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- *50, 100 and 150 Years Ago*
- *News Scan*
- *Skeptic*
- *The Myth of the Beginning of Time*
- *Ask the Experts*

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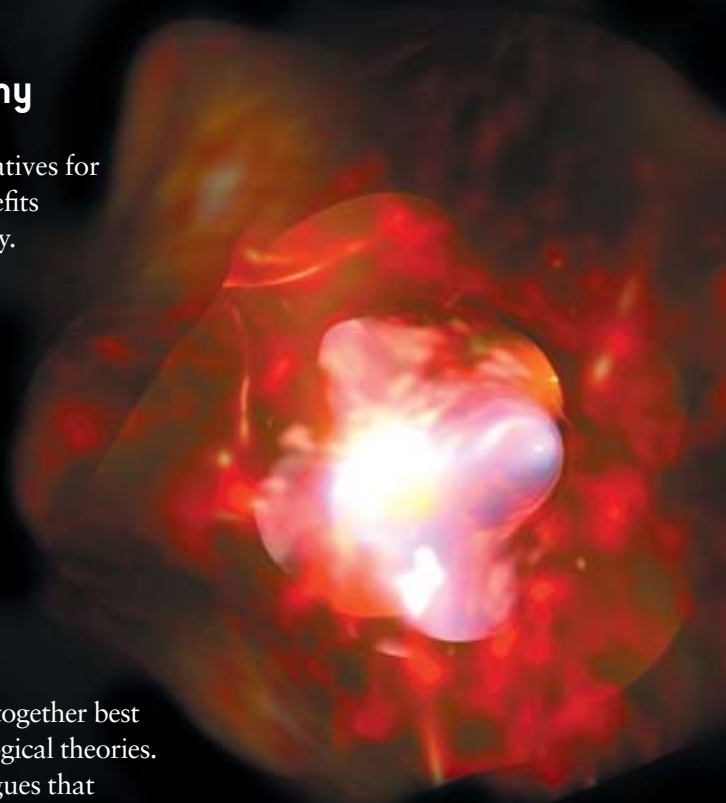

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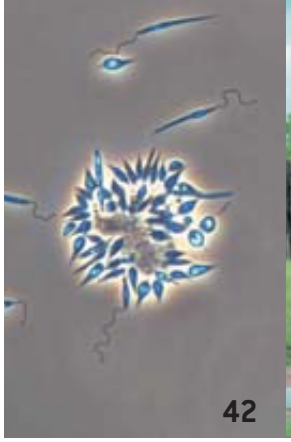

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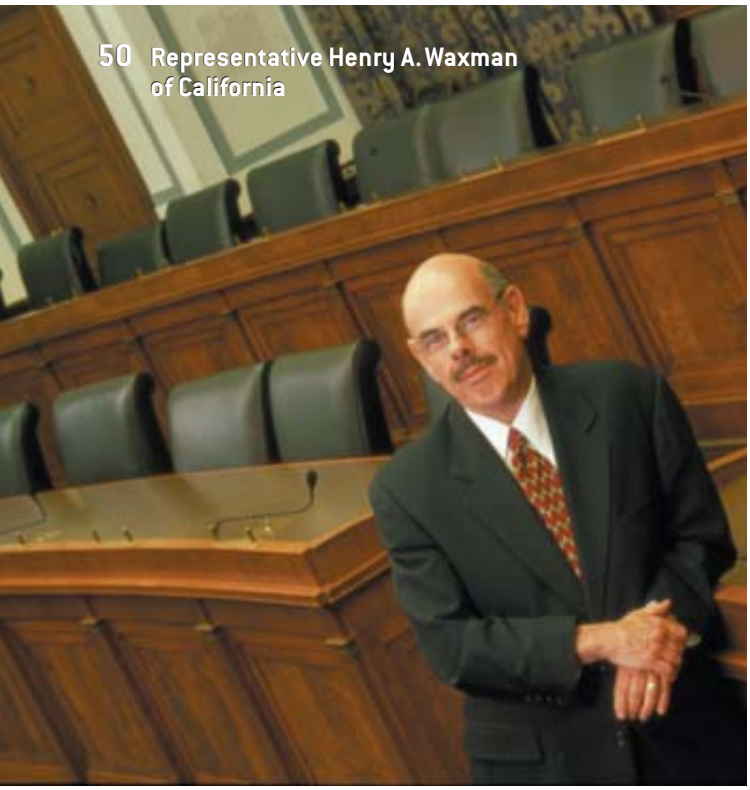
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SA Perspectives

Bush-League Lysenkoism

Starting in the 1930s, the Soviets spurned genetics in favor of Lysenkoism, a fraudulent theory of heredity inspired by Communist ideology. Doing so crippled agriculture in the U.S.S.R. for decades. You would think that bad precedent would have taught President George W. Bush something. But perhaps he is no better at history than at science.

In February his White House received failing marks in a statement signed by 62 leading scientists, including 20 Nobel laureates, 19 recipients of the National Medal of Science, and advisers to the Eisenhower and Nixon administrations. It begins, "Successful application of science has played a large part in the policies that have made the United States of America the world's most powerful nation and its citizens increasingly prosperous and healthy. Although scientific input to the government is rarely the only factor in public policy decisions, this input should always be weighed from an objective and impartial perspective to avoid perilous consequences.... The administration of George W. Bush has, however, disregarded this principle."

STANDING UP for science—or stepping on it?

J. SCOTT APPLEWHITE *AP Photo*

Doubters of that judgment should read the report from the Union of Concerned Scientists (UCS) that accompanies the statement, "Restoring Scientific Integrity in Policy Making" (available at www.ucsusa.org). Among the affronts that it details: The administration misrepresented the findings of the National Academy of Sciences and other experts on climate change. It meddled with the discussion of climate change in an Environmental Protection Agency report until the EPA eliminated that section. It suppressed another EPA study that showed that the administration's proposed Clear Skies Act would do less than current law to reduce air pollution and mercury contamination of fish. It even dropped independent scientists from advisory committees on lead poisoning and drug abuse in favor of ones with ties to industry.

Let us offer more examples of our own. The Department of Health and Human Services deleted information from its Web sites that runs contrary to the president's preference for "abstinence only" sex education programs. The Office of Foreign Assets Control made it much more difficult for anyone from "hostile nations" to be published in the U.S., so some scientific journals will no longer consider submissions from them. The Office of Management and Budget has proposed overhauling peer review for funding of science that bears on environmental and health regulations—in effect, industry scientists would get to approve what research is conducted by the EPA.

None of those criticisms fazes the president, though. Less than two weeks after the UCS statement was released, Bush unceremoniously replaced two advocates of human embryonic stem cell research on his advisory Council on Bioethics with individuals more likely to give him a hallelujah chorus of opposition to it.

Blind loyalists to the president will dismiss the UCS report because that organization often tilts left—never mind that some of those signatories are conservatives. They may brush off this magazine's reproofs the same way, as well as the regular salvos launched by California Representative Henry A. Waxman of the House Government Reform Committee [see Insights, on page 52] and maybe even Arizona Senator John McCain's scrutiny for the Committee on Commerce, Science and Transportation. But it is increasingly impossible to ignore that this White House disdains research that inconveniences it.

THE EDITORS editors@sciam.com

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50, 100 & 150 Years Ago

FROM *SCIENTIFIC AMERICAN*

Deathly Dust ▪ Living Clock ▪ Killer Whale

MAY 1954

RADIOACTIVE FOOD—"The second thermonuclear experiment at the explosion grounds in the Marshall Islands was said to be 600 times as forceful as the Hiroshima atomic bomb. The immediate brunt fell on a Japanese fishing vessel called *The Fortunate Dragon,* carrying a harvest of tuna and shark in its open hold. Caught 80 miles from the explosion, it was showered with a white ash of particles which blistered the 23 fishermen's skin and made the fish radioactive. When the ship made port, some of the fish were sold before the government could stop it. Overnight the Japanese people stopped eating fish; housewives shopped with Geiger counters; the price of tuna fell to one third with few takers. The Japanese newspapers looked upon the shower of 'death dust' as the third atomic bombing of Japan."

GOLLY... THEY *DID* LIKE IKE!—"But for the 1948 Democrats who left their party, General Eisenhower would not have gone to the White House. What were the motives behind this great swing of voters to the Republican candidate? A nationwide study was undertaken to provide as full an answer as possible to that intriguing question. A sizable number in each group appeared 'non-partisan' on the candidates' personal qualities, yet among strikingly large percentages of each group of voters, the General held high favor over Governor Stevenson. This strong leaning to Eisenhower as a person appears to have been the one factor which united all the groups that voted for him."

MAY 1904

FLOWER CLOCK—"The Louisiana Purchase Exposition opened at St. Louis, commemorating one of the most important centennials in American history. Its floral clock will be sixteen times larger than any timepiece in the world [*see illustration*]. It will keep accurate time, for beneath the vines and other plants, skilled artisans have constructed machinery similar to the works of a watch. The hands are long steel troughs, in which fertilized earth has been placed to supply nourishment to the vines that will cover the metal. The numerals of the hours will be dark tall foliage plants."

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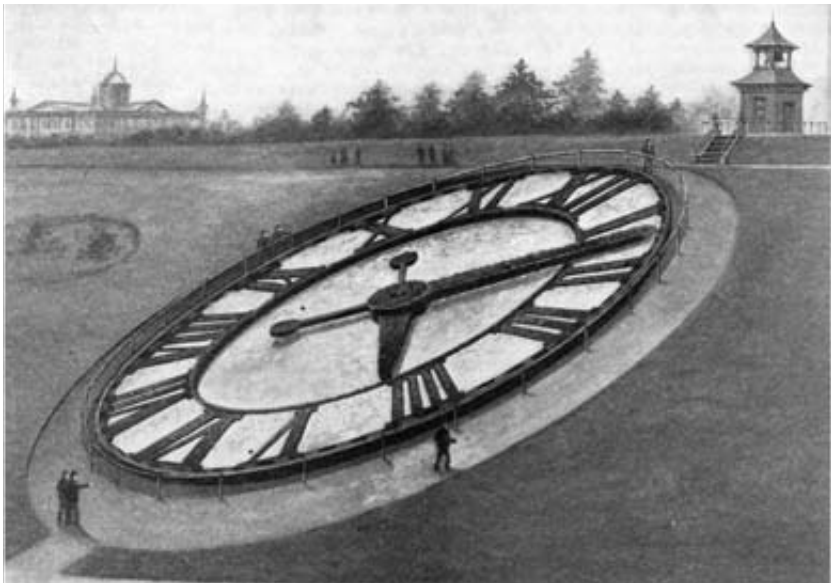

CLOCK made of flowers, St. Louis, 1904

HYDROELECTRICITY AND CO_2—"In San Francisco the cost of electric current for power and light is almost exactly one-seventh of what it was a few years ago, and it is possible to deliver at the factory on the coast, from the melting snows and glaciers of the Rockies, power at a smaller cost than that procured from steam. It has been estimated that the quantity of carbonic acid annually exhaled by the population of New York City is about 450,000 tons, and that this amount is less than three per cent of that produced by the fuel combustion of that city; so we may expect that, with the removal of this great source of contamination of the atmosphere, even the air of our greater cities will be practically as pure as that of the country."

MAY 1854

ORCA—"Lieut. Maury said that Captain Royes, a New England whaleman, wrote him a letter describing sixteen kinds of whales, one of them a strange fish, which the Lieutenant did not find named in any of the books. The Captain called it the 'Killer Whale,' and described him as thirty feet long, yielding about five barrels of oil, having sharp, strong teeth and on the middle of the back a fin, very stout, about four feet long. This 'Killer' is an exceedingly pugnacious fellow. He attacks the right whale, seizing him by the throat, biting till the blood spouts, or till another 'Killer' comes by and eats out the tongue of the tortured fish. This tongue of a right whale is an oily mass, weighing three or four tons. The 'Killer' scours the ocean from pole to pole, is in every sea, and all old whalemen have met him."

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BIOTECH

Body Building

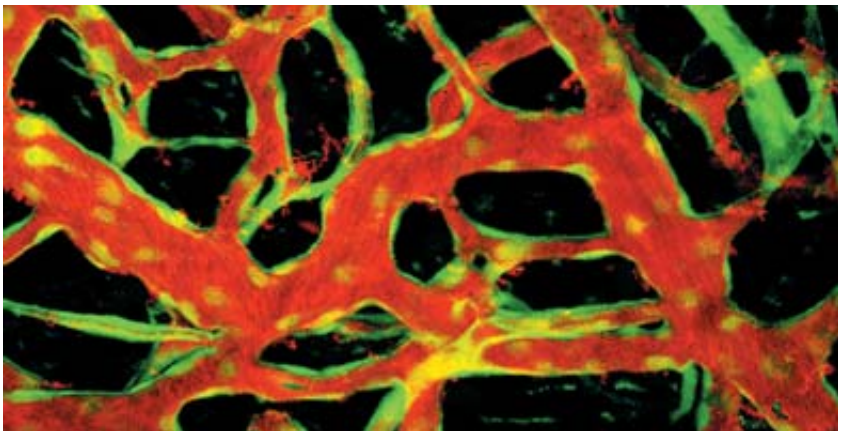
GROWING REPLACEMENT ORGANS IS STILL A LONG WAY OFF **BY CHRISTINE SOARES**

Six years ago Michael Sefton of the University of Toronto challenged his colleagues in the fledgling field of tissue engineering to build a functioning human heart within 10 years. With the isolation of human embryonic stem cells later that year, Sefton's challenge seemed all the more relevant: stem cells, after all, are nature's starting point for building working organs.

Now Sefton admits that the deadline on his Living Implants from Engineering ("LIFE") initiative was naive, and he thinks it will be at least another 10 to 20 years. "We need to be able to walk before we can run," he says, "and the worry today is, Can we make a vascularized piece of tissue or a tissue with two or three cell types in a controlled way?"

Thin sheets of skin and single blood vessels have been grown in the laboratory, and some versions have already been put through human clinical trials. Yet any whole organ would be a complex three-dimensional edifice comprising specialized cells, nerves and muscle, all interwoven with a dense web of veins and capillaries diffusing oxygen and nutrients. The main hurdles have been just getting multiple cell types to grow and work in harmony and spurring formation of the blood vessels required to nourish tissues more than a few hundredths of a millimeter thick.

By mimicking the natural 3-D shape in which an organ grows, tissue engineers are trying to get adjacent cells to "talk" to one another and complete the task of building the desired tissues. This approach has yielded "ink-jet"-dispensed dollops of cell aggregates "printed" in simple patterns that flow together, linking up into larger pieces of tissue. The next step will be to "print" designs using multiple cell types and eventually to print them layer on layer to create larger structures. A similar technique suspends living cells in a clear hydrogel matrix that can be layered or molded into 3-D shapes. Neither tactic has yielded the all-important vascular network needed to sustain thicker tissues.



BLOOD WORK: Rakesh K. Jain of Harvard Medical School grew this web of blood vessels inside a mouse on a scaffold seeded with human vascular endothelial cells (*green*) and muscle precursor cells. Infusing artificial organs with such complex vasculature has proved more difficult.

N. KOIKE ET AL. IN *NATURE*, VOL. 428, PAGES 138–139; 2004

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WHEN HUMANS MEET PIGS

Custom-grown spare parts from stem cells are years away. That means animal organs may be the only realistic alternative for patients awaiting transplants. But xenotransplantation took a serious blow in January, when Jeffrey L. Platt of the Mayo Clinic and his colleagues confirmed that a virus present in most pigs, porcine endogenous retrovirus (PERV), could infect human cells in vivo. PERVs are harmless to pigs, but no one knows how they might react when transplanted into humans. The Mayo team injected human stem cells into fetal swine; after the pigs were born, the researchers found that PERV infected the host cells as well as the human cells. What is more, they detected chimeric cells containing fused pig and human DNA that were positive for PERV, too.

More progress has been made by seeding stem cells onto a variety of simple scaffolds impregnated with growth-promoting chemicals. Last fall, for example, researchers from the Massachusetts Institute of Technology and the Technion-Israel Institute of Technology reported generating tissues of neural, liver and cartilage cells, as well as formation of a "3D vessel-like network" on a biodegradable polymer scaffold seeded with human embryonic stem cells. When transplanted into a mouse, the constructs remained intact and appeared to connect with the animal's blood supply.

"RENAL UNIT"—a proto-kidney—produced urinelike liquid after 12 weeks of growth.

Still, scientists working with stem cells, embryonic or otherwise, admit that they are just beginning to learn tricks for controlling the kind of tissue the cells become and just starting to discern the cues cells give to one another as well as take from their natural environment during the course of organ development. "We don't have anything like [nature's] exquisite repertoire of tools," Sefton says.

And so most models for growing entire organs involve using some kind of living "bioreactor." In some cases, it could be the same patient in need of the organ. Anthony Atala of Wake Forest University, who once grew a simple bladder in a beaker and transplanted it into a dog, teamed up more recently with Robert P. Lanza, also now with Wake Forest, and others to grow a mini kidney inside a cow. Kidney progenitor cells were taken from a fetal clone of the cow in question, then implanted into the cow's body, where they developed into proto-organs with all the cell types of a normal kidney. These "renal units" even produced a urinelike liquid.

The idea of seeding an organ and letting the body do the rest of the construction might work for a kidney, because the patient could be treated with dialysis while the new organ was being generated, according to Jeffrey L. Platt, director of transplantation biology at the Mayo Clinic. For a patient suffering from lung or heart failure, however, growing a new organ would put too much strain on an already weak body. But every advance toward creating ever more complex tissues might yield a lifesaving patch for a moderately damaged heart or liver, Platt says, along with fresh insight into how nature builds bigger body parts.

COURTESY OF ROBERT P. LANZA AND ANTHONY J. ATALA

ASTRONOMY

Burning Down to Rock

GAS GIANTS MIGHT GET COOKED CLEAN TO THEIR SOLID CORES **BY CHARLES CHOI**

The first rocky worlds astronomers detect circling other stars could resemble Inferno more than Earth. The existence of such lava-coated planets, which may prove commonplace, will force a reconsideration of theories about planetary formation.

Since 1991 observers have discovered some 120 exoplanets—worlds outside our solar system. All but three appear, by their great size and low density, to be gas giants. Roughly a sixth are "hot Jupiters" surprisingly near their stars, all closer than Mercury is to our sun.

Some hot Jupiters live just too close to their stars for comfort. Last year the Hubble Space Telescope provided the first evidence of an evaporating atmosphere, from an exoplanet, HD 209458b, that circles its star at a distance of less than 1/20 the distance between the sun and Earth. The star roasts the exoplanet and rips at it with its gravity. The result: the exoplanet blows away at least 10,000 tons of gas a second, which streaks off in a vast plume 200,000 kilometers long. Astronomer Alfred Vidal-Madjar of the Institute

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of Astrophysics in Paris and his team dubbed the world "Osiris," after the Egyptian god torn to pieces by his evil brother Set.

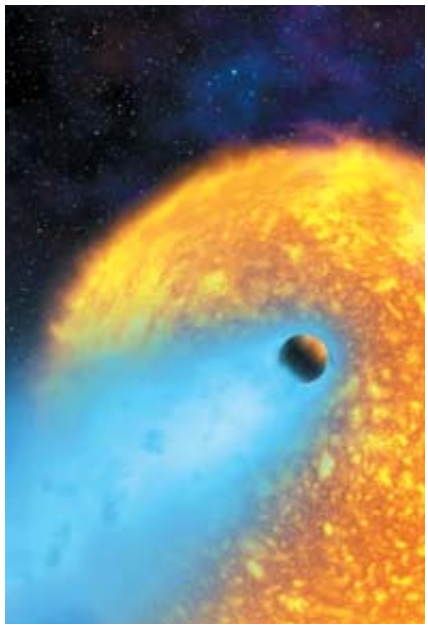
In contemplating the fate of Osiris, Vidal-Madjar and his team calculated how long it and other giants might live. At roughly 220 times Earth's mass, Osiris boasts a gravitational pull strong enough to hold its atmosphere until its star dies. But the researchers speculate the hellish rate of evaporation might completely scour all gas off smaller hot Jupiters or those closer to their stars than Osiris.

This could lead to a new class of planets—a dead giant's hard, bare heart. The astronomers named such worlds "chthonians," after primeval Greek deities of the underworld. In findings to appear in *Astronomy and Astrophysics*, astronomer Alain Lecavelier des Etangs of the Institute of Astrophysics and his co-workers figure that the four exoplanets discovered so far may one day become chthonians.

Though remnants of far larger worlds, chthonians would still weigh in at roughly 10 to 15 times Earth's mass and six to eight times Earth's diameter. With searing temperatures of roughly 1,000 degrees Celsius at their surfaces, they would look "like lava planets," Lecavelier des Etangs imagines. If chthonian exoplanets exist, "it is probable that they will be the first rocky planets to be detected around other stars," Vidal-Madjar remarks. (Three planets, two about three to four times Earth's mass and the third twice the mass of the moon, were discovered in the 1990s and most likely are solid, but they all orbit a pulsar.)

Spotting chthonians would help answer questions regarding planetary formation, explains astronomer Adam Burrows of the University of Arizona. Researchers think that worlds are born from disks of gas and dust encircling stars. The most popular idea proposes that solid cores amass from protoplanetary disks and behave like seeds, attracting gas to grow into giant planets.

The alternative theory suggests that giant planets may not possess hard cores. Instead they may have fluid centers, after having condensed directly from protoplanetary disks without forming solid hearts. Scientists have not conclusively identified whether the centers of giants in our own solar system are solid. Detecting chthonians could prove one scenario of planetary formation right.



GAS GIANTS may lose their atmospheres to their stars, resulting in rocky worlds called chthonians.

The European Southern Observatory telescope in Chile has an outside chance of finding them next year: a new instrument there could detect planets as low as about 15 times Earth's mass by looking for the gravitational tugs each has on its star. The best chance to spot chthonians will come from the first space probes sensitive enough to see Earth-size planets: the French satellite COROT, scheduled for launch in 2006, and NASA's Kepler, around 2007. These missions might uncover several tens of chthonians, probably by spotting them when they pass in front of their stars, dimming them.

Burrows thinks that chthonian exoplanets may not turn out to be all rock. If a chthonian's star does not strip off its atmosphere, ices found in a giant's core might survive underneath. Lecavelier des Etangs says that chthonians might even support life, although it would almost certainly be "very different from what we know on Earth."

Charles Choi, a frequent contributor, is based in New York City.

ESA, ALFRED VIDAL-MADJAR *Institute of Astrophysics* AND NASA

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The Enchanted Glass

Francis Bacon and experimental psychologists show why the facts in science never just speak for themselves By MICHAEL SHERMER

In the first trimester of the gestation of science, one of science's midwives, Francis Bacon, penned an immodest work entitled *Novum Organum* ("new tool," after Aristotle's *Organon*) that would open the gates to the "Great Instauration" he hoped to inaugurate through the scientific method. Rejecting both the unempirical tradition of scholasticism and the Renaissance quest to recover and preserve ancient wisdom, Bacon sought a blend of sensory data and reasoned theory.

Cognitive barriers that color clear judgment presented a major impediment to Bacon's goal. He identified four: idols of the cave (individual peculiarities), idols of the marketplace (limits of language), idols of the theater (preexisting beliefs) and idols of the tribe (inherited foibles of human thought).

We have a cognitive bias to see ourselves in a more positive light than others see us.

Experimental psychologists have recently corroborated Bacon's idols, particularly those of the tribe, in the form of numerous cognitive biases. The self-serving bias, for example, dictates that we tend to see ourselves in a more positive light than others see us: national surveys show that most businesspeople believe that they are more moral than other businesspeople, and psychologists who study moral intuition think they are more moral than other such psychologists. In one College Entrance Examination Board survey of 829,000 high school seniors, less than 1 percent rated themselves below average in "ability to get along with others," and 60 percent put themselves in the top 10 percent. And according to a 1997 *U.S. News and World Report* study on who Americans believe are most likely to go to heaven, 52 percent said Bill Clinton, 60 percent thought Princess Diana, 65 percent chose Michael Jordan and 79 percent selected Mother Teresa. Fully 87 percent decided that the person most likely to see paradise was the survey taker!

Princeton University psychology professor Emily Pronin and her colleagues tested an idol called bias blind spot, in which subjects recognized the existence and influence of eight different cognitive biases in other people but failed to see those same biases in themselves. In one study on Stanford University students, when asked to compare themselves with their peers on such personal qualities as friendliness and selfishness, they predictably rated themselves higher. Even when the subjects were warned about the "better than average" bias and asked to reconsider their original assessments, 63 percent claimed that their initial evaluations were objective, and 13 percent even claimed to be too modest.

In a second study, Pronin randomly assigned subjects high or low scores on a "social intelligence" test. Unsurprisingly, those who were given high marks rated the test as being fairer and more useful than those receiving low marks. When the subjects were then asked if it was possible that they had been influenced by the score on the test, they responded that other participants had been far more biased than they were. In a third study, in which Pronin queried subjects about what method they used to assess their own biases and those of others, she found that people tend to use general theories of behavior when evaluating others but use introspection when appraising themselves. In what is called the introspection illusion, people do not believe that others can be trusted to do the same: okay for me but not for thee.

Psychologist Frank J. Sulloway of the University of California at Berkeley and I made a similar discovery of an attribution bias in a study we conducted on why people say they believe in God and why they think other people do so. In general, most individuals attribute their own faith to such intellectual reasons as the good design and complexity of the world, whereas they attribute others' belief in God to such emotional reasons as that it is comforting, that it gives meaning and that it is how they were raised.

None of these findings would surprise Francis Bacon, who, four centuries ago, noted: "For the mind of man is far from the nature of a clear and equal glass, wherein the beams of things should reflect according to their true incidence; nay, it is rather like an enchanted glass, full of superstition and imposture, if it be not delivered and reduced." SA

Michael Shermer is publisher of Skeptic *(www.skeptic.com) and author of* The Science of Good and Evil.

BRAD HINES

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the myth of TIME

The Beginning of

By Gabriele Veneziano

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String theory suggests that the BIG BANG was not the origin of the universe but simply the outcome of a preexisting state

Was the big bang really the beginning of time?

Or did the universe exist before then? Such a question seemed almost blasphemous only a decade ago. Most cosmologists insisted that it simply made no sense—that to contemplate a time before the big bang was like asking for directions to a place north of the North Pole. But developments in theoretical physics, especially the rise of string theory, have changed their perspective. The pre-bang universe has become the latest frontier of cosmology.

The new willingness to consider what might have happened before the bang is the latest swing of an intellectual pendulum that has rocked back and forth for millennia. In one form or another, the issue of the ultimate beginning has engaged philosophers and theologians in nearly every culture. It is entwined with a grand set of concerns, one famously encapsulated in an 1897 painting by Paul Gauguin: *D'ou venons-nous? Que sommes-nous? Ou allons-nous?* "Where do we come from? What are we? Where are we going?" The piece depicts the cycle of birth, life and death—origin, identity and destiny for each individual—and these personal concerns connect directly to cosmic ones. We can trace our lineage back through the generations, back through our animal ancestors, to early forms of life and protolife, to the elements synthesized in the primordial universe, to the amorphous energy deposited in space before that. Does our family tree extend forever backward? Or do its roots terminate? Is the cosmos as impermanent as we are?

The ancient Greeks debated the origin of time fiercely. Aristotle, taking the no-beginning side, invoked the principle that out of nothing, nothing comes. If the universe could never have gone from nothingness to somethingness, it must always have existed. For this and other reasons, time must stretch eternally into the past and future. Christian theologians tended to take the opposite point of view. Augustine contended that God exists outside of space and time, able to bring these constructs into existence as surely as he could forge other aspects of our world. When asked, "What was God doing *before* he created the world?" Augustine answered, "Time itself being part of God's creation, there was simply no *before!*"

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Einstein's general theory of relativity led modern cosmologists to much the same conclusion. The theory holds that space and time are soft, malleable entities. On the largest scales, space is naturally dynamic, expanding or contracting over time, carrying matter like driftwood on the tide. Astronomers confirmed in the 1920s that our universe is currently expanding: distant galaxies move apart from one another. One consequence, as physicists Stephen Hawking and Roger Penrose proved in the 1960s, is that time cannot extend back indefinitely. As you play cosmic history backward in time, the galaxies all come together to a single infinitesimal point, known as a singularity—almost as if they were descending into a black hole. Each galaxy or its precursor is squeezed down to zero size. Quantities such as density, temperature and spacetime curvature become infinite. The singularity is the ultimate cataclysm, beyond which our cosmic ancestry cannot extend.

Strange Coincidence

THE UNAVOIDABLE singularity poses serious problems for cosmologists. In particular, it sits uneasily with the high degree of homogeneity and isotropy that the universe exhibits on large scales. For the cosmos to look broadly the same everywhere, some kind of communication had to pass among distant regions of space, coordinating their properties. But the idea of such communication contradicts the old cosmological paradigm.

To be specific, consider what has happened over the 13.7 billion years since the release of the cosmic microwave background radiation. The distance between galaxies has grown by a factor of about 1,000 (because of the expansion), while the radius of the observable universe has grown by the much larger factor of about 100,000 (because light outpaces the expansion). We see parts of the universe today that we could not have seen 13.7 billion years ago. Indeed, this is the first time in cosmic history that light from the most distant galaxies has reached the Milky Way.

Nevertheless, the properties of the Milky Way are basically the same as those of distant galaxies. It is as though you showed up at a party only to find you were wearing exactly the same clothes as a dozen of your closest friends. If just two of you were dressed the same, it might be explained away as coincidence, but a dozen suggests that the partygoers had coordinated their attire in advance. In cosmology, the number is not a dozen but tens of thousands—the number of independent yet statistically identical patches of sky in the microwave background.

One possibility is that all those regions of space were endowed at birth with identical properties—in other words, that the homogeneity is mere coincidence. Physicists, however, have thought about two more natural ways out of the impasse: the early universe was much smaller or much older than in standard cosmology. Either (or both, acting together) would have made intercommunication possible.

The most popular choice follows the first alternative. It postulates that the universe went through a period of accelerating expansion, known as inflation, early in its history. Before this phase, galaxies or their precursors were so closely packed that they could easily coordinate their properties. During inflation, they fell out of contact because light was unable to keep pace with the frenetic expansion. After inflation ended, the expansion began to decelerate, so galaxies gradually came back into one another's view.

Physicists ascribe the inflationary spurt to the potential energy stored in a new quantum field, the inflaton, about 10^{-35} second after the big bang. Potential energy, as opposed to rest mass or kinetic energy, leads to gravitational repulsion. Rather than slowing down the expansion, as the gravitation of ordinary matter would, the inflaton accelerated it. Proposed in 1981, inflation has explained a wide variety of observations with precision [see "The Inflationary Universe," by Alan H. Guth and Paul J. Steinhardt; SCIENTIFIC AMERICAN, May 1984; and "Four Keys to Cosmology," Special report; SCIENTIFIC AMERICAN, February]. A number of possible theoretical problems remain, though, beginning with the questions of what exactly the inflaton was and what gave it such a huge initial potential energy.

A second, less widely known way to solve the puzzle follows the second alternative by getting rid of the singularity. If time did not begin at the bang, if a long era preceded the onset of the present cosmic expansion, matter could have had plenty of time to arrange itself smoothly. Therefore, researchers have reexamined the reasoning that led them to infer a singularity.

One of the assumptions—that relativity theory is always valid—is question-

Overview/*String Cosmology*

- Philosophers, theologians and scientists have long debated whether time is eternal or finite—that is, whether the universe has always existed or whether it had a definite genesis. Einstein's general theory of relativity implies finiteness. An expanding universe must have begun at the big bang.
- Yet general relativity ceases to be valid in the vicinity of the bang because quantum mechanics comes into play. Today's leading candidate for a full quantum theory of gravity—string theory—introduces a minimal quantum of length as a new fundamental constant of nature, making the very concept of a bangian genesis untenable.
- The bang still took place, but it did not involve a moment of infinite density, and the universe may have predated it. The symmetries of string theory suggest that time did not have a beginning and will not have an end. The universe could have begun almost empty and built up to the bang, or it might even have gone through a cycle of death and rebirth. In either case, the pre-bang epoch would have shaped the present-day cosmos.

ALFRED T. KAMAJIAN (*preceding pages*)

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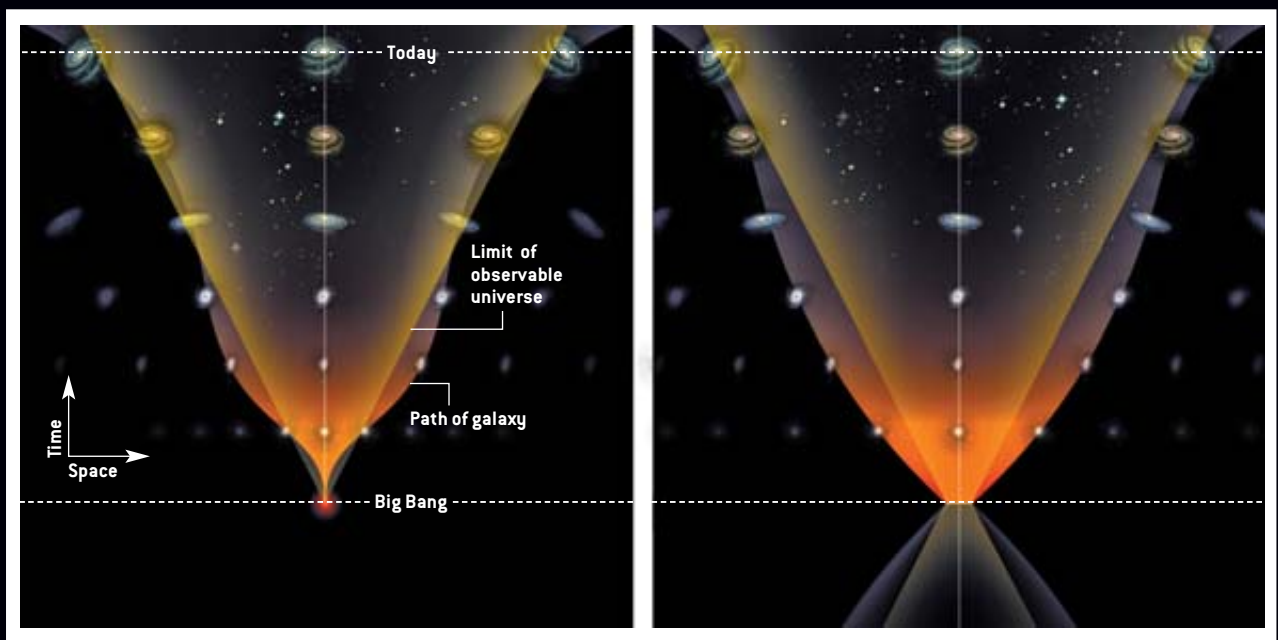
Two Views of the Beginning

In our expanding universe, galaxies rush away from one another like a dispersing mob. Any two galaxies recede at a speed proportional to the distance between them: a pair 500 million light-years apart separates twice as fast as one 250 million light-years apart. Therefore, all the galaxies we see must have started from the same place at the same time—the big bang. The conclusion holds even though cosmic expansion has gone through periods of acceleration and deceleration; in spacetime diagrams (*below*), galaxies follow sinuous paths that take them in and out of the observable region of space (*yellow wedge*). The situation became uncertain, however, at the precise moment when the galaxies (or their ancestors) began their outward motion.



In standard big bang cosmology, which is based on Einstein's general theory of relativity, the distance between any two galaxies was zero a finite time ago. Before that moment, time loses meaning.

In more sophisticated models, which include quantum effects, any pair of galaxies must have started off a certain minimum distance apart. These models open up the possibility of a pre-bang universe.

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able. Close to the putative singularity, quantum effects must have been important, even dominant. Standard relativity takes no account of such effects, so accepting the inevitability of the singularity amounts to trusting the theory beyond reason. To know what really happened, physicists need to subsume relativity in a quantum theory of gravity. The task has occupied theorists from Einstein onward, but progress was almost zero until the mid-1980s.

Evolution of a Revolution

TODAY TWO APPROACHES stand out. One, going by the name of loop quantum gravity, retains Einstein's theory essentially intact but changes the procedure for implementing it in quantum mechanics [see "Atoms of Space and Time," by Lee Smolin; SCIENTIFIC AMERICAN, January]. Practitioners of loop quantum gravity have taken great strides and achieved deep insights over the past several years. Still, their approach may not be revolutionary enough to resolve the fundamental problems of quantizing gravity. A similar problem faced particle theorists after Enrico Fermi introduced his effective theory of the weak nuclear force in 1934. All efforts to construct a quantum version of Fermi's theory failed miserably. What was needed was not a new technique but the deep modifications brought by the electroweak theory of Sheldon L. Glashow, Steven Weinberg and Abdus Salam in the late 1960s.

The second approach, which I consider more promising, is string theory—a truly revolutionary modification of Einstein's theory. This article will focus on it, although proponents of loop quantum gravity claim to reach many of the same conclusions.

String theory grew out of a model that I wrote down in 1968 to describe the world of nuclear particles (such as protons and neutrons) and their interactions. Despite much initial excitement, the model failed. It was abandoned several

THE AUTHOR

GABRIELE VENEZIANO, a theoretical physicist at CERN, was the father of string theory in the late 1960s—an accomplishment for which he received this year's Heineman Prize of the American Physical Society and the American Institute of Physics. At the time, the theory was regarded as a failure; it did not achieve its goal of explaining the atomic nucleus, and Veneziano soon shifted his attention to quantum chromodynamics, to which he made major contributions. After string theory made its comeback as a theory of gravity in the 1980s, Veneziano became one of the first physicists to apply it to black holes and cosmology.

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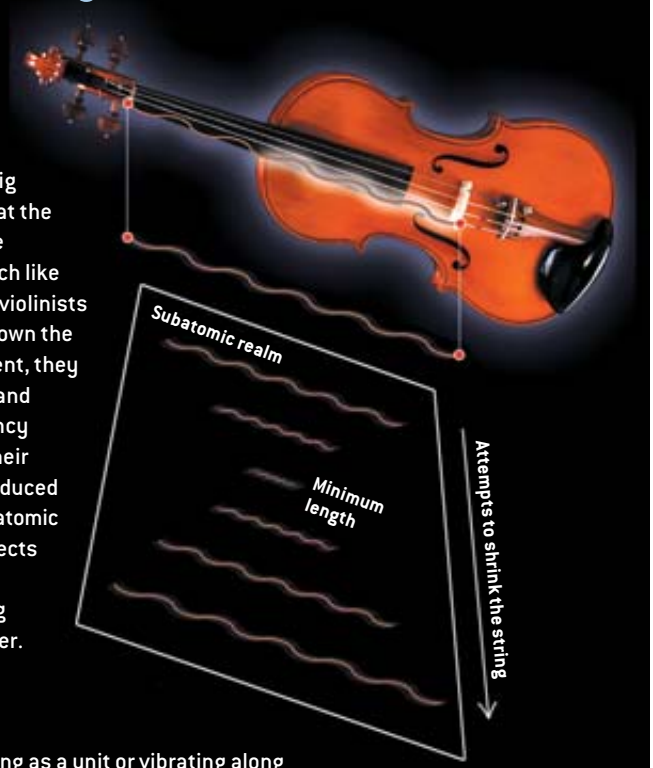
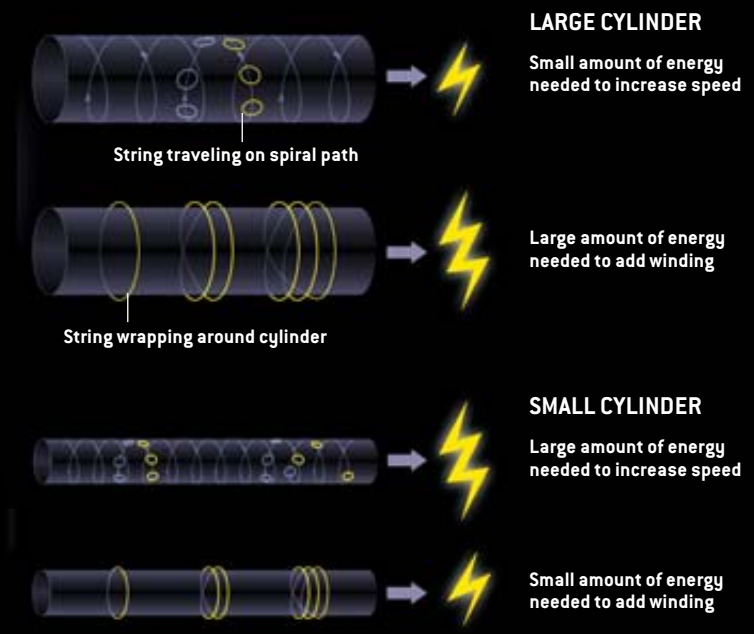
String Theory 101

String theory is the leading (though not only) theory that tries to describe what happened at the moment of the big bang. The strings that the theory describes are material objects much like those on a violin. As violinists move their fingers down the neck of the instrument, they shorten the strings and increase the frequency (hence energy) of their vibrations. If they reduced a string to a sub-subatomic length, quantum effects would take over and prevent it from being shortened any further.



In addition to traveling as a unit or vibrating along its length, a subatomic string can wind up like a spring. Suppose that space has a cylindrical shape. If the circumference is larger than the minimum allowed string length, each increase in the travel speed requires a small increment of energy, whereas each extra winding requires a large one. But if the circumference is smaller than the minimum length, an extra winding is less costly than an extra bit of velocity. The net energy—which is all that really matters—is the same for both small and large circumferences. In effect, the string does not shrink. This property prevents matter from reaching an infinite density.



years later in favor of quantum chromodynamics, which describes nuclear particles in terms of more elementary constituents, quarks. Quarks are confined inside a proton or a neutron, as if they were tied together by elastic strings. In retrospect, the original string theory had captured those stringy aspects of the nuclear world. Only later was it revived as a candidate for combining general relativity and quantum theory.

The basic idea is that elementary particles are not pointlike but rather infinitely thin one-dimensional objects, the strings. The large zoo of elementary particles, each with its own characteristic properties, reflects the many possible vibration patterns of a string. How can such a simple-minded theory describe the complicated world of particles and their interactions? The answer can be found in what we may call quantum string magic. Once the rules of quantum mechanics are applied to a vibrating string—just like a miniature violin string, except that the vibrations propagate along it at the speed of light—new properties appear. All have profound implications for particle physics and cosmology.

First, quantum strings have a finite size. Were it not for quantum effects, a violin string could be cut in half, cut in half again and so on all the way down, finally becoming a massless pointlike particle. But the Heisenberg uncertainty principle eventually intrudes and prevents the lightest strings from being sliced smaller than about 10^{-34} meter. This irreducible quantum of length, denoted l_s, is a new constant of nature introduced by string theory side by side with the speed of light, c, and Planck's constant, h. It plays a crucial role in almost every aspect of string theory, putting a finite limit on quantities that otherwise could become either zero or infinite.

Second, quantum strings may have angular momentum even if they lack mass. In classical physics, angular momentum is a property of an object that rotates with respect to an axis. The formula for angular momentum multiplies together velocity, mass and distance from the axis; hence, a massless object can have no angular momentum. But quan-

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tum fluctuations change the situation. A tiny string can acquire up to two units of *h* of angular momentum without gaining any mass. This feature is very welcome because it precisely matches the properties of the carriers of all known fundamental forces, such as the photon (for electromagnetism) and the graviton (for gravity). Historically, angular momentum is what clued in physicists to the quantum-gravitational implications of string theory.

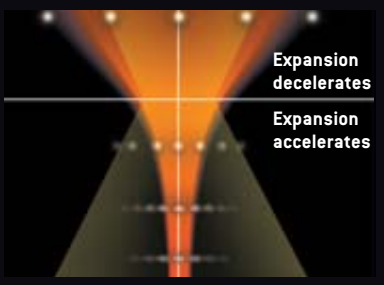
Third, quantum strings demand the existence of extra dimensions of space, in addition to the usual three. Whereas a classical violin string will vibrate no matter what the properties of space and time are, a quantum string is more finicky. The equations describing the vibration become inconsistent unless spacetime either is highly curved (in contradiction with observations) or contains six extra spatial dimensions.

Fourth, physical constants—such as Newton's and Coulomb's constants, which appear in the equations of physics and determine the properties of nature—no longer have arbitrary, fixed values. They occur in string theory as fields, rather like the electromagnetic field, that can adjust their values dynamically. These fields may have taken different values in different cosmological epochs or in remote regions of space, and even today the physical "constants" may vary by a small amount. Observing any variation would provide an enormous boost to string theory. [*Editors' note: An upcoming article will discuss searches for these variations.*]

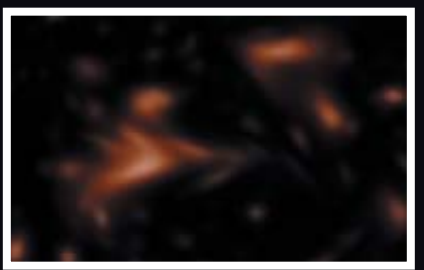
One such field, called the dilaton, is the master key to string theory; it determines the overall strength of all interactions. The dilaton fascinates string theorists because its value can be reinterpreted as the size of an extra dimension of space, giving a grand total of 11 spacetime dimensions.

PRE–BIG BANG SCENARIO

A pioneering effort to apply string theory to cosmology was the so-called pre–big bang scenario, according to which the bang is not the ultimate origin of the universe but a transition. Beforehand, expansion accelerated; afterward, it decelerated (at least initially). The path of a galaxy through spacetime (*right*) is shaped like a wineglass.

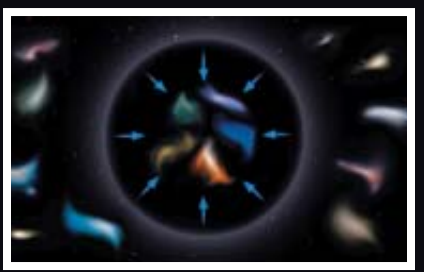


The universe has existed forever. In the distant past, it was nearly empty. Forces such as gravitation were inherently weak.

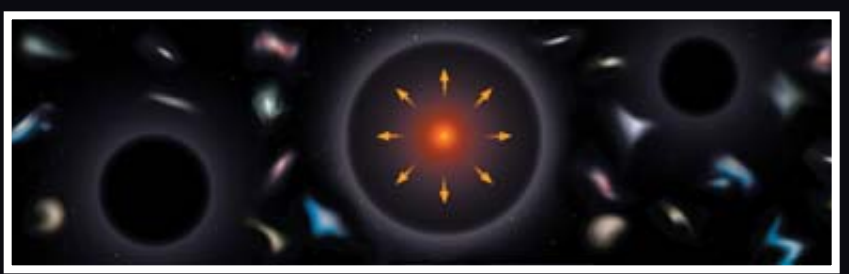


The forces gradually strengthened, so matter began to clump. In some regions, it grew so dense that a black hole formed.

Space inside the hole expanded at an accelerating rate. Matter inside was cut off from matter outside.



Inside the hole, matter fell toward the middle and increased in density until reaching the limit imposed by string theory.



When matter reached the maximum allowed density, quantum effects caused it to rebound in a big bang. Outside, other holes began to form—each, in effect, a distinct universe.

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Tying Down the Loose Ends

FINALLY, QUANTUM strings have introduced physicists to some striking new symmetries of nature known as dualities, which alter our intuition for what happens when objects get extremely small. I have already alluded to a form of duality: normally, a short string is lighter than a long one, but if we attempt to squeeze down its size below the fundamental length l_s, the string gets heavier again.

Another form of the symmetry, T-duality, holds that small and large extra dimensions are equivalent. This symmetry arises because strings can move in more complicated ways than pointlike particles can. Consider a closed string (a loop) located on a cylindrically shaped space, whose circular cross section represents one finite extra dimension. Besides vibrating, the string can either turn

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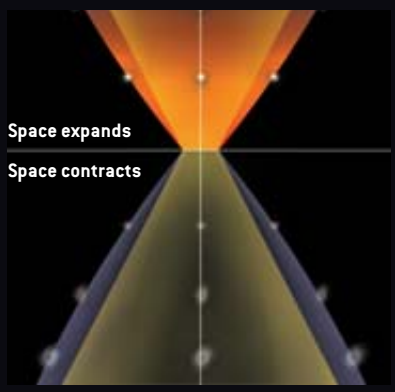
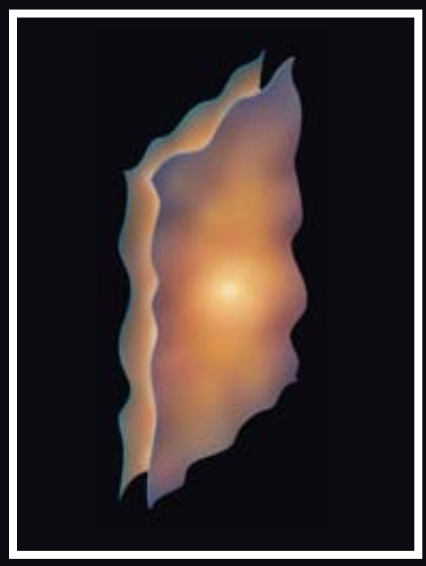
EKPYROTIC SCENARIO

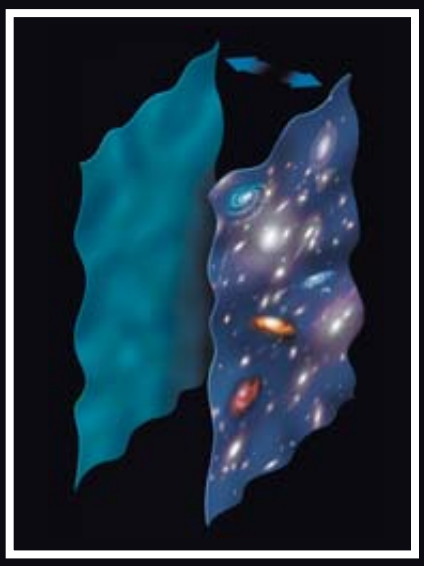
If our universe is a multidimensional membrane, or simply a "brane," cruising through a higher-dimensional space, the big bang may have been the collision of our brane with a parallel one. The collisions might recur cyclically. Each galaxy follows an hourglass-shaped path through spacetime (*below*).



Two nearly empty branes pull each other together. Each is contracting in a direction perpendicular to its motion.



The branes collide, converting their kinetic energy into matter and radiation. This collision is the big bang.



The branes rebound. They start expanding at a decelerating rate. Matter clumps into structures such as galaxy clusters.

In the cyclic model, as the branes move apart, the attractive force between them slows them down. Matter thins out.

The branes stop moving apart and start approaching each other. During the reversal, each brane expands at an accelerated rate.

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as a whole around the cylinder or wind around it, one or several times, like a rubber band wrapped around a rolled-up poster [*see illustration on page 58*].

The energetic cost of these two states of the string depends on the size of the cylinder. The energy of winding is directly proportional to the cylinder radius: larger cylinders require the string to stretch more as it wraps around, so the windings contain more energy than they would on a smaller cylinder. The energy associated with moving around the circle, on the other hand, is inversely proportional to the radius: larger cylinders allow for longer wavelengths (smaller frequencies), which represent less energy than shorter wavelengths do. If a large cylinder is substituted for a small one, the two states of motion can swap roles. Energies that had been produced by circular motion are instead produced by winding, and vice versa. An outside observer notices only the energy levels, not the origin of those levels. To that observer, the large and small radii are physically equivalent.

Although T-duality is usually described in terms of cylindrical spaces, in which one dimension (the circumference) is finite, a variant of it applies to our or-

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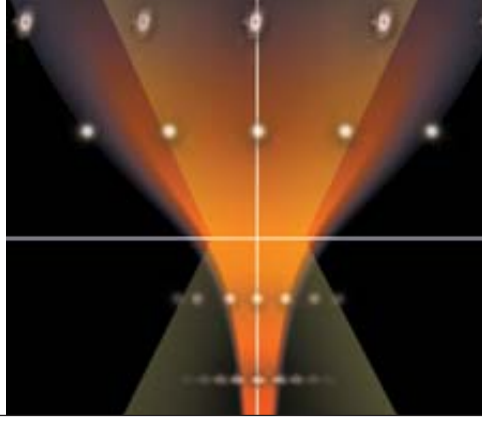
Strings abhor infinity. They cannot collapse to an infinitesimal point, so they avoid the paradoxes that collapse would entail.



dinary three dimensions, which appear to stretch on indefinitely. One must be careful when talking about the expansion of an infinite space. Its overall size cannot change; it remains infinite. But it can still expand in the sense that bodies embedded within it, such as galaxies, move apart from one another. The crucial variable is not the size of the space as a whole but its scale factor—the factor by which the distance between galaxies changes, manifesting itself as the galactic redshift that astronomers observe. According to T-duality, universes with small scale factors are equivalent to ones with large scale factors. No such symmetry is present in Einstein's equations; it emerges from the unification that string theory embodies, with the dilaton playing a central role.

For years, string theorists thought that T-duality applied only to closed strings, as opposed to open strings, which have loose ends and thus cannot wind. In 1995 Joseph Polchinski of the University of California at Santa Barbara realized that T-duality did apply to open strings, provided that the switch between large and small radii was accompanied by a change in the conditions at the end points of the string. Until then, physicists had postulated boundary conditions in which no force acted on the ends of the strings, leaving them free to flap around. Under T-duality, these conditions become so-called Dirichlet boundary conditions, whereby the ends stay put.

Any given string can mix both types of boundary conditions. For instance, electrons may be strings whose ends can move around freely in three of the 10 spatial dimensions but are stuck within the other seven. Those three dimensions form a subspace known as a Dirichlet membrane, or D-brane. In 1996 Petr Horava of the University of California at Berkeley and Edward Witten of the Institute for Advanced Study in Princeton, N.J., proposed that our universe resides on such a brane. The partial mobility of electrons and other particles explains why we are unable to perceive the full 10-dimensional glory of space.

Taming the Infinite

ALL THE MAGIC properties of quantum strings point in one direction: strings abhor infinity. They cannot collapse to an infinitesimal point, so they avoid the paradoxes that collapse entails. Their nonzero size and novel symmetries set upper bounds to physical quantities that increase without limit in conventional theories, and they set lower bounds to quantities that decrease. String theorists expect that when one plays the history of the universe backward in time, the curvature of spacetime starts to increase. But instead of going all the way to infinity (at the traditional big bang singularity), it eventually hits a maximum and shrinks once more. Before string theory, physicists were hard-pressed to imagine any mechanism that could so cleanly eliminate the singularity.

Conditions near the zero time of the big bang were so extreme that no one yet knows how to solve the equations. Nevertheless, string theorists have hazarded guesses about the pre-bang universe. Two popular models are floating around.

The first, known as the pre–big bang scenario, which my colleagues and I began to develop in 1991, combines T-duality with the better-known symmetry of time reversal, whereby the equations of physics work equally well when applied backward and forward in time. The combination gives rise to new possible cosmologies in which the universe, say, five seconds before the big bang expanded at the same pace as it did five seconds after the bang. But the rate of change of the expansion was opposite at the two instants: if it was decelerating after the bang, it was accelerating before. In short, the big bang may not have been the origin of the universe but simply a violent transition from acceleration to deceleration.

The beauty of this picture is that it automatically incorporates the great insight of standard inflationary theory—namely, that the universe had to undergo a period of acceleration to become so homogeneous and isotropic. In the standard theory, acceleration occurs after the big bang because of an ad hoc inflaton field. In the pre–big bang scenario, it occurs before the bang as a natural outcome of the novel symmetries of string theory.

According to the scenario, the pre-bang universe was almost a perfect mirror image of the post-bang one [*see illustration on page 59*]. If the universe is eternal into the future, its contents thinning to a meager gruel, it is also eternal into the past. Infinitely long ago it was nearly empty, filled only with a tenuous, widely dispersed, chaotic gas of radiation and matter. The forces of nature, controlled by the dilaton field, were so feeble that particles in this gas barely interacted.

As time went on, the forces gained in strength and pulled matter together. Randomly, some regions accumulated matter at the expense of their surroundings. Eventually the density in these regions became so high that black holes started to form. Matter inside those regions was then cut off from the outside, breaking up the universe into disconnected pieces.

Inside a black hole, space and time swap roles. The center of the black hole is not a point in space but an instant in time. As the infalling matter approached the center, it reached higher and higher densities. But when the density, temperature

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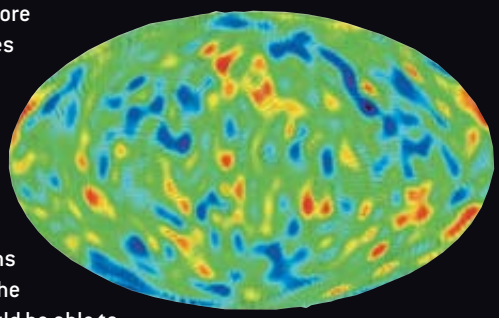
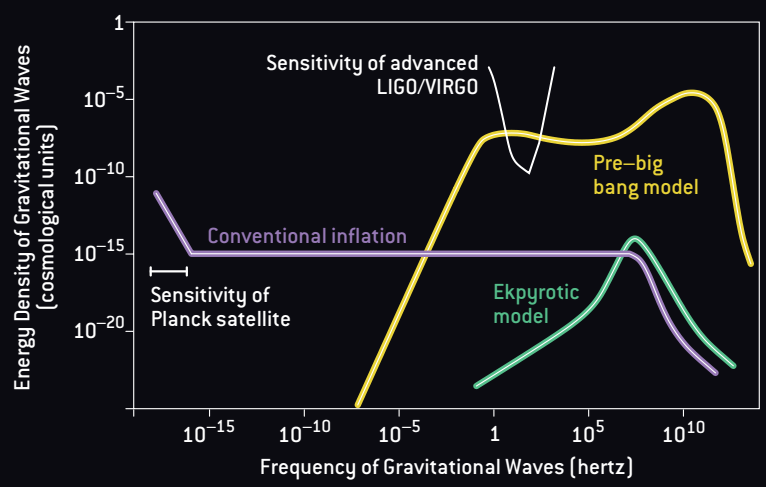
OBSERVATIONS

Observing the pre-bang universe may sound like a hopeless task, but one form of radiation could survive from that epoch: gravitational radiation. These periodic variations in the gravitational field might be detected indirectly, by their effect on the polarization of the cosmic microwave background (*simulated view, below*), or directly, at ground-based observatories. The pre–big bang and ekpyrotic scenarios predict more high-frequency gravitational waves and fewer low-frequency ones than do conventional models of inflation (*bottom*). Existing measurements of various astronomical phenomena cannot distinguish among these models, but upcoming observations by the Planck satellite as well as the LIGO and VIRGO observatories should be able to.





and curvature reached the maximum values allowed by string theory, these quantities bounced and started decreasing. The moment of that reversal is what we call a big bang. The interior of one of those black holes became our universe.

Not surprisingly, such an unconventional scenario has provoked controversy. Andrei Linde of Stanford University has argued that for this scenario to match observations, the black hole that gave rise to our universe would have to have formed with an unusually large size—much larger than the length scale of string theory. An answer to this objection is that the equations predict black holes of all possible sizes. Our universe just happened to form inside a sufficiently large one.

A more serious objection, raised by Thibault Damour of the Institut des Hautes Études Scientifiques in Bures-sur-Yvette, France, and Marc Henneaux of the Free University of Brussels, is that matter and spacetime would have behaved chaotically near the moment of the bang, in possible contradiction with the observed regularity of the early universe. I have recently proposed that a chaotic state would produce a dense gas of miniature "string holes"—strings that were so small and massive that they were on the verge of becoming black holes. The behavior of these holes could solve the problem identified by Damour and Henneaux. A similar proposal has been put forward by Thomas Banks of Rutgers University and Willy Fischler of the University of Texas at Austin. Other critiques also exist, and whether they have uncovered a fatal flaw in the scenario remains to be determined.

Bashing Branes

THE OTHER LEADING model for the universe before the bang is the ekpyrotic ("conflagration") scenario. Developed three years ago by a team of cosmologists and string theorists—Justin Khoury of Columbia University, Paul J. Steinhardt of Princeton University, Burt A. Ovrut of the University of Pennsylvania, Nathan Seiberg of the Institute for Advanced Study and Neil Turok of the University of Cambridge—the ekpyrotic scenario relies on the idea that our universe is one of many D-branes floating within a higher-dimensional space. The branes exert attractive forces on one another and occasionally collide. The big bang could be the impact of another brane into ours [*see illustration on page 62*].

In a variant of this scenario, the collisions occur cyclically. Two branes might hit, bounce off each other, move apart, pull each other together, hit again, and so on. In between collisions, the branes behave like Silly Putty, expanding as they recede and contracting somewhat as they come back together. During the turnaround, the expansion rate accelerates; indeed, the present accelerating expansion of the universe may augur another collision.

The pre–big bang and ekpyrotic scenarios share some common features. Both begin with a large, cold, nearly empty universe, and both share the difficult (and unresolved) problem of making the transition between the pre- and the post-bang phase. Mathematically, the main difference between the scenarios is the behavior of the dilaton field. In the pre–big bang, the dilaton begins with a low value—so that the forces of nature are weak—and steadily gains strength. The opposite is true for the ekpyrotic scenario, in which the collision occurs when forces are at their weakest.

The developers of the ekpyrotic theory initially hoped that the weakness of the forces would allow the bounce to be analyzed more easily, but they were still confronted with a difficult high-curvature situation, so the jury is out on whether the scenario truly avoids a singularity.

NASA (*top*); GABRIELE VENEZIANO *CERN* (*bottom*)

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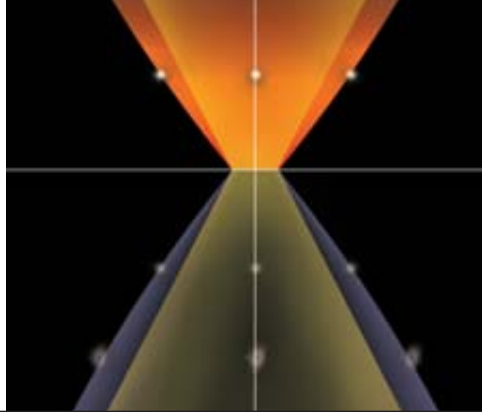
Vestiges of the pre-bangian epoch might show up in galactic and intergalactic magnetic fields.



Also, the ekpyrotic scenario must entail very special conditions to solve the usual cosmological puzzles. For instance, the about-to-collide branes must have been almost exactly parallel to one another, or else the collision could not have given rise to a sufficiently homogeneous bang. The cyclic version may be able to take care of this problem, because successive collisions would allow the branes to straighten themselves.

Leaving aside the difficult task of fully justifying these two scenarios mathematically, physicists must ask whether they have any observable physical consequences. At first sight, both scenarios might seem like an exercise not in physics but in metaphysics—interesting ideas that observers could never prove right or wrong. That attitude is too pessimistic. Like the details of the inflationary phase, those of a possible pre-bangian epoch could have observable consequences, especially for the small variations observed in the cosmic microwave background temperature.

First, observations show that the temperature fluctuations were shaped by acoustic waves for several hundred thousand years. The regularity of the fluctuations indicates that the waves were synchronized. Cosmologists have discarded many cosmological models over the years because they failed to account for this synchrony. The inflationary, pre–big bang and ekpyrotic scenarios all pass this first test. In these three models, the waves were triggered by quantum processes amplified during the period of accelerating cosmic expansion. The phases of the waves were aligned.

Second, each model predicts a different distribution of the temperature fluctuations with respect to angular size. Observers have found that fluctuations of all sizes have approximately the same amplitude. (Discernible deviations occur only on very small scales, for which the primordial fluctuations have been altered by subsequent processes.) Inflationary models neatly reproduce this distribution. During inflation, the curvature of space changed relatively slowly, so fluctuations of different sizes were generated under much the same conditions. In both the stringy models, the curvature evolved quickly, increasing the amplitude of small-scale fluctuations, but other processes boosted the large-scale ones, leaving all fluctuations with the same strength. For the ekpyrotic scenario, those other processes involved the extra dimension of space, the one that separated the colliding branes. For the pre–big bang scenario, they involved a quantum field, the axion, related to the dilaton. In short, all three models match the data.

Third, temperature variations can arise from two distinct processes in the early universe: fluctuations in the density of matter and rippling caused by gravitational waves. Inflation involves both processes, whereas the pre–big bang and ekpyrotic scenarios predominantly involve density variations. Gravitational waves of certain sizes would leave a distinctive signature in the polarization of the microwave background [see "Echoes from the Big Bang," by Robert R. Caldwell and Marc Kamionkowski; Scientific American, January 2001]. Future observatories, such as European Space Agency's Planck satellite, should be able to see that signature, if it exists—providing a nearly definitive test.

A fourth test pertains to the statistics of the fluctuations. In inflation the fluctuations follow a bell-shaped curve, known to physicists as a Gaussian. The same may be true in the ekpyrotic case, whereas the pre–big bang scenario allows for sizable deviation from Gaussianity.

Analysis of the microwave background is not the only way to verify these theories. The pre–big bang scenario should also produce a random background of gravitational waves in a range of frequencies that, though irrelevant for the microwave background, should be detectable by future gravitational-wave observatories. Moreover, because the pre–big bang and ekpyrotic scenarios involve changes in the dilaton field, which is coupled to the electromagnetic field, they would both lead to large-scale magnetic field fluctuations. Vestiges of these fluctuations might show up in galactic and intergalactic magnetic fields.

So, when did time begin? Science does not have a conclusive answer yet, but at least two potentially testable theories plausibly hold that the universe—and therefore time—existed well before the big bang. If either scenario is right, the cosmos has always been in existence and, even if it recollapses one day, will never end. SA

MORE TO EXPLORE

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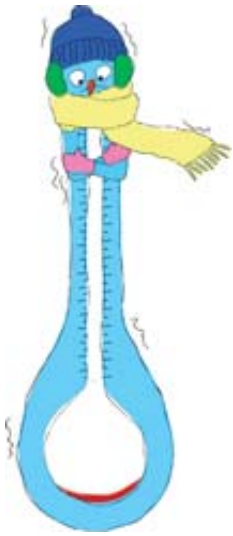
ASK THE EXPERTS

How are temperatures close to absolute zero achieved and measured?

Wolfgang Ketterle of the Massachusetts Institute of Technology, who won the Nobel Prize in Physics in 2001 for his work with ultracold atoms, explains:

First, let me introduce the scientific meaning of temperature: it is a measure of the energy content of matter. When air molecules are hot, they move fast and have high kinetic energy. The colder the molecules are, the lower their velocities and the less energy they have. Absolute zero corresponds to zero kelvins (–273 degrees Celsius or –460 degrees Fahrenheit).

Cooling requires extracting energy from an object and depositing that energy somewhere else. By combining laser cooling and evaporative cooling, scientists have been able to achieve temperatures in clouds of atomic gases below one nanokelvin (one billionth of a kelvin). The current record, described by our group in the September 12, 2003, issue of *Science,* is 450 picokelvins (half a billionth of a kelvin).



In laser cooling, the target atoms scatter laser light. An incoming laser photon is absorbed and then reemitted in a different direction. On average, the color of the scattered photon is slightly shifted to the blue relative to the laser light. That is, a scattered photon has a slightly higher energy than does an absorbed photon. Because total energy is conserved, the difference in photon energy is extracted from the atomic motion—the atoms slow down.

As an atomic cloud becomes denser and colder, the cooling effect becomes dominated by other processes, which still result in some trembling motion of the atoms. The processes include energy release from collisions between atoms and the random recoil kicks in light scattering. At this point, however, the atoms are cold enough to be confined by magnetic fields. We choose atomic species that have an unpaired electron and therefore a magnetic moment. These atoms behave like little bar magnets. External magnetic fields levitate the atoms against gravity and keep them together; in effect, the fields form invisible walls that contain the atoms in a magnetic cage.

Evaporative cooling can then selectively remove the most energetic atoms from the system. In a magnetic trap, the most energetic atoms can move farther against the pull of the magnetic forces and can reach regions with higher magnetic fields than can the colder atoms. When the atoms encounter those higher magnetic fields, they get into resonance with radio waves or microwaves, which changes the magnetic moment in such a way that the atoms escape from the trap.

How do we measure very low temperatures of atoms? One way is simply to look at the extension of the cloud. The larger the cloud, the more energetic its atoms must be, because they can move farther against the magnetic forces. Another method is to measure the atoms' kinetic energy. The magnetic trap is switched off. In the absence of magnetic forces, the atoms fly away, and the cloud expands ballistically. The cloud size increases with time, and this increase is a direct way to observe the velocity of the atoms and, hence, their temperature. When a smaller cloud is observed after a fixed time of expansion, that change indicates the achievement of lower temperature.

If heat rises, why is air cooler at higher elevations?

Paul B. Shepson, professor of atmospheric chemistry at Purdue University's School of Science, provides this answer:

In the earth's atmosphere, pressure, which is related to the number of molecules per unit volume, decreases exponentially with altitude. Therefore, if a parcel of air from the surface rises (because of wind flowing up the side of a mountain, for example), it undergoes an expansion, from higher to lower pressure. When air expands, it cools. This phenomenon is familiar to everyone—stick your finger on the valve of a car tire and let some air escape. It is not cool inside the tire, but as the air comes out it expands and thus cools. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert

SARA CHEN

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