What if string theory is WRONG?

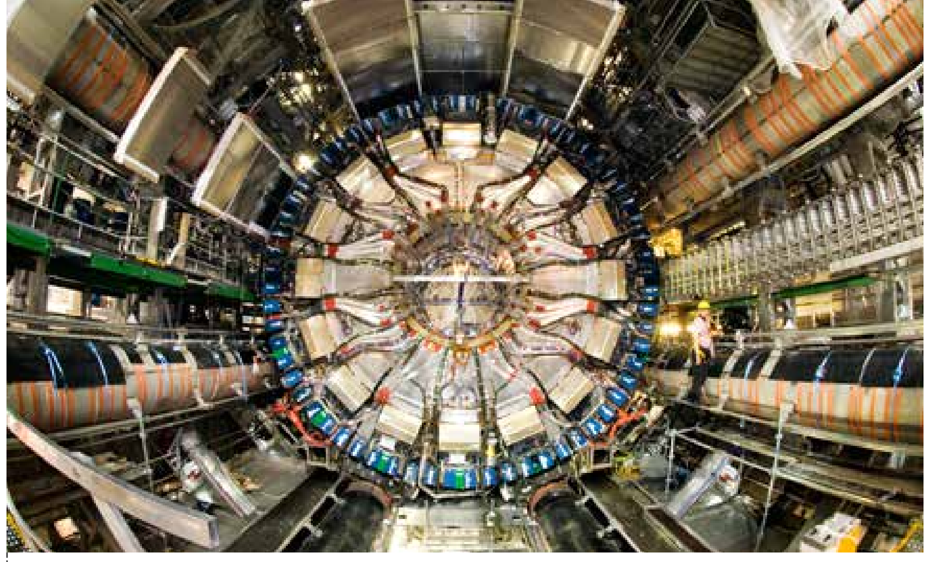
If it is, then dark matter, dark energy, and cosmic inflation are in big trouble. /// BY STEN ODENWALD

Scientists pin their hopes of unifying nature's fundamental forces to a single concept crafted over the course of 3 decades by thousands of mathematicians and physicists. It's called superstring theory.

Its basic ingredients are one-dimensional strings of pure energy that exist in a 10-dimensional universe, four of which are our familiar spatial dimensions plus time. Strings' vibration and movement create the fabric of space itself, along with all of nature's fundamental forces and elementary particles.

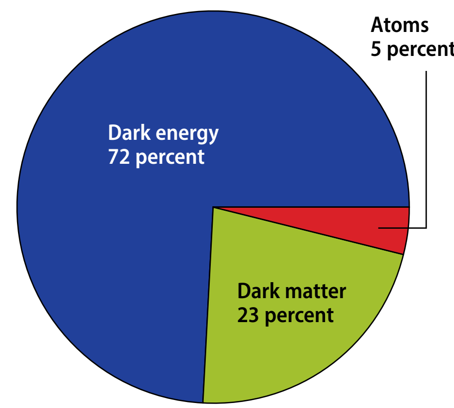
Now, imagine a future in which physicists are delivered the bad news: irrefutable data proving superstring theory doesn't work in our physical world. We're nowhere near such a crisis today, but it's sobering to realize what we stand to lose if physics' best bet proves to be a complete dead end.

IF CURRENT THEORIES about supersymmetry are correct, every elementary particle has a massive superpartner not yet detected. Scientists hope to detect some of these particles using the Large Hadron Collider, which smashes atomic nuclei to liberate the fundamental constituents of matter. DON DIXON FOR *ASTRONOMY*



SCIENTISTS AT CERN will use the Large Hadron Collider's ATLAS detector to smash together high-velocity proton beams. The resulting subatomic debris should reveal fundamental particle processes. The ATLAS experiment is one of the largest collaborative efforts ever attempted in the physical sciences. The project involves 2,500 physicists from 169 institutions in 37 countries. CERN/CLAUDIA MARCELLONI

Cosmic constituents



COSMOLOGISTS' best tally of cosmic content comes from NASA's Wilkinson Microwave Anisotropy Probe (WMAP). Normal matter accounts for only about 5 percent of the total. *ASTRONOMY*: ROEN KELLY

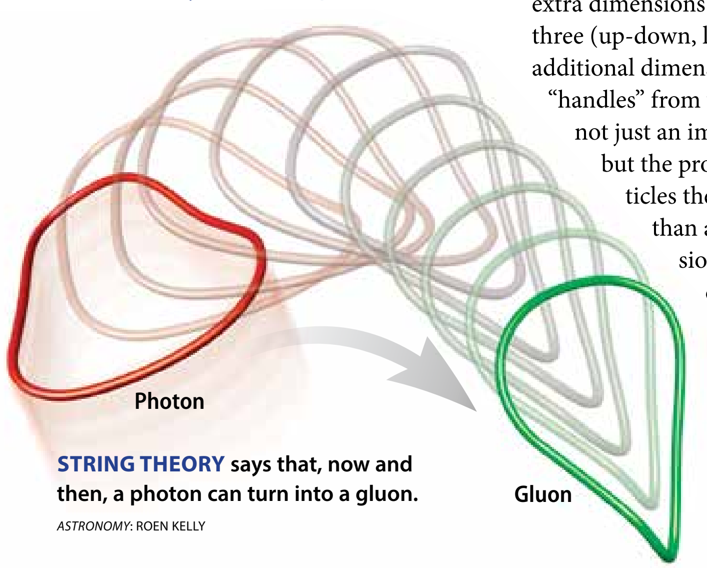
Extra dimensions

Superstring theory is based on three key ideas that remain experimentally unproven after 30 years of research: the principle of supersymmetry, additional spatial dimensions, and gravity as a force defined by the exchange of quantum particles.

Supersymmetry is a mathematical principle that allows force-carrying particles, such as photons and gluons, to transform into one another. It also allows the unification of gravity with other forces because its particle, which some call the graviton, can transform into one of the other force-carriers. Although this idea is mathematically elegant, and puts gravity on an equal footing with the other forces, no one has ever detected, for example, a photon turning into a gluon. Luckily, other ways to search for supersymmetry exist.

If nature follows supersymmetry, then every normal particle has a superpartner: Electrons partner with "selectrons," photons with "photinos," quarks with "squarks," and so on. These superpartners haven't been seen yet, but scientists built a new accelerator, the Large Hadron Collider (LHC), at the European Organization for Nuclear Research (CERN) in Switzerland to find them. Researchers hope experiments with the LHC will turn up at least a few of the lightest superparticles. Such a success would be a prelude to confirming the most bizarre physics idea of the last 80 years — extra dimensions to space.

Identity change



STRING THEORY says that, now and then, a photon can turn into a gluon. *ASTRONOMY*: ROEN KELLY

Space-time is just the start

Conventional superstring theory requires extra dimensions to space beyond the usual three (up-down, left-right, near-far). These additional dimensions give physicists extra "handles" from which they can fashion not just an improved theory of gravity but the properties of the known particles themselves. Vastly smaller than a proton, the extra dimensions appear as six additional coordinates attached to each point in space.

They actually form their own closed, six-dimensional spaces that must be everywhere. Otherwise, particles would take on different properties as they move through our three-dimensional world. There are trillions of possible six-dimensional geometries, each calling into existence a unique universe with specific physical laws, particles, and forces. Which one is ours?

Some researchers feel all geometric possibilities exist in the multiverse — the collection of all possible universes with all possible physical laws logically allowed by superstring theory. Ours, then, is a Goldilocks Universe, where exactly the right six-dimensional geometry allows the existence of life as we know it. There may be 10^{100} universes that fail this challenge. There may be others in which new, unthinkable possibilities for life could flourish.

If extra dimensions really exist, they'll change the behavior of gravity at small distances. In 2003, John Price of the University of Colorado at Boulder and his colleagues announced an ultra-precise measurement of gravity at scales of one-tenth of a millimeter. The team saw no departure from gravity's inverse-square law, in which the force of attraction decreases by the square of the distance between bodies. So, the hunt resumes below this limit to test other extra-dimensional possibilities.

"We have a number of hints from experiments and theoretical ideas that make us think they're probably out there," says Joseph Lykken, a physicist at Fermi National Accelerator Laboratory in Batavia, Illinois. "That's why we're so excited about looking for them."

If scientists validate superstring theory, we'll see the birth of the first unified description of the physical world. Along the way, we'll have to make peace with the idea of a multiverse in which trillions of other universes may exist, each with its own natural laws, forces, and particles.

But what would happen if all these ideas are wrong? String theory would go down in history as the most spectacular wrong turn science has ever taken. It will have sent thousands of physicists on a spectacular wild-goose chase, while simultaneously revolutionizing obscure subjects in pure mathematics.

Forget supersymmetry?

If extra dimensions don't exist, then supersymmetry doesn't either. Without both of these cornerstones of string theory, physicists would be left with what they refer to as the standard model.

The standard model combines electroweak theory (EW) — itself a combination of electromagnetism and the weak nuclear force — with a separate theory of the strong nuclear force called quantum chromodynamics (QCD). Each part behaves like a train on a separate track. But just as electricity and magnetism were unified into electromagnetism, the standard model's EW and QCD are so similar that they, too, must be unified.

Grand unification theories (GUTs) tried to do just this. Physicists worked with dozens of prospects between 1975 and 1980; most failed. Many predicted the proton, the foundation of atomic nuclei, would rapidly decay; some introduced faster-than-light tachyons as new physical particles.

None turned out to work very well once physicists puzzled out their intricate mathematics and compared them to the real world. Physicist Mark Srednicki at the University of California, Santa Barbara, once complained about one candidate, "It is impossible to get this pile of junk to come out anything like the standard model."

> LITERALLY trillions of possible six-dimensional geometries exist, each calling into existence a unique universe. Which one is ours?

In some respects, a world without superstring theory isn't so bad. The standard model and ordinary general relativity hold that all astronomers need to describe accurately most of the phenomena they study, from galaxy evolution and supernova detonations to the extreme physics of neutron stars and black holes.

As for unification, the late physicist Richard Feynman once said, "Perhaps it is difficult for physicists to unify gravity with the other forces because nature never intended for them to be unified in the first place."

Cosmic trouble

Astronomers have also discovered there is far more to the universe than what we can see. The standard model has absolutely no place in it for dark matter and dark energy, ingredients that constitute 95 percent of the universe's gravitating "stuff."

And it gets worse.

Without supersymmetry, some physicists have proven that the energy of empty space would be so enormous that the universe would instantly collapse.

Only by understanding physics beyond the standard model can we hope to understand how the vacuum and the universe's dark side work. And only string theory appears able to serve as a reliable mathematical guide to that larger universe.

Another major disaster to astronomy would be in our understanding of the largest structures in the universe and the universe's large-scale smoothness revealed by studies of the cosmic microwave background (CMB).

Inflation, a super-fast expansion of the universe when it was less than a trillionth of a trillionth of a second old, explains observations of the CMB made by satellites such as NASA's Wilkinson Microwave Anisotropy Probe (WMAP). But it can't account for

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Astronomer **Sten Odenwald** *works at NASA's Goddard Space Flight Center in Maryland and is investigating the cosmic infrared background.*

STRING SPEAK

GENERAL RELATIVITY
Albert Einstein's formulation of gravity, which shows that space and time communicate the gravitational force through their curvature.

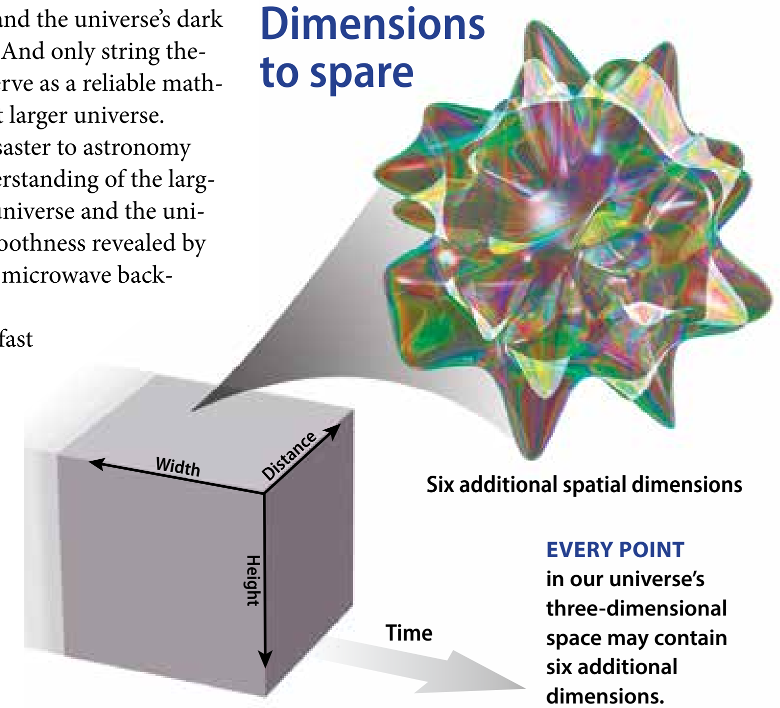
GLUON
The smallest bundle of the strong nuclear force, which holds atomic nuclei together.

QUANTUM MECHANICS
Laws governing the universe on subatomic scales in which uncertainty and the dual nature of waves and particles become apparent.

STANDARD MODEL
A theory of interactions of nature's most fundamental known particles (e.g., electrons and quarks) developed in the 1960s and early 1970s. Its inability to explain gravity suggests a more fundamental theory exists.

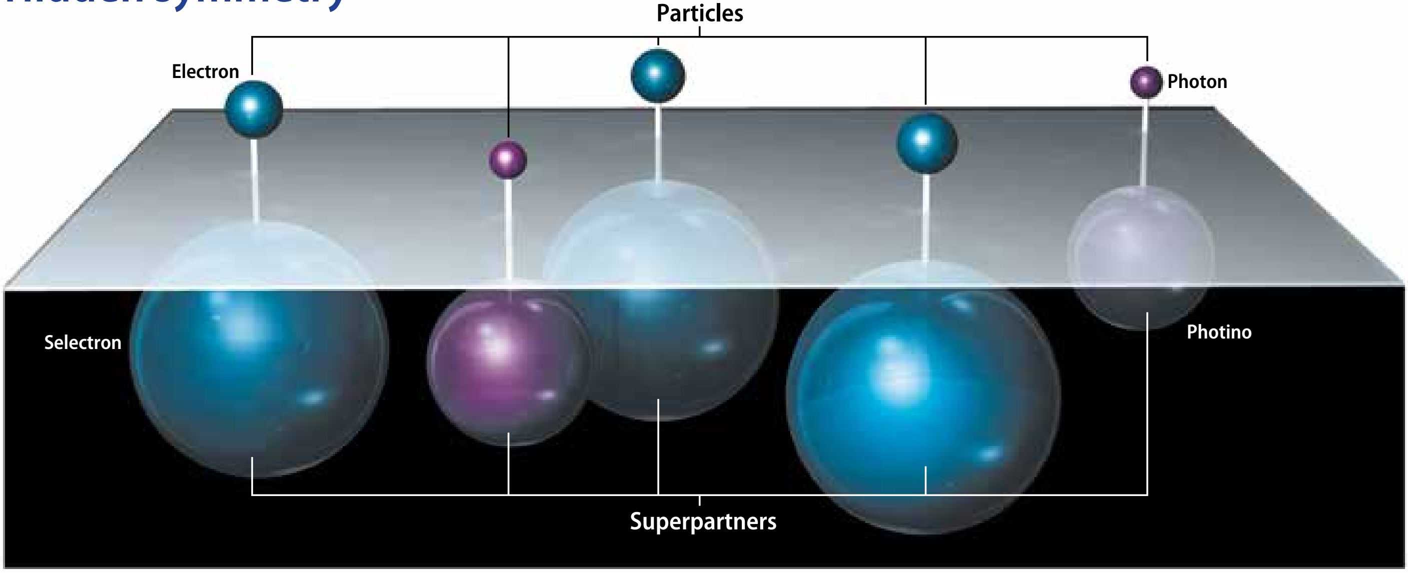
STRING THEORY
A unified theory of the universe postulating that the fundamental ingredients of nature are not particles but one-dimensional filaments called strings. String theory unites quantum mechanics and general relativity, which are otherwise incompatible; often short for superstring theory.

Dimensions to spare



EVERY POINT in our universe's three-dimensional space may contain six additional dimensions. *ASTRONOMY*: ROEN KELLY

Hidden symmetry



SUPERSYMMETRY envisions a "shadow world" that links known particles to massive superpartners not yet detected. *ASTRONOMY*: ROEN KELLY

the small-scale structure that led to galaxy formation. Only by reaching back to the era before inflation, often called the quantum-gravity era or Planck Era, can cosmologists explain why today's universe looks the way it does at galactic scales.

The standard model and ordinary general relativity aren't enough. Only some larger, more encompassing theory can lead the way. "It is hard to find a serious paper about particle phenomenology that doesn't in some way use the tools of superstring theory," says Stanford University physicist Leonard Susskind. "Furthermore, we all agree that the origin of elementary particles is most likely at the Planck scale and cannot be understood without a good theory of quantum gravity."

Mediating gravity

THE GRAVITY FORCE we feel arises from hypothetical gravitons, according to superstring theory.
ASTRONOMY: ROEN KELLY

In the 1980s, when Alan Guth at the Massachusetts Institute of Technology and Andrei Linde, now at Stanford University, first developed the inflation idea, it had nothing to do with string theory, extra dimensions, or supersymmetry. Refinements to inflation have come only by borrowing ideas from string theory.

End game

Without superstring theory, we'd lose the intriguing philosophical prospects for the multiverse, with its infinite and eternal creativity in spawning new universes. We'd have no mathematics for spanning the gap between everyday physics and the high energies where quantum gravity operates. The road to creating a quantum description of gravity will be a murky one.

More immediately, dark matter and dark energy would remain imponderable enigmas, shorn of any clues about where they come from. Astronomers can live without knowing the quantum properties of gravity. But to learn that 95 percent of the cosmos is unknowable would be a bitter pill for astronomers to swallow.

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It would be even worse for physicists. Without a logical framework in which to pose and answer questions, our inquiries into the fundamental aspects of the physical world would devolve into semantic quibbles. Other impacts prevent us from simply turning back the theoretical clock to the 1970s.

"We would be ignoring the vast amount of mathematical knowledge that has been gained over the subsequent years, mostly from string theory," Susskind explains. "That is just not going to happen. The changes in our theoretical understanding of quantum field theory, gravity, and black holes are completely irreversible. The mathematics of superstring theory has even worked its way into nuclear physics and heavy ion collisions, as well as into condensed matter physics."

Historically, there are many examples of scientists forced to abandon ideas. Steady-state cosmology lasted nearly 30 years before science tossed it aside. While string theory is sparse on experimental validation, the situation is not so different from general relativity in its early days, when difficult mathematics made calculating a prediction extremely challenging.

Princeton University physicist Ed Witten once described string theory as 21st-century physics glimpsed long before its time. Let's hope it doesn't represent a bit of 25th-century mathematics, too. ■