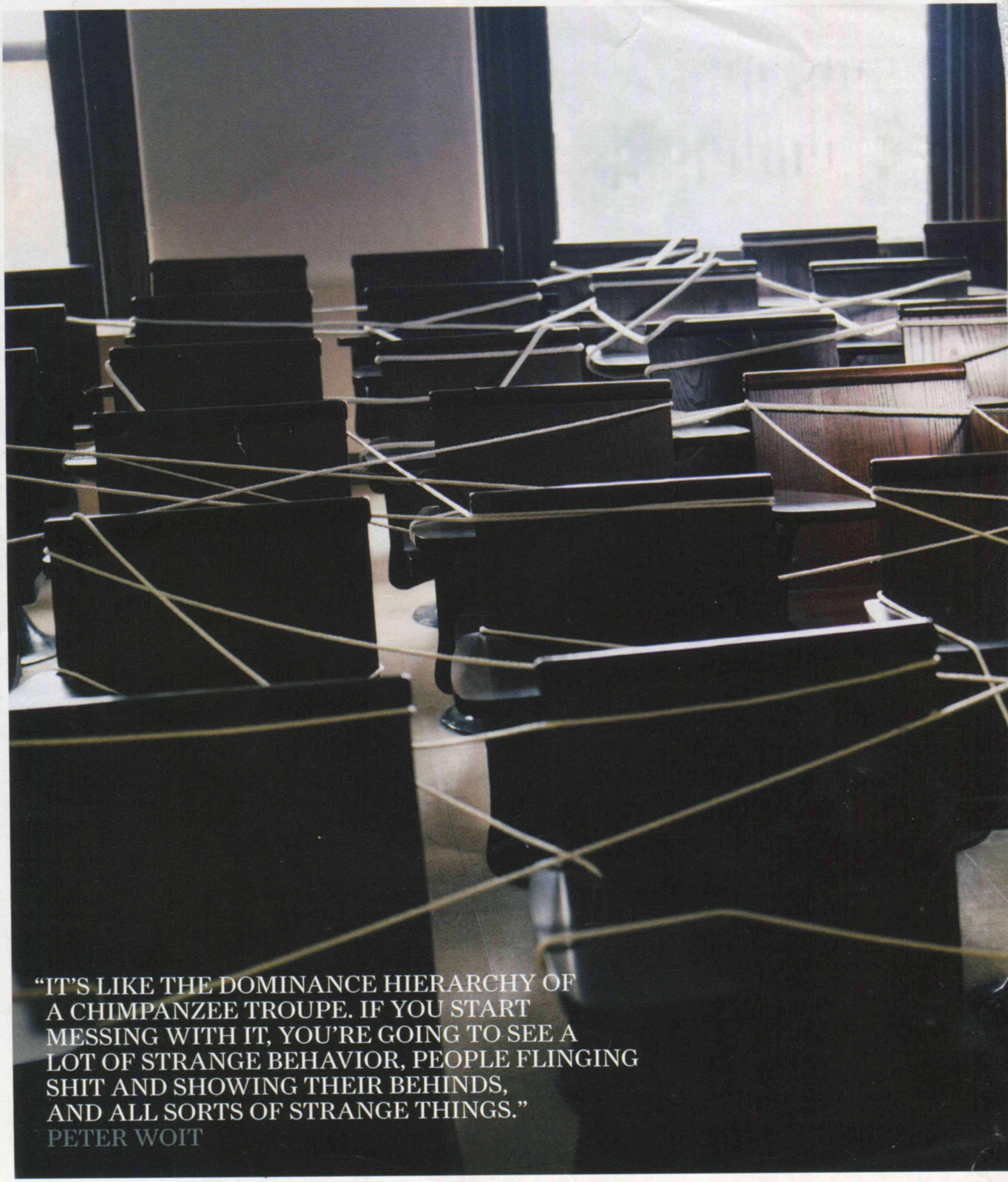
WHILE GREENE REMAINS unflappable, the book has certainly rattled cages elsewhere. "It's because I don't fit into the usual hierarchy that I end up being kind of challenging to people," Woit says. "It's like the dominance hierarchy of a chimpanzee troupe. If you start messing with it, you're going to see a lot of strange behavior, people flinging shit and showing their behinds, and all sorts of strange things."

Like a rather distressing bit of rhetoric from Lubos Motl, an assistant professor in Harvard's physics department, on his blog, The Reference Frame. Motl started denouncing the "black crackpot," referring to Woit's black book cover, and the "blue crackpot," the physicist **LEE SMOLIN**—another Harvard graduate, now at the Perimeter Institute in Ontario—who, after spending much of his career in string theory, recently published a blue-covered



A POSTING WAS MADE TO WOIT'S BLOG BY SOMEONE IDENTIFYING HIMSELF AS LUBOS: "DEAR CRACKPOT PETER, YOU ARE A DAMN ASSHOLE . . . I HOPE YOU WILL DIE SOON."

Columbia lecturer Peter Woit (right) has inflamed the already tense debate over string theory with his blog, and then book, *Not Even Wrong*.



"IT'S LIKE THE DOMINANCE HIERARCHY OF A CHIMPANZEE TROUPE. IF YOU START MESSING WITH IT, YOU'RE GOING TO SEE A LOT OF STRANGE BEHAVIOR, PEOPLE FLINGING SHIT AND SHOWING THEIR BEHINDS, AND ALL SORTS OF STRANGE THINGS."
PETER WOIT

BRINGING OUT THE BIG GUNS

THE LARGE HADRON COLLIDER

IF, AS CARL SAGAN CONTENDED, extraordinary claims require extraordinary evidence, string theory will require an unprecedented physical effort to prove (or refute) its remarkable suppositions.

Enter the Large Hadron Collider, an underground colossus of a particle accelerator, bestriding the border between France and Switzerland at CERN, the world's largest particle physics laboratory. After an enormous effort by the scientific community, the first experiments in the LHC should be running by the end of next year, and physicists' breath is decidedly bated.

The collider, appropriately enough, collides beams of protons traveling in opposite directions around a circumference of nearly 20 miles, guided by coils exerting 100,000 times Earth's magnetic field. With so much juice, the protons will travel at just about the speed of light, and will collide every 25 nanoseconds or so, releasing 14 trillion electron volts each.

So what does a giant, circular bumper-car course for subatomic particles in the middle of the Alps have to do with, well, everything?

The LHC's five major experiments could give string theory an enormous boost, just as some critics are prophesying its downfall. The high-speed collisions will create conditions similar to the ones just seconds after the Big Bang; with careful measurements of the debris from such powerful collisions, CERN experimenters may be able to detect the as-yet-unseen "superparticles" that, according to the theory, complement the familiar subatomic building blocks. (Imagine crashing two SUVs into each other in order to study their engines. With protons, of course, you can't just open the hood.)

The most optimistic experimenters are hoping for even more extraordinary finds. Tiny black holes—much smaller than an atomic nucleus and deteriorating harmlessly—could emit particles visible (so to speak) in our three-dimensional world but exhibiting characteristics of the extra dimensions that string theory predicts. In theory, observers might be able to count the number of dimensions in the universe from deep within the Alpine tunnels.

Of course, even experiments conforming to string theorists' predictions are unlikely to quiet critics. In a *New York Times* op-ed published in October, string theory impresario BRIAN GREENE acknowledged that no single experiment could prove string theory absolutely: "The bottom line is that it's hard to test a theory that not only taxes the capacity of today's technology but is also still very much under development." Some have even argued that unless it were the size of the universe, a proton collider would be useless in a robust verification of the theory. MICHIO KAKU, physics professor and author of *Hyperspace*, one of the earliest popularizations of string theory, calls this argument "silly." "Most science is done indirectly, not directly," he says. "No one has been to the sun, but we know what the sun is made of by analyzing its sunlight."

Meanwhile, a few Cassandras have even speculated about the possibility of a universe-liquidating black hole created by the concentration of energy involved in the Collider's heavy-ion collisions. Similar concerns arose in 1999, with the completion of the Relativistic Ion Collider in Upton, N.Y.; physicists at CERN assure us that the collapse of the universe is no more likely to start outside Geneva than it was on Long Island. **Greg Atwan** critique, *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next*. According to Woit, Motl declared that Woit's sins against science were so great, his "otherwise worthless life [was not] a sufficient price to repay his crimes." A few days later, a posting was made to Woit's blog by someone identifying himself as Lubos: "Dear crackpot Peter, you are a damn asshole ... I hope you will die soon."

Alarmed, Woit says, he complained to the Harvard physics chairman, who silenced Motl on the subject of string theory critics. By e-mail, Motl declined a request for an interview: "I don't enjoy elementary human rights right now." Needless to say, this created a buzz in the string theory blogosphere. A science consultant summarized the clash by saying that Motl had done to the image of string theory "what the movie *Deliverance* did for canoeing holidays."

PERHAPS IT IS THE ALLURING beauty of what Greene has called the "Aeolian" harmonies of these invisible strings; perhaps it's because any theory that touts itself as the Theory of Everything is bound to attract the ambitious; or perhaps because, in a winner-take-all world, the leading theory in physics, too, is destined to crowd out all the others. For whatever reason, string theory is It, and has been It for well over 20 years. No one can even say for sure what's in second place. Motl's Harvard colleague, professor Cumrun Vafa, calls string theory "the major leagues" in the field of quantum gravity. As for other theoretical pursuits, he derides them as "little efforts here and there." And critics like Woit? "My question to them is: 'Why are you wasting your time challenging these guys?' Do your job! Write your own paper. It would revolutionize the field."

Solidly as it is entrenched now, string theory began fairly humbly, when some researchers in Europe and the United States were trying to puzzle out how a fairly esoteric 200-year-old mathematical formula almost perfectly described some effects of the "strong force" involving interactions between quarks and gluons within the nucleus of an atom. An Italian physicist named Gabriele Veneziano had made the claim in a paper he published in 1968. String theory grew out of one answer and has continued to grow ever since. The math made sense, it turned out, only if some of the particles involved did not behave like particles at all but like something "stringy," as theorists like to say of a single extendable dimension, in which these new particles could vibrate at particular frequencies by stretching and contracting like rubber bands.

In 1974, Joel Scherk and **JOHN SCHWARZ**, entranced by the simple beauty of this image, used the idea to analyze a mysterious particle with two units of spin that showed up when they were doing their own calculations on the strong force. To their amazement, the properties of the so-called "spin-two" particle matched the properties of the graviton, a massless particle that conveys the force of gravity. Before then, gravity had simply not fit the conception, it was so subtle at the quantum level. And it was so different, too. In quantum mechanics, particles career wildly about, crashing into each other or, sometimes, passing right through. Gravity is far more stately and smooth as it arcs through space. But there the graviton was in the equation, yet another pitch in the harmony of all the vibrating strings. Says Steven Gubser of Princeton: "It was a syllogism—if strings and quantum mechanics, then gravity." Because of some lingering inconsistencies between string theory and quantum mechanics, other physicists remained skeptical until 1984, when Schwarz and another collaborator worked them out. And once they did, "everything broke open," Schwarz told me. "There was a big reaction." The rebels had stormed the palace gates.

The theory led rapidly to other implications—"not things that were added," insists **MICHAEL PESKIN** of the Stanford Linear Accelerator Center, "but all properties of the original mathematical framework." To explain the commonality of force and matter in this new unified theory, theorists imported the notion of supersymmetry that had been incorporated into the Standard Model, by which each elementary particle, the fermions that make up matter and the bosons that account for force, had a heretofore unknown partner of the other class. To work out the math, 10 space-time dimensions would be necessary. "You can imagine them, it just takes a little practice," Peskin says, only half-joking. A group of physicists including Harvard's **ANDY STROMINGER** gave one possible explanation: six-dimensional Calabi-Yau spaces, theoretical configurations that might look like crumpled-up Mobius strips, with all the extra dimensions folded in. In theory, Calabi-Yau spaces are hiding everywhere, tucked inside the three-dimensional space we know—plus time makes 10—each one possibly housing strings that vibrate through them.

To Smolin, the string revolution that provoked this flurry of theories came about too quickly. He watched in some distress as "there developed an almost cultlike atmosphere.... Nothing else was important or worth thinking about." Woit steered clear entirely, distrustful of so much theory being constructed on so little evidence. In particular, he recoiled at the massive readjustments to the Standard Model required by string theory's brand of supersymmetry. He cites the no-nonsense physicist Richard Feynman, who likewise disdained the string theorists: "I don't like that they're not calculating anything. I don't like that they don't check their ideas. I don't like that for anything that disagrees with an experiment, they cook up an explanation—a fix-up to say, 'Well, it still might be true.'"

Indeed, the Calabi-Yau spaces raised more questions. They come in a nearly infinite variety, each one representing a different physical make-up of the universe. Yet so far, none of these alternate universes has matched the characteristics of our own—a significant liability to a theory that was supposed to do just that. "The closest are caricatures of our world," admits Barton Zwiebach, a leading string theorist at MIT. "That's a disappointment."

And how was supersymmetry, with all its new "partner" particles, to fit in? Five different versions of string theory were advanced to try to explain that. All seemed plausible, but none was compatible with the others. Physicists longed for a "metatheory" that would somehow make each, as Peskin puts it, a "facet" of one ultimate solution.

IT WAS A NEW SEARCH for the Theory of Everything, and Ed Witten rose to the challenge. He was a professor at Princeton's Institute for Advanced Study, where Einstein famously hung his hat. In a world that ranks itself by the smart, the really smart, and the *really* smart, Witten was indisputably the class act of the field. "He's a god," Woit says.

In 1995, Witten produced the metatheory so many had hoped for, posing, among other things, the new idea of a membrane, or "brane," which extended the one-dimensional string into higher dimensions—raising the question of whether the branes themselves weren't the fundaments of nature. Although the theory touched on the five theories, it left a lot to be filled in. It was less a theory, in fact, than a proclamation that a theory exists. "Nobody really knows what it is," admits Peskin. Witten himself was rather cavalier about it. He called it M-theory, noting blithely that the M stood for "magic, mystery or membrane, according to taste."

Reinvigorated nonetheless, string theorists have gone on to take string theory out from the microworld of subatomic particles to the vast reaches of the cosmos. The branes might describe the three-dimensional world we know as being embedded in a larger, multidimensional universe. They might also help explain black holes. And the strings might account for the "wormholes" within black holes—or possibly even some other unusual formation, Peskin says, "like a neck or a knot." Since black holes contain singularities—points of infinite density—in space, might there not be an equivalent in space-time? That would take us back in time to that other singularity, the Big Bang. Perhaps string theory explains that? "It's so hot, so dense, and so compact that the usual application of gravity without quantum mechanics would not work," MIT's Zwiebach says of the beginning of the universe. Because string theory incorporates gravity, however, it would. "So you can really ask the question of what happened at the very earliest times," Zwiebach says. "We could see the origin of the universe, and the very deep meaning of how space and time are born and what they are." And even, Peskin adds intriguingly, possibly back through the Big Bang, to discover a universe that might have existed before time as we know it began. "But there is a big debate as to whether this idea makes any sense."

While string theorists view their work as a cathedral in the making, to Woit it is a far less promising, far more rickety affair—a vast, teetering Tinkertoy assemblage of only tangentially related theorems, propositions, and wan hopes that have left the simple clarity of those quivering strings a long way behind. Smolin likewise complains of the endless "maneuvering" of string theorists to account for the fresh problems that arise from each new theoretical development. "As long as no one quite knows exactly what string theory is," Woit writes, "its proponents are able to hold very optimistic theories about it." And there remains that nagging problem of evidence. "It has become the dominant paradigm in the field without any experimental basis," Woit complains. "And there's no conceivable experiment we have now which can ever show that it's wrong or show that it's right. And I haven't really ever seen that happen before in the history of physics." Smolin is more judicious in his summary. "I've gone back and forth on it," he tells me, before giving a finely calibrated answer: "Basically I think that it is a very interesting set of ideas and examples and approximate calculations. But—and there are several buts—other approaches to quantum gravity are more promising. String theory has simply not worked out as well as we expected."

Both sides of the argument are hoping for some resolution from the Large Hadron Collider, which CERN scientists will turn on next year. With a track nearly 20 miles around, it is capable of detecting particles about a 10th the size of the ones that show up now. That would take researchers down to 10^{-16} centimeters, no small accomplishment. But the strings, if they exist, are flyspecks, down nearly to Planck length: 10^{-33} centimeters, or 10,000 trillion times smaller. At that scale, scientists will detect the strings only by inference—most likely by finding evidence of at least one of the "partner" particles posited by supersymmetry (to find the strings themselves, Woit claims, the track would have to swing not 20 miles but around the galaxy). But even if the new collider does discover evidence of supersymmetry, Woit adds, it still won't prove the validity of string theory, since many other competing theories involve supersymmetry as well. Greene conceded as much in the *Times* op-ed: "No one successful experiment would establish that string theory is right, but neither would the failure of all such experiments prove the theory wrong." So string theory remains: vast promise, little hard evidence.

UNLIKE MOST OF THE STRING THEORISTS, Woit came of age in the late '60s. He was a young boy in Paris during the student uprising of 1968, which passed by his window. That left him with a distrust of authority, and the ever-expanding social structure of string theory makes him highly suspicious. But he can see that it is safer to play along with the existing hierarchy than to question it. And the complexity of string theory only increases the obligation; it is a field that can require total commitment. Just to grasp the quantum mechanics on which the field is built requires several years of study, and string theory infinitely more, as its many offshoots evolve into thickening branches of increasingly abstruse theory. Once you get a handle on it, in short, it has a handle on you.

Harvard physics professor Nima Arkani-Hamed scoffs at the idea that there is any kind of "string theory cabal," and says he believes that physicists can "vote with their feet" like any other professionals. But there does seem to be a dangerous insularity to the field. Even the ever-politic Greene became slightly testy when I asked if he was inclined to dismiss Woit because of a lack of standing. He replied that the question was "a touch awkward to respond to. So I'd rather not go there." Still, he insisted that he had no particular stake in the outcome of the theory. "I have only one investment, and that's in finding truth." While Greene avoided taking Woit on personally, others either dismiss his criticisms as "not very interesting" or dispute his book without having read it. As a longtime practitioner in the field. Smolin has been taken more seriously, but he has changed no minds. In string theory, it appears, one is either pro or con.

Woit himself has backed off from some of the more extreme attitudes in his book, and he bears the look of someone who has been kicked once too often. "I'm continually getting grief from people who say, 'Oh, you're saying string theory is completely useless.'" He now shades it a little differently, acknowledging that string theory has made important contributions to the understanding of how certain subatomic particles behave and has led to some "very interesting" mathematics. Lee Smolin may be closer to the mark when he calls string theory an "overinvestment." Although they overlap in the same math department, Woit and Greene rarely see each other, and when they do, they never discuss their disagreement in any detail. Indeed, they occupy such different spheres that it is almost as if each is tucked away in a divergent alternative universe. The difference is situational, but stylistic too. Harvard physics professor LISA RANDALL went to Stuyvesant High School in New York with Greene, who won citywide math championships all four years; she observes that the showman in Greene sometimes wins out over the scientist. "He gives a more polished, more finished view," she says. "And it comes out more established and more confident than it is in reality." But then she pauses, perhaps afraid of going too far. "The fact is, science is messy, and in any intermediate stage we don't know what is going on." This causes a skeptic like Woit to be skeptical, and a promoter like Greene to promote. Ultimately, the debate will be resolved by the facts, but in a realm of physics as audacious as string theory, that may take a while. Or forever.

EAGER ACTUALLY TO LAY EYES on Brian Greene, after Woit and I had lunch at a French place a few blocks from his office, I took a short walk across the campus to the physics department to see if I could scare him up. When I asked the department secretary if Greene was around, she shrugged. "We never know where he is." But she did show me his Institute for Strings, Cosmology and Astroparticle Physics, which was down the hall. I was expecting something as impressive as its title, but when she swung the door open, I encountered a large, mostly empty space with three graduate students peering into standard-issue computer screens. On the walls, there was only a blurry photograph of some stars. No picture of a superstring? I joked. "Oh, God, no," said one of the grad students with a laugh. "If you had one of those, you'd be famous." ■