THE NEW YORKER

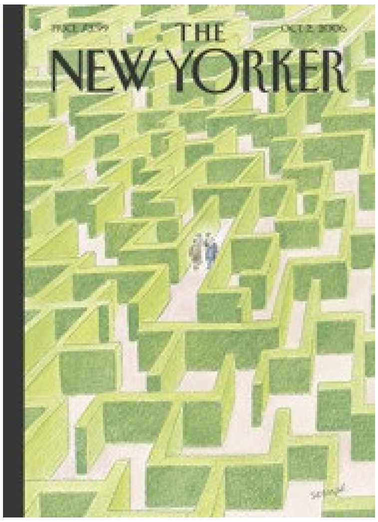
A CRITIC AT LARGE

UNSTRUNG

In string theory, beauty is truth, truth beauty. Is that really all we need to know?

by Jim Holt

OCTOBER 2, 2006



It is the best of times in physics. Physicists are on the verge of obtaining the long-sought Theory of Everything. In a few elegant equations, perhaps concise enough to be emblazoned on a T-shirt, this theory will reveal how the universe began and how it will end. The key insight is that the smallest constituents of the world are not particles, as had been supposed since ancient times, but “strings”—tiny strands of energy. By vibrating in different ways, these strings produce the essential phenomena of nature, the way violin strings produce musical notes. String theory isn’t just powerful; it’s also mathematically beautiful. All that remains to be done is to write down the actual equations. This is taking a little longer than expected. But, with almost the entire theoretical-physics community working on the problem—presided over by a sage in Princeton, New Jersey—the millennia-old dream of a final theory is sure to be realized before long.

It is the worst of times in physics. For more than a generation, physicists have been chasing a will-o’-the-wisp called string theory. The beginning of this chase marked the end of what had been three-quarters of a century of progress. Dozens of string-theory conferences have been held, hundreds of new Ph.D.s have been minted, and thousands of papers have been written. Yet, for all this activity, not a single new testable prediction has been made, not a single theoretical puzzle has been solved. In fact, there *is* no theory so far—just a set of hunches and calculations suggesting that a theory might exist. And, even if it does, this theory will come in such a bewildering number of versions that it will be of no practical use: a Theory of Nothing. Yet the physics establishment promotes string theory with irrational fervor, ruthlessly weeding dissenting physicists from the profession. Meanwhile, physics is stuck in a paradigm doomed to barrenness.

So which is it: the best of times or the worst of times? This is, after all, theoretical physics, not a Victorian novel. If you are a casual reader of science articles in the newspaper, you are probably more familiar with the optimistic view. But string theory has always had a few vocal skeptics. Almost two decades ago, Richard Feynman dismissed it as “crazy,” “nonsense,” and “the wrong direction” for physics. Sheldon Glashow, who won a Nobel Prize for making one of the last great advances in physics before the beginning of the string-theory era, has likened string theory to a “new version of medieval theology,” and campaigned to keep string theorists out of his own department at Harvard. (He failed.)

Now two members of the string-theory generation have come forward with exposés of what they deem to be the current mess. “The story I will tell could be read by some as a tragedy,” Lee Smolin writes in “The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next” (Houghton Mifflin; $26). Peter Woit, in “Not Even Wrong: The Failure of String Theory and the Search for Unity in Physical Law” (Basic; $26.95), prefers the term “disaster.” Both Smolin and Woit were journeyman physicists when string theory became fashionable, in the early nineteen-eighties. Both are now outsiders: Smolin, a reformed string theorist (he wrote eighteen papers on the subject), has helped found a sort of Menshevik cell of physicists in Canada called the Perimeter Institute; Woit abandoned professional physics for mathematics (he is a lecturer in the mathematics department at Columbia), which gives him a cross-disciplinary perspective. Each author delivers a bill of indictment that is a mixture of science, philosophy, aesthetics, and, surprisingly, sociology. Physics, in their view, has been overtaken by a cutthroat culture that rewards technicians who work on officially sanctioned problems and discourages visionaries in the mold of Albert Einstein. Woit argues that string theory's lack of rigor has left its practitioners unable to distinguish between a scientific hoax and a genuine contribution. Smolin adds a moral dimension to his plaint, linking string theory to the physics profession's "blatant prejudice" against women and blacks. Pondering the cult of empty mathematical virtuosity, he asks, "How many leading theoretical physicists were once insecure, small, pimply boys who got their revenge besting the jocks (who got the girls) in the one place they could—math class?"

It is strange to think that such sordid motives might affect something as pure and objective as physics. But these are strange days in the discipline. For the first time in its history, theory has caught up with experiment. In the absence of new data, physicists must steer by something other than hard empirical evidence in their quest for a final theory. And that something they call "beauty." But in physics, as in the rest of life, beauty can be a slippery thing.

The gold standard for beauty in physics is Albert Einstein's theory of general relativity. What makes it beautiful? First, there is its simplicity. In a single equation, it explains the force of gravity as a curving in the geometry of space-time caused by the presence of mass: mass tells space-time how to curve, space-time tells mass how to move. Then, there is its surprise: who would have imagined that this whole theory would flow from the natural assumption that all frames of reference are equal, that the laws of physics should not change when you hop on a merry-go-round? Finally, there is its aura of inevitability. Nothing about it can be modified without destroying its logical structure. The physicist Steven Weinberg has compared it to Raphael's "Holy Family," in which every figure on the canvas is perfectly placed and there is nothing you would have wanted the artist to do differently.

Einstein's general relativity was one of two revolutionary innovations in the early part of the twentieth century which inaugurated the modern era in physics. The other was quantum mechanics. Of the two, quantum mechanics was the more radical departure from the old Newtonian physics. Unlike general relativity, which dealt with well-defined objects existing in a smooth (albeit curved) space-time geometry, quantum mechanics described a random, choppy microworld where change happens in leaps, where particles act like waves (and vice versa), and where uncertainty reigns.

In the decades after this dual revolution, most of the action was on the quantum side. In addition to gravity, there are three basic forces that govern nature: electromagnetism, the "strong" force (which holds the nucleus of an atom together), and the "weak" force (which causes radioactive decay). Eventually, physicists managed to incorporate all three into the framework of quantum mechanics, creating the "standard model" of particle physics. The standard model is something of a stick-and-bubble-gum contraption: it clumsily joins very dissimilar kinds of interactions, and its equations contain about twenty arbitrary-seeming numbers—corresponding to the masses of the various particles, the ratios of the force strengths, and so on—that had to be experimentally measured and put in "by hand." Still, the standard model has proved to be splendidly useful, predicting the result of every subsequent experiment in particle physics with exquisite accuracy, often down to the eleventh decimal place. As Feynman once observed, that's like calculating the distance from Los Angeles to New York to within a hairbreadth.

The standard model was hammered out by the mid-nineteen-seventies, and has not had to be seriously revised since. It tells how nature behaves on the scale of molecules, atoms, electrons, and on down, where the force of gravity is weak enough to be overlooked. General relativity tells how nature behaves on the scale of apples, planets, galaxies, and on up, where quantum uncertainties average out and can be ignored. Between the two theories, all nature seems to be covered. But most physicists aren't happy with this division of labor. Everything in nature, after all, interacts with everything else. Shouldn't there be a single set of rules for describing it, rather than two inconsistent sets? And what happens when the domains of the two theories overlap—that is, when the very massive is also the very small? Just after the big bang, for example, the entire mass of what is now the observable universe was packed into a volume the size of an atom. At that tiny scale, quantum uncertainty causes the smooth geometry of general relativity to break up, and there is no telling how gravity will behave. To understand the birth of the universe, we need a theory that "unifies" general relativity and quantum mechanics. That is the theoretical physicist's dream.

String theory came into existence by accident. In the late nineteen-sixties, a couple of young physicists thumbing through mathematics books came upon a centuries-old formula that, miraculously, seemed to fit the latest experimental data about elementary particles. At first, no one had a clue why this should be. Within a few years, however, the hidden meaning of the formula emerged: if elementary particles were thought of as tiny wriggling strings, it all made sense. What were these strings supposed to be made of? Nothing, really. As one physicist put it, they were to be thought of as "tiny one-dimensional rips in the smooth fabric of space."

This wasn't the only way in which the new theory broke with previous thinking. We seem to live in a world that has three spatial dimensions (along with one time dimension). But for string theory to make mathematical sense the world must have *nine* spatial dimensions. Why don't we notice the six extra dimensions? Because, according to string theory, they are curled up into some microgeometry that makes them invisible. (Think of a garden hose: from a distance it looks one-dimensional, like a line; up close, however, it can be seen to have a second dimension, curled up into a little circle.) The assumption of hidden dimensions struck some physicists as extravagant. To others, though, it seemed a small price to pay. In Smolin's words, "String theory promised what no other theory had before—a quantum theory of gravity that is also a genuine unification of forces and matter."

But when would it make good on that promise? In the decades since its possibilities were first glimpsed, string theory has been through a couple of "revolutions." The first took place in 1984, when some potentially fatal kinks in the theory were worked out. On the heels of this achievement, four physicists at Princeton, dubbed the Princeton String Quartet, showed that string theory could indeed encompass all the forces of nature. Within a few years, physicists around the world had written more than a thousand papers on string theory. The theory also attracted the interest of the leading figure in the world of theoretical physics, Edward Witten.

Witten, now at the Institute for Advanced Study, in Princeton, is held in awe by his fellow-physicists, who have been known to compare him to Einstein. As a teen-ager, he was more interested in politics than in physics. In 1968, at the age of seventeen, he published an article in *The Nation* arguing that the New Left had no political strategy. He majored in history at Brandeis, and worked on George McGovern's 1972 Presidential campaign. (McGovern wrote him a letter of recommendation for graduate school.) When he decided to pursue a career in physics, he proved to be a quick study: Princeton Ph.D., Harvard postdoc, full professorship at Princeton at the age of twenty-nine, MacArthur "genius grant" two years later. Witten's papers are models of depth and clarity. Other physicists attack problems by doing complicated calculations; he solves them by reasoning from first principles. Witten once said that "the greatest intellectual thrill of my life" was learning that string theory could encompass both gravity and quantum mechanics. His string-theoretic investigations have led to stunning advances in pure mathematics, especially in the abstract study of knots. In 1990, he became the first physicist to be awarded the Fields Medal, considered the Nobel Prize of mathematics.

It was Witten who ushered in the second string-theory revolution, which addressed a conundrum that had arisen, in part, from all those extra dimensions. They had to be curled up so that they were invisibly small, but it turned out that there were various ways of doing this, and physicists were continually finding new ones. If there was more than one version of string theory, how could we decide which version was correct? No experiment could resolve the matter, since string theory concerns energies far beyond those which can be attained by particle accelerators. By the early nineteen-nineties, no fewer than five versions of string theory had been devised. Discouragement was in the air. But the mood improved markedly when, in 1995, Witten announced to an audience of string theorists at a conference in Los Angeles that these five seemingly distinct theories were mere facets of something deeper, which he called "M-theory." In addition to vibrating strings, M-theory allowed for vibrating membranes and blobs. As for the name of the new theory, Witten was noncommittal; he said that "M stands for magic, mystery, or membrane, according to taste." Later, he mentioned "murky" as a possibility, since "our understanding of the theory is, in fact, so primitive." Other physicists have suggested "matrix," "mother" (as in "mother of all theories"), and "masturbation." The skeptical Sheldon Glashow wondered whether the "M" wasn't an upside-down "W," for Witten.

Today, more than a decade after the second revolution, the theory formerly known as strings remains a seductive conjecture rather than an actual set of equations, and the non-uniqueness problem has grown to ridiculous proportions. At the latest count, the number of string theories is estimated to be something like one followed by five hundred zeros. "Why not just take this situation as a *reductio ad absurdum*?" Smolin asks. But some string theorists are unabashed: each member of this vast ensemble of alternative theories, they observe, describes a different possible universe, one with its own "local weather" and history. What if all these possible universes actually exist? Perhaps every one of them bubbled into being just as our universe did. (Physicists who believe in such a "multiverse" sometimes picture it as a cosmic champagne glass frothing with universe-bubbles.) Most of these universes will not be biofriendly, but a few will have precisely the right conditions for the emergence of intelligent life-forms like us. The fact that our universe appears to be fine-tuned to engender life is not a matter of luck. Rather, it is a consequence of the "anthropic principle": if our universe weren't the way it is, we wouldn't be here to observe it. Partisans of the anthropic principle say that it can be used to weed out all the versions of string theory that are incompatible with our existence, and so rescue string theory from the problem of non-uniqueness.

Copernicus may have dislodged man from the center of the universe, but the anthropic principle seems to restore him to that privileged position. Many physicists despise it; one has depicted it as a "virus" infecting the minds of his fellow-theorists. Others, including Witten, accept the anthropic principle, but provisionally and in a spirit of gloom. Still others seem to take perverse pleasure in it. The controversy among these factions has been likened by one participant to "a high-school-cafeteria food fight."

In their books against string theory, Smolin and Woit view the anthropic approach as a betrayal of science. Both agree with Karl Popper's dictum that if a theory is to be scientific it must be open to falsification. But string theory, Woit points out, is like Alice's Restaurant, where, as Arlo Guthrie's song had it, "you can get anything you want." It comes in so many versions that it predicts anything and everything. In that sense, string theory is, in the words of Woit's title, "not even wrong." Supporters of the anthropic principle, for their part, rail against the "Popperazzi" and insist that it would be silly for physicists to reject string theory because of what some philosopher said that science should be. Steven Weinberg, who has a good claim to be the father of the standard model of particle physics, has argued that anthropic reasoning may open a new epoch. "Most advances in the history of science have been marked by discoveries about nature," he recently observed, "but at certain turning points we have made discoveries about science itself."

Is physics, then, going postmodern? (At Harvard, as Smolin notes, the string-theory seminar was for a time actually called "Postmodern Physics.") The modern era of particle physics was empirical; theory developed in concert with experiment. The standard model may be ugly, but it works, so presumably it is at least an approximation of the truth. In the postmodern era, we are told, aesthetics must take over where experiment leaves off. Since string theory does not deign to be tested directly, its beauty must be the warrant of its truth.

In the past century, physicists who have followed their aesthetic sense in the absence of experimental data seem to have done quite well. As Paul Dirac said, "Anyone who appreciates the fundamental harmony connecting the way Nature runs and general mathematical principles must feel that a theory with the beauty and elegance of Einstein's theory has to be substantially correct." The idea that "beauty is truth, truth beauty" may be a beautiful one, but is there any reason to think it is true? Truth, after all, is a relationship between a theory and the world, whereas beauty is a relationship between a theory and the mind. Perhaps, some have conjectured, a kind of cultural Darwinism has drilled it into us to take aesthetic pleasure in theories that are more likely to be true. Or perhaps physicists are somehow inclined to choose problems that have beautiful solutions rather than messy ones. Or perhaps nature itself, at its most fundamental level, possesses an abstract beauty that a true theory is bound to mirror. What makes all these explanations suspect is that standards of theoretical beauty tend to be ephemeral, routinely getting overthrown in scientific revolutions. "Every property that has at some date been seen as aesthetically attractive in theories has at other times been judged as displeasing or aesthetically neutral," James W. McAllister, a philosopher of science, has observed.

The closest thing to an enduring mark of beauty is simplicity; Pythagoras and Euclid prized it, and contemporary physicists continue to pay lip service to it. All else being equal, the fewer the equations, the greater the elegance. And how does string theory do by this criterion? Pretty darn well, one of its partisans has facetiously observed, since the number of defining equations it has so far produced remains precisely zero. At first, string theory seemed the very Tao of simplicity, reducing all known particles and forces to the notes of a vibrating string. As one of its pioneers commented, "String theory was too beautiful a mathematical structure to be completely irrelevant to nature." Over the years, though, it has repeatedly had to be jury-rigged in the face of new difficulties, so that it has become a Rube Goldberg machine—or, rather, a vast landscape of them. Its proponents now inveigh against what they call "the myth of uniqueness and elegance." Nature is not simple, they maintain, nor should our ultimate theory of it be. "A good, honest look at the real world does not suggest a pattern of mathematical minimality," says the Stanford physicist Leonard Susskind, who seems to have no regrets about string theory's having "gone from being Beauty to the Beast."

If neither predictive value nor beauty explains the persistence of string theory, then what does? Since the late eighteenth century, no major scientific theory has been around for more than a decade without getting a thumbs-up or a thumbs-down. Correct theories nearly always triumph quickly. But string theory, in one form or another, has been hanging on inconclusively for more than thirty-five years. Einstein's own pursuit of a unified theory of physics in the last three decades of his life is often cited as a case study in futility. Have a thousand string theorists done any better?

The usual excuse offered for sticking with what increasingly looks like a failed program is that no one has come up with any better ideas for unifying physics. But Smolin and Woit have a different explanation, one that can be summed up in the word "sociology." Both are worried that academic physics has become dangerously like what the social constructivists have long charged it with being: a community that is no more rational or objective than any other group of humans. String theorists dominate the country's top physics departments. At the Institute for Advanced Study, the director and nearly all of the particle physicists with permanent positions are string theorists. Eight of the nine MacArthur fellowships awarded to particle physicists over the years have gone to string theorists. Since the fall-off in academic hiring in the nineteen-seventies, the average age of tenured physics professors has reached nearly sixty. Every year, around eighty people receive Ph.D.s in particle physics, but only around ten of them can expect to get permanent jobs in the field. In this hypercompetitive environment, the only hope for a young theoretical physicist is to curry favor by solving a set problem in string theory. "Nowadays," one established figure in the field has said, "if you're a hot-shot young string theorist you've got it made."

Both authors also detect a cultlike aspect to the string-theory community, with Witten as the guru. Perhaps, it has been joked, physicists might have an easier time getting funding from the Bush Administration if they represented string theory as a “faith-based initiative.” Smolin deplores what he considers to be the shoddy scientific standards that prevail in the string-theory community, where long-standing but unproved conjectures are assumed to be true because “no sensible person”—that is, no member of the tribe—doubts them. The most hilarious recent symptom of string theory’s lack of rigor is the so-called Bogdanov Affair, in which French twin brothers, Igor and Grichka Bogdanov, managed to publish egregiously nonsensical articles on string theory in five peer-reviewed physics journals. Was it a reverse Sokal hoax? (In 1996, the physicist Alan Sokal fooled the editors of the postmodern journal *Social Text* into publishing an artful bit of drivel on the “hermeneutics of quantum gravity.”) The Bogdanov brothers have indignantly denied it, but even the Harvard string-theory group was said to be unsure, alternating between laughter at the obviousness of the fraud and hesitant concession that the authors might have been sincere.

These two books present the case against string theory with wit and conviction, though Smolin’s book is by far the more lucid and accessible. Woit has too many pages full of indigestible sentences like “The Hilbert space of the Wess-Zumino-Witten model is a representation not only of the Kac-Moody group, but of the group of conformal transformations as well.” (Distressingly, he goes on to confess that this is “a serious oversimplification.”) Let’s assume that the situation in theoretical physics is as bad as Smolin and Woit say it is. What are non-physicists supposed to do about it? Should we form a sort of children’s crusade to capture the holy land of physics from the string-theory usurpers? And whom should we install in their place?

Smolin furnishes the more definite answer. The current problem with physics, he thinks, is basically a problem of style. The initiators of the dual revolution a century ago—Einstein, Bohr, Schrödinger, Heisenberg—were deep thinkers, or “seers.” They confronted questions about space, time, and matter in a philosophical way. The new theories they created were essentially correct. But, Smolin writes, “the development of these theories required a lot of hard technical work, and so for several generations physics was ‘normal science’ and was dominated by master craftspeople.” Today, the challenge of unifying those theories will require another revolution, one that mere virtuoso calculators are ill-equipped to carry out. “The paradoxical situation of string theory—so much promise, so little fulfillment—is exactly what you get when a lot of highly trained master craftspeople try to do the work of seers,” Smolin writes.

The solution is to cultivate a new generation of seers. And what, really, is standing in the way of that? Einstein, after all, didn’t need to be nurtured by the physics establishment, and Smolin gives many examples of outsider physicists in the style of Einstein, including one who spent ten years in a rural farmhouse successfully reinterpreting general relativity. Neither Smolin nor Woit calls for the forcible suppression of string theory. They simply ask for a little more diversity. “We are talking about perhaps two dozen theorists,” Smolin says. This is an exceedingly modest request, for theoretical physics is the cheapest of endeavors. Its practitioners require no expensive equipment. All they need is legal pads and pencils and blackboards and chalk to ply their trade, plus room and board and health insurance and a place to park their bikes. Intellectually daunting as the crisis in physics may be, its practical solution would seem to demand little more than the annual interest on the rounding error of a Google founder’s fortune.

“How strange it would be if the final theory were to be discovered in our own lifetimes!” Steven Weinberg wrote some years ago, adding that such a discovery would mark the sharpest discontinuity in intellectual history since the beginning of modern science, in the seventeenth century. Of course, it is possible that a final theory will never be found, that neither string theory nor any of the alternatives mentioned by Smolin and Woit will come to anything. Perhaps the most fundamental truth about nature is simply beyond the human intellect, the way that quantum mechanics is beyond the intellect of a dog. Or perhaps, as Karl Popper believed, there will prove to be no end to the succession of deeper and deeper theories. And, even if a final theory is found, it will leave the questions about nature that most concern us—how the brain gives rise to consciousness, how we are constituted by our genes—untouched. Theoretical physics will be finished, but the rest of science will hardly notice. ♦