Special Section: Big Rip, Superstrings, the Multiverse and More

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Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ APRIL 23, 2011

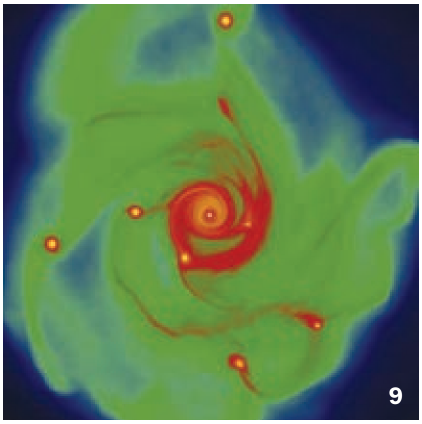
Cosmic Questions

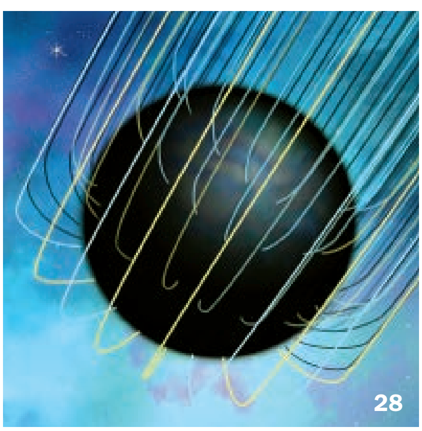
Unraveling the universe's greatest riddles

Ancient Chinese Mariners

Superbunny Fossil Found

Dye Delays Dying in Worms



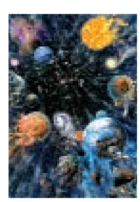


ScienceNews

In The News

Special Issue

Departments



COVER Scientists don't yet know whether the universe will end with a Crunch, Freeze or Rip (shown)—or by way of some other unknown calamity.
Nicolle Rager Fuller

ScienceNews
MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

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FROM THE EDITOR

Suggesting risky answers to Top 5 cosmic questions

In the musings of scientists seeking cosmic secrets, one sentiment frequently recurs: Questions are more important than answers.

Ambiguous questions spawn "fruitless controversy," the philosopher Bertrand Russell wrote. Physicist David Bohm once averred that "half the battle is over when we know what are the right questions to ask." And Nobel laureate Anthony Leggett lamented frustrations in finding the right questions at the borders between knowledge and ignorance: "Where physics tangles with philosophy, the difficulties usually lie less in finding answers to well-posed questions than in formulating the fruitful questions in the first place."

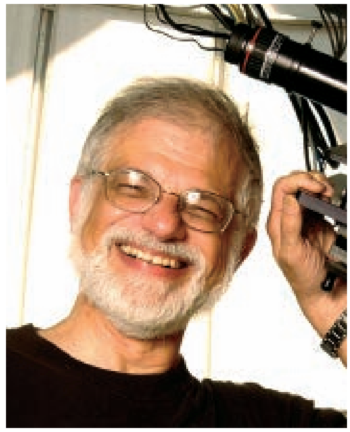
So it is no great surprise that in current efforts to comprehend the universe, some grand questions have commanded more attention than the answers (to lesser questions) that scientists have recently provided. It's nice to know how old the universe is, for instance, and how much of it consists of ordinary matter. Two decades ago, nobody knew. But this progress has merely inflated scientific curiosity about the greater issues that cosmologists have yet to resolve.

In this issue, *Science News* writers and editors provide a status report on the top five cosmic questions of the day, as voted on by *Science News* writers and editors. You will not find final answers to these questions, of course, because otherwise they would no longer be the top questions. An additional consideration, perhaps, is an old observation by the French historian Charles Seignobos. "It is useful to ask oneself questions," he declared, "but very dangerous to answer them."

But what the heck. If you really want to know, here are the answers (none guaranteed):

- **What happened before the Big Bang?** Physicists in a preexisting universe had just figured out what happened before their Big Bang — and then tested it.
- **What is the universe made of?** Information: The digital bits that describe matter and energy (dark or otherwise) aren't actually the description; it's matter and energy that describe the information.
- **Is there a theory of everything?** Not yet.
- **Are space and time fundamental?** No, but there is not enough space or time available to explain why.
- **What is the universe's fate?** An unhappy ending. But don't worry. The universe will end only after all the great questions have real answers. —*Tom Siegfried, Editor in Chief*

Scientific Observations



"A few fortunate astronomers investigate cosmic rays or the solar system. All other astronomers must construct stories about objects with which they can have no direct contact, things like stars and galaxies that can't be manipulated, isolated, or made the subject of experiment. This sets astronomers apart from most other scientists, who can thump on, cut up, and pour chemicals over their objects of study. In this sense, astronomy is a lot more like paleontology than it is like physics. Trying to tell the story of a galaxy is like trying to reconstruct a dinosaur from bits of fossilized bone. We will never have the galaxy or dinosaur in our laboratory, and must do guesswork based on flimsy, secondhand evidence." **—ASTRONOMER FREDERICK CHROMEY OF VASSAR COLLEGE IN HIS 2010 BOOK *TO MEASURE THE SKY***

Science Past | FROM THE ISSUE OF APRIL 22, 1961

RUSSIAN FIRST MAN IN SPACE — The Russians put the first man in orbit and returned him safely. A Soviet Air Force major, father of two, has circled the earth in 89.1 minutes, and come back, the official Russian news agency Tass reported. The height of the orbit varied from 110 to 188 miles. Maj. Yuri Gagarin, 27, landed at 2:55 EST, April 12, without suffering any harm.... The Soviet success in orbiting and recovering a man from space means that they can get a man on the moon in four or five years, and probably will. The best the United States can hope to do is get an American to the moon in 1971, according to an estimate by the National Aeronautics and Space Administration.

Science Future

May 6
Eta Aquarid meteor shower peaks before dawn. Go to earthsky.org/tonight for info.

May 6
The first female "private space explorer" speaks at Pittsburgh's Carnegie Science Awards. See www.carnegiesciencecenter.org

May 15
Deadline to submit photos of "chemistry in our drinks" to the Colors of Chemistry calendar competition. Find out more at colorsofchemistry.org

SN Online

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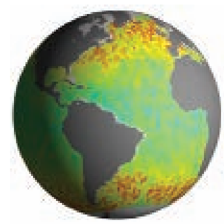
BODY & BRAIN
Some people who can't feel pain also can't smell anything. See "Who felt it not, smelt it not."

ATOM & COSMOS
Laser beams could save satellites from debris damage. See "Laser proposed to deflect space junk."

EARTH
Severe winds and high waves have become faster and taller worldwide. Read "Global gale warning."

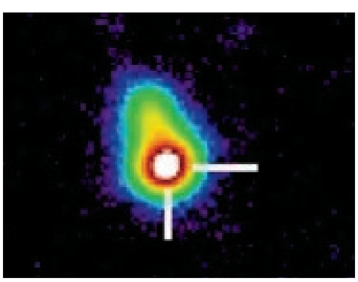


LIFE
An Amazonian fish carries seeds far from home. Read "Fruit-eating fish does far-flung forestry."

Certain wasps may fling ants away when vying for food. See "Wasps airlift annoying ants."

The (-est)

Astronomers have spotted the brightest example yet of one type of superbright supernova. The stellar explosion (below), dubbed Supernova 2008am, hit a peak luminosity nearly 100 billion times as bright as the sun before fading off, making its glow 100 times that of run-of-the-mill supernovas. Given the explosion's characteristics, the most probable explanation for the über-radiance is that the light comes from a blast wave created as supernova ejecta collide with a dense shell of material thrown off sometime before the explosion, Emmanouil Chatzopoulos of the University of Texas at Austin and colleagues report in the March 10 *Astrophysical Journal.*

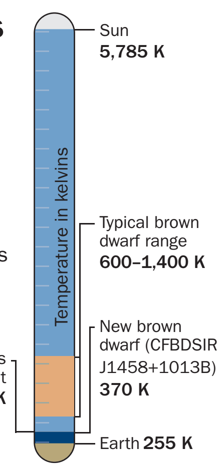


Science Stats

CHILLY STARS

Cosmic temperatures

Failed stars called brown dwarfs are known to be relatively cold, but a newly discovered dwarf glows at about 370 kelvins, near the temperature of boiling water.



SOURCE: M.C. LIU *ET AL*/ *ASTROPHYSICAL J.* 2011

CLOCKWISE FROM TOP LEFT: STANLEY GOLDBLATT; ©*SCIENCE*/AAAS; E. FELICIANO; D. PERLEY & J. BLOOM/W.M. KECK OBSERVATORY

“ Our data show very substantial amounts of human impact on the environment over thousands of years. ” —JED KAPLAN, PAGE 17

In the News

STORY ONE

Rising sea levels inspired ancient crossings from China to Taiwan

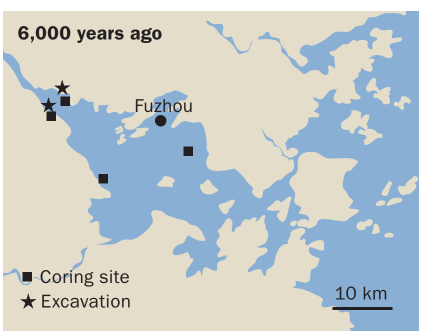
Environmental conditions cultivated seafaring, not rice

By Bruce Bower

Coastal residents of southeastern China navigate waterways today on bamboo rafts like this one. Island dwellers in the region took sea voyages as far as Taiwan 5,000 years ago, perhaps using similar rafts equipped with sails, researchers say.

A rising tide lifts all boats, but in a surprising twist, ascending sea levels launched a flotilla of rafts or canoes on voyages from China to Taiwan around 5,000 years ago, a new study suggests.

At a time when rice farming dominated in other regions, the inundation of the Fuzhou Basin in southeastern China beginning about 9,000 years ago led to the creation of a maritime culture that eventually took to the seas, says a team led by archaeologist Barry Rolett of the University of Hawaii at Manoa.



Research sites and the modern city of Fuzhou are shown on a map of the Min River Delta coastline in southeastern China during a period of higher sea level.

Analyses of sediment cores extracted from the Fuzhou Basin indicate that, at that time, the kind of marshy areas needed for rice paddies disappeared under rising seas. What are hilltops in the region today were islands no more than one mile across.

Locals built outposts on newly minted islands starting around 5,500 years ago and honed their nautical skills, probably using wooden canoes or bamboo rafts to obtain fish and other aquatic food in a vast estuary, Rolett and his colleagues report in the April *Quaternary Science Reviews*. A largely rice-free, maritime lifestyle eventually enabled sea voyages of 130 kilometers to Taiwan, Rolett proposes. Farming villages first appeared on Taiwan about 5,000 years ago.

Rolett’s findings challenge a popular scientific view that a transition to village life farther north in China around 8,000 years ago triggered rice-fueled population growth that spread southward. In that scenario, shortages of marshy land suitable for rice paddies motivated sea crossings to Taiwan, possibly originating just north of the Fuzhou Basin in the Yangtze River Delta, where researchers have found a 7,700-year-old canoe and three wooden paddles.

“People of the Fuzhou Basin lived on little islands in an estuary that favored maritime activities and seafaring,” Rolett says. “Rice farming was not part of the equation.” Small amounts of rice could have been tended on patches of dry land watered by rain, he holds.

Rolett’s evidence that fishing and seafaring dwarfed rice growing in a submerged section of southeastern China, possibly prompting Taiwan’s colonization, “is quite plausible,” comments archaeologist Robert Bettinger of the University of California, Davis.

FROM TOP: B. ROLETT; B. ROLETT *ET AL*/*QUAT. SCI. REV.* 2011

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SN Today at **www.sciencenews.org**

Villages from around 5,000 years ago in the Fuzhou Basin and on Taiwan contain similar types of pottery, supporting Rolett's argument, remarks archaeobotanist Dorian Fuller of University College London. Excavations of early Taiwanese villages have yielded millet, a type of grain, as well as some rice. Experienced Fuzhou Basin mariners may have first explored and traded up and down China's coast, acquiring millet where it grows along the northern coast before taking the grain to Taiwan, Fuller suggests.

Seafaring ignited by ancient flooding of the Fuzhou Basin may have been crucial for colonization of islands beyond Taiwan, Fuller says. Many linguists think that ancestral populations of Austronesian language speakers now inhabiting Southeast Asian and Pacific islands — from the Philippines to Fiji — probably came from Taiwan.

No remains of watercraft have been recovered at early villages in southeastern China. Rolett suspects that ancient Fuzhou Basin residents used bamboo rafts much like those still used today to tool around the Min River. Bamboo rafts maintain excellent stability on water even with sails attached, Rolett says.

The notion of people sailing the open ocean thousands of years ago in small boats isn't new. Some researchers contend that ancient *Homo* species sailed rafts across the Mediterranean Sea at least 130,000 years ago (*SN: 1/30/10, p. 14*) and from mainland Asia to islands in present-day Indonesia some 800,000 years ago (*SN: 10/18/03, p. 248*).

Similarities between these two 5,000-year-old pots from Fuzhou and others from Taiwan suggest contact.

Rolett's team analyzed four Fuzhou Basin sediment cores, including two extracted from marshes near a pair of ancient settlements. These villages, located 80 kilometers inland, are on hills situated on opposite sides of the Min River. Work at these sites has produced artifacts from a Neolithic culture that has been dated to between 5,000 and 4,300 years ago. Investigations at one site indicate that it was occupied by 5,500 years ago.

Large amounts of shellfish debris, but only a few grains of rice, have been recovered at these sites. Many archaeologists assume that poor preservation of rice grains obscures extensive Neolithic rice cultivation in the Fuzhou Basin, Rolett says.

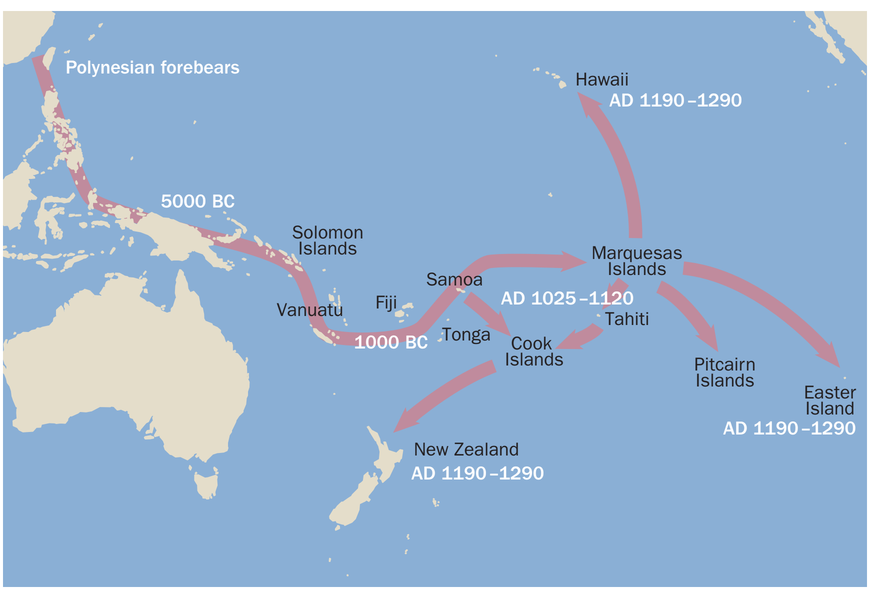
Radiocarbon measurements of wood and plant fragments in sediment cores allowed Rolett's group to estimate when and for how long particular environmental conditions persisted in the Fuzhou Basin.

Peat layers, chemical composition of soil sections and other evidence indicate that flooding of the Fuzhou Basin began about 9,000 years ago, reached a peak by 7,000 years ago and remained stable until an abrupt sea level decline nearly 2,000 years ago.

The amount of grass pollen seen in Fuzhou Basin cores increases dramatically around 2,000 years ago, Rolett adds. Rice pollen is hard to distinguish from other types of grass pollen, but this general trend probably reflects a later shift from maritime pursuits to rice farming, in his view. ■

Back Story | OUT TO SEA

The people who took to the water in southeastern China thousands of years ago may have played a role in kicking off one of the most dramatic episodes in human prehistory — the colonization of the Pacific islands. Through a series of island-hopping sea voyages, some covering thousands of miles of open water, Polynesian sailors settled the most remote islands of the South Pacific and probably even reached South America. In recent years, a combination of genetic, linguistic and archaeological evidence has suggested that the Polynesian expansion into the Pacific originated in Taiwan, just 130 kilometers off the coast of China.



POTS: LIN GONGWU; MAP: GEOATLAS/GRAPH-OGRE, ADAPTED BY E. FELICIANO

"Thanks Stauer for making me look like a hero to my wife!"

— *Stauer Client,*
Oklahoma City, OK

In 1931, This Ring Saved My Life

Recapture an old-fashioned romance with this stunning lab-created star ruby for ONLY $79!

Before he popped the question, my father knew the ring had to be right. "Your mother was picky," he said. "It had to be perfect." He searched and searched until one stone winked back from the window of a downtown store. It was a ruby, her favorite, and it shimmered like no other red gem he'd ever seen. Dad knew the sparkle would bring a twinkle to her eye. Years later, that twinkle would be me. I shudder to think what would have happened if she hated the ring. As it turns out, I owe my life to Dad's good taste... and that ring.

Eighty years later, I've recreated the design. The vintage treasure that brought my parents together lives again in the stunning ***Aster lab-created Ruby Ring***. Today mined star rubies can fetch more than $5000 per carat. But gemologists have perfected a method for crafting a stunning piece that is chemically identical to the natural gemstone, without the exorbitant cost.

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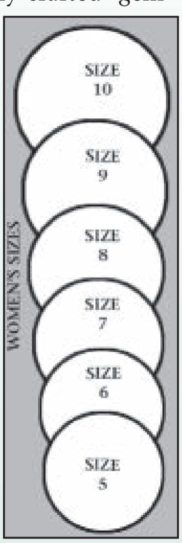
Inside the ***Aster Ring*** you can see what looks like a shimmering star trapped inside the scientifically-crafted gemstone. In nature, only a select few stones are graced with this extra-special effect (a phenomenon known as "asterism," after "aster" the Greek word for star). Even then, it requires the skilled hand of a master gem cutter to coax out the inner beauty.



USING THE RING SIZE CHART
Place one of her rings on top of one of the circle diagrams. Her ring size is the circle that matches the inside diameter of the ring diagram. If her ring falls between sizes, order the next larger size.

Old-fashioned romance returns. The idea was to bring back the most important ring in my life and share its magic with you. And since my father kept the original receipt, I thought it made sense to offer the ring **at its original price: $79.** That was a lot of money back then, but he assured me that Mom was worth every penny. I couldn't agree more.

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Body & Brain

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Obesity impairs brain performance

White matter damage may explain deficits in memory, thinking

By Janet Raloff

Obesity subtly diminishes memory and other features of thinking and reasoning even among seemingly healthy people, new research shows. At least some of these impairments appear reversible through weight loss. One likely mechanism for those cognitive deficits appears to be damage to the wiring that links the brain's information-processing regions.

Studies have shown that individuals with diseases linked to obesity, including cardiovascular disease, hypertension and type 2 diabetes, don't score as well on cognitive tests as less hefty people do. To test whether weight alone — and not disease — might be partially responsible, John Gunstad of Kent State University in Ohio and colleagues gave a series of cognitive tests to 150 obese volunteers. Those participants weighed on average just under 300 pounds, although some were much heavier. Two-thirds would shortly undergo weight-loss surgery.

Scores on the tests were assessed against those of healthy people in the Brain Resource International Database. On average, obese participants initially performed on the low end of the normal range for healthy people, Gunstad says. But nearly one-quarter of the obese participants' scores on memory and learning actually fell within what researchers consider the impaired range.

Tested 12 weeks after bariatric surgery — when most had shed some 50 pounds — the lighter but still heavy patients scored substantially better. Most now performed "within the average or greater-than-average range for all cognitive tests," the researchers reported online last October in *Surgery for Obesity and Related Diseases*. Those who didn't have surgery — or lose weight — performed worse on the second test.

In a second study, appearing in the March *Obesity*, Gunstad's group used brain imaging to probe the wiring that connects nerve cells and moves information throughout the brain. Sheathed in a layer of white insulation, the bundled cables of fibers are called white matter. In obese individuals — but not normal-weight or merely overweight people — this sheathing shows signs of damage. "It's not as though a cable has been cut," Gunstad says. "It's just that its integrity is diminished," jeopardizing the strength or clarity of signals that must traverse these cognitive highways.

Stefan Knecht of the University of Münster in Germany notes that his team recently showed that "low-grade inflammation, which is strongly correlated with obesity, could be an important mediator" of white matter damage.

Chemical impact on who mice woo

Males court both sexes when deprived of serotonin in brain

By Laura Sanders

When courting, male mice lacking the chemical messenger serotonin don't seem to care whether the object of their affection is female. Mice without the molecule no longer eschew the smells of other males, instead wooing them with squeaky love songs and attempts to mount them, researchers report online March 23 in *Nature*.

"Nobody thought that serotonin could be involved in this kind of sexual preference," says study coauthor Zhou-Feng Chen of Washington University School of Medicine in St. Louis.

The male-male courtship seen in the lab isn't equivalent to human homosexuality. And what, if anything, serotonin has to do with human sexual behavior is still an open question.

In the study, male mice genetically engineered to lack serotonin-producing brain cells still courted females. But when given a choice, these mice no longer reliably chose females over males. In tests where both a male and a female mating partner were present, nearly half of the serotonin-lacking males mounted the male first, report researchers led by Yi Rao of Peking University in Beijing.

> "These mice are not gay."
> MILTON WAINBERG

These mice were also more likely than normal mice to emit ultrasonic squeaks — a type of mouse love song — toward other males and spent equal time sniffing male and female odors. Some of the altered sexual behaviors could be reversed by restoring serotonin to the brain, the team found.

Psychiatrist and sexual-research scientist Milton Wainberg of Columbia University says that it's too simplistic to apply the experimental results to human sexuality. "These mice are not gay," he says. "These mice have a disease that makes them do one behavior, which … can be thought of as a homosexual behavior, but it's not homosexuality."

The new result "opens now quite a lot of fascinating avenues," including questions about where, when and how serotonin exerts its control over mouse sexual behavior, says Harvard molecular neuroscientist Catherine Dulac.

In humans, antidepressant drugs that increase active serotonin levels in the brain do have some sex-related side effects. Some can decrease libido in people. Yet there's no evidence that serotonin has any influence on sexual orientation, Wainberg says.

Atom & Cosmos

58.7 **Earth days** Time it takes Mercury to rotate on its axis

88 **Earth days** Time it takes Mercury to travel around the sun

New scenario for planetary births

Theory offers way to explain diversity of extrasolar orbs

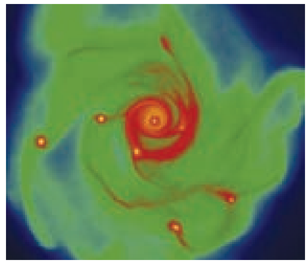
By Ron Cowen

A radical new theory that planets are born within a massive veil of gas may help explain how recently discovered extrasolar planets developed their stunning diversity of sizes and locations.

In the theory, planets are born under wraps, hidden at the centers of giant gas clouds far from their parent stars. A star's gravity then reels in the planetary cloud, stripping away some or all of the gas to reveal the planet inside.

Depending on how much of the gas is removed in the process, the unveiled planet would resemble a gas giant like Jupiter, a solid core with a layer of gas like Neptune, or a solid body like Earth. Sergei Nayakshin of the University of Leicester in England describes the process in an upcoming *Monthly Notices of the Royal Astronomical Society* as well as in several papers posted online at arXiv.org.

Such a beginning might explain the abundance of small-to-middling extrasolar planets spotted by NASA's Kepler spacecraft in orbits within roasting distance of their stars (*SN: 2/26/11, p. 18*). Standard planet-formation models can't easily account for the many types of exoplanets described since 1995, notes theorist Aaron Boley of the University of Florida in Gainesville. "At the end of the day, we need to explain this diversity of planetary systems," he says.



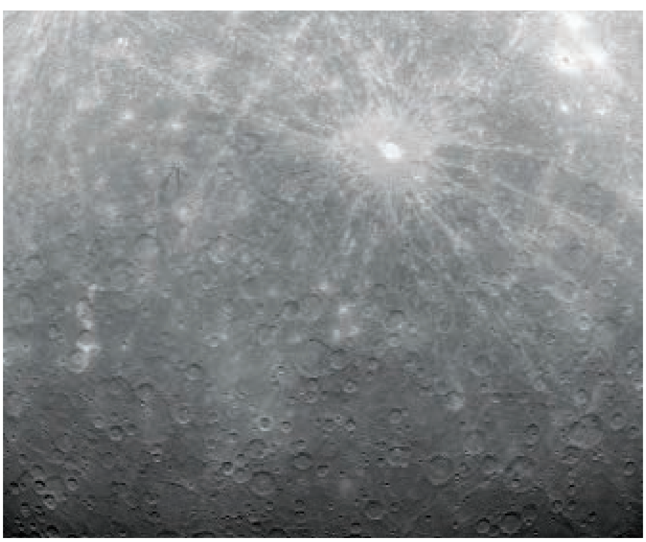
Young planets may develop within gas clouds that are later stripped away to sculpt a mature planet's form.

Nayakshin's theory, along with a similar one by Boley and his colleagues, borrows ideas from two traditional models. In the "core accretion" scenario, bits of solid particles coalesce within the disk of gas and dust around a young star and form a solid core that resembles Mercury or Earth. The core may then snare enough gas to form a Jupiter. In the "gravitational instability" model, gas within the planet-forming disk suddenly fragments to form a giant blob, forming a Jupiter in one fell swoop.

In contrast, Nayakshin begins with the giant blob of gas generated by gravitational instability. Then, he suggests, dust settles to the core of the blob, ultimately forming a solid body that snares some of the gas around it, as in the core accretion model. The gassy envelope around the core is initially fluffy and easily removed. As the clump migrates toward its star and reaches a distance similar to that separating Mars from the sun, some of the gas may be stripped away by the star's gravitational tidal forces. Removing the outer layers of gas produces rocky planets.

If migration is slower, the gas envelope has enough time to contract and become denser, resisting stripping. In that case, only if the blob moves very close to the star, much nearer than Mercury's distance from the sun, can the star's tidal forces remove part or all of the dense gas envelope. Such a downsized planet could be a hot version of Jupiter, Neptune or Earth.

Some think the theory is worth further exploration, but Jack Lissauer of NASA's Ames Research Center in Mountain View, Calif., calls it weak, adding that "the idea of forming planetary cores in this manner is far from demonstrated."



Mercury viewed close-up

NASA's MESSENGER spacecraft has returned the first images ever taken by a probe orbiting the solar system's innermost planet. Recorded on March 29, the historic close-ups show parts of Mercury's south polar terrain never before viewed by a spacecraft. NASA released the first image taken from orbit on March 29 and several others March 30. The first image (left) shows two craters and part of the south polar region, resolving features as small as about 5 kilometers across. Other portraits show details of a surprisingly high number of secondary craters, small pockmarks created during the formation of larger craters. "That's the barest hint of what we'll have on a regular basis," says MESSENGER lead scientist Sean Solomon of the Carnegie Institution for Science in Washington, D.C. By the mission's end in March 2012, the craft will have taken some 75,000 images that will create a global mosaic of Mercury. —*Ron Cowen*

FROM TOP: SEUNG-HOON CHA, S. NAYAKSHIN/ARXIV.ORG/ABS/1010.1489; NASA, JHU APL, CARNEGIE INST. FOR SCIENCE

Genes & Cells

2–3 weeks Life span of a *C. elegans* roundworm

2–3 years Life span of a laboratory mouse

2–3 decades Life span of a rhesus macaque

Worms live longer with thioflavin T

Dye used in Alzheimer's research promotes longevity in lab

By Daniel Strain

Wriggly roundworms (*Caenorhabditis elegans*) have found themselves a philosopher's stone of sorts. A dye used to visualize the proteins that build up in the brains of Alzheimer's patients can boost a worm's two- to three-week life span by more than half, Gordon Lithgow of the Buck Institute for Research on Aging in Novato, Calif., and his colleagues report online March 30 in *Nature*. The dye, called thioflavin T, seems to prevent the deviant protein clumps often associated with a number of human age-related diseases, including Alzheimer's, researchers say.

During aging, the body accumulates proteins that aren't shaped, or "folded," the way they should be, says Richard Morimoto, a molecular biologist at Northwestern University in Evanston, Ill. For reasons that remain a hot topic of study, misshapen proteins often sit in big clumps that have been spotted in any number of chronic illnesses from Alzheimer's to Parkinson's and Huntington's disease. "The underpinning for all these diseases may be aging," Morimoto says.

Longer, healthier life may be possible, then, if doctors can keep misshapen proteins under wraps. The California team fed the dye to roundworms genetically prone to getting debilitating clumps of the protein amyloid-beta in their muscles — the same protein that forms plaques in the brains of Alzheimer's sufferers. Thioflavin T blocked many of those clumps from accumulating in the treated worms, extending their lives. Normal worms lived longer after eating the chemical, too.

What's going on in the worms isn't clear yet. The dye seems to bind directly to misshapen proteins, which is why researchers use it to look at Alzheimer's clumps under the microscope, and may change the shape of those proteins.

But the dye doesn't work alone. Some of the critters' normal stress responses are necessary to block clumping, too. These responses, very similar to those in humans and other animals, help to shape proteins as a cell churns them out and may even produce antioxidants that protect proteins from damage. Lithgow suspects that the dye begins the process, fudging the shapes of bad proteins. That may tip the body off to the problem, triggering the normal stress responses to come in and "take out the garbage," he says.

Other substances may turn on the same stress responses. In an earlier study in worms, molecular geneticist Chris Link of the University of Colorado at Boulder and colleagues showed that certain chemicals in coffee also seemed to slow the formation of protein clumps, potentially by cranking up wormy antioxidants.

Coffee: That's one delicious fountain of youth.

Brain cell growth restores function

New neurons help patch up learning, memory after injury

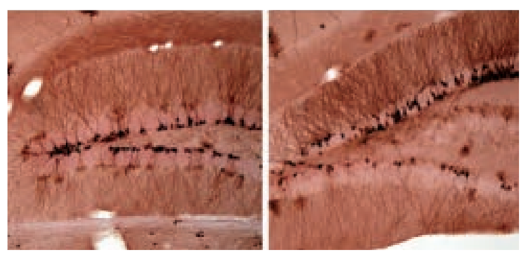
By Tina Hesman Saey

Newborn nerve cells may help heal the brain after a traumatic injury.

In mice, blocking the birth of new neurons hindered the animals' ability to learn and remember a water maze after a brain injury, Steven Kernie and colleagues from the University of Texas Southwestern Medical Center at Dallas report in the March 30 *Journal of Neuroscience*. The finding could help settle a debate about what new nerve cells do for the brain and may eventually change the way brain-injured patients are treated.

Although scientists have known for a decade that two regions in adult brains can make new neurons, the role of the newborn cells has been unclear. Some thought that new neurons may not affect the adult brain at all.

The study suggests that newborn neurons in the hippocampus — an important learning and memory center — are beneficial, at least in aiding recovery after traumatic brain injuries. "It's clear they are doing something, and that that something aids recovery," says Jack Parent, a neurologist and neuroscientist at the University of Michigan Medical Center.



Uninjured control — Six months after injury

Injury can trigger the birth of new neurons in the brain. More treelike neurons were seen in mice after injury (right) than in uninjured mice (left).

STEVEN KERNIE

To discover what role, if any, neurogenesis plays after a brain injury, the Texas team genetically labeled newborn cells in the hippocampi of mice. The researchers found that traumatic brain injury stimulates birth of more brain cells than usual. Using another genetic technique, the researchers blocked the regrowth in some mice. Mice that couldn't make new brain cells didn't recover the ability to learn a water maze after brain injury as effectively as mice that could generate new neurons. The result indicates that newborn neurons play a role in learning that involves the hippocampus.

"This changes the way we think about the inheritance of disease." —JOSEPH NADEAU

Ghost of ancestor's genes lingers

Antiobesity DNA is absent, but its benefits to mice remain

By Laura Sanders

Great-grandfathers may impart more than engraved watches. A sugar-regulating gene that made a brief appearance in a lineage of mice but wasn't passed on seems to have made animals resistant to obesity up to four generations later.

"This changes the way we think about the inheritance of disease," study coauthor Joseph Nadeau of the Institute for Systems Biology in Seattle said March 30. The results may force researchers to grapple with complicated transgenerational gene influences.

The surprising effect may be caused by the single-generation appearance of a genetic variation that affects the maintenance of blood sugar. Nadeau and colleagues allowed two inbred strains of mice to eat as many of the mouse equivalent of double cheeseburgers as they wanted. One type of mouse grew obese and developed health problems such as insulin resistance, high blood pressure and cardiovascular disease. The other type didn't gain weight, even though these mice ate more and exercised less.

Mice on a rich diet became fat (right) or thin depending on an ancestor's genes.

When the part of the skinny mouse's DNA containing the blood sugar gene was inserted into the obesity-prone mouse, the mice stayed slim on the high-fat diet.

But here the story gets strange: Even if the piece of DNA swapped into a mouse was not passed on to descendants, the effect was still evident generations later. The original mouse's great-grandchildren remained slender, even on a high-fat diet. Though these mice didn't inherit the actual gene, they did inherit some ghostly imprint of it. "The reason they are the way they are isn't in them," Nadeau said. "It was in the previous generation."

The findings are "breathtaking," says computational biologist Sorin Istrail of Brown University. The results might help resolve a genetics mystery: Some traits — including obesity — are strongly inherited. But so far, researchers have been able to identify genes that explain just a tiny part of this total heritability. A gene from generations earlier that left a biochemical mark might explain some of the "missing" effect, Istrail said.

Nadeau and colleagues don't understand how the ghostly gene's effect persists. One hint comes from preliminary signs of changes in the way small pieces of RNA regulate protein production.

New mutations evolve in cancer

Acute myeloid leukemia data may aid choice of treatment

By Laura Sanders

As a man's cells grew cancerous, a wide range of mutations emerged too, a new genetic study finds. The results provide a deep understanding of the genetic changes that allowed an aggressive form of leukemia to take hold in one patient.

"Cancer's origins lie in the genome," Elaine Mardis of Washington University in St. Louis said March 28. "These genetic approaches are really addressing the underlying questions of cancer biology."

In the new study, Mardis and colleagues collected cells from a 65-year-old man with myelodysplastic syndrome, a blood disease. About one in four people with this disorder develop a rapidly progressing cancer called acute myeloid leukemia. Two years after those samples were taken, the man was diagnosed with full-blown acute myeloid leukemia, and the researchers harvested a second batch of cells. By reading the cells' DNA sequences letter by letter, the team pinpointed genetic changes as the cells turned cancerous.

Over time, the cells accumulated new genetic mutations. Early mutations didn't run rampant and overtake all the cancerous cells but didn't disappear, either. Early mutations became present in less and less of the cancer-cell population.

Watching the same cancer in the same person over time allows the team to see just how this cancer evolves, says computational biologist Cenk Sahinalp of Simon Fraser University in Canada.

The finding helps answer a long-standing question: In leukemia, does a group of cells with a particular mutation rapidly spread, or do additional mutations pop up along the way and result in a cancer that's more genetically mixed? In colon cancer, for instance, most cells in the final tumors contain the same mutations as the early mutations, suggesting that they spread quickly. Yet in this patient, for this particular leukemia, more mutations occurred.

This steady accumulation of multiple mutations — and the genetically complex mishmash of cells that results — may confound some treatment options aimed at one select problem, Mardis says. But it's important for doctors to be aware of the likely genetic complexities of leukemia when they're deciding on a treatment. "Physicians need to know what they're up against," she says.

Knowing what genes change, and when, may lead to more specific and effective treatments for leukemia, Mardis says.

J. NADEAU

Humans

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Toolmaking folk went east early

Hand ax innovators reached India 1.5 million years ago

By Bruce Bower

Finds unearthed in southeastern India offer a cutting-edge revision of hominid migrations out of Africa more than 1 million years ago that spread pivotal toolmaking methods.

Makers of a specific style of teardrop-shaped stone hand ax, flat-edged cleavers and other implements that originated in Africa around 1.6 million years ago (*SN: 1/31/09, p. 11*) reached South Asia not long afterward, between 1.5 million and 1 million years ago, say archaeologist Shanti Pappu of the Sharma Center for Heritage Education in Tamil Nadu, India, and colleagues.

Rather than waiting until around 500,000 years ago to head into South Asia, as many researchers have thought, the African hand ax crowd wasted relatively little time before hightailing it to India, Pappu's team concludes in the March 25 *Science*.

Archaeologists categorize stone hand axes and related implements as Acheulian tools. Most researchers regard *Homo erectus*, a species that originated around 2 million years ago, as the original brains behind Acheulian innovations.

"Acheulian toolmakers were clearly present in South Asia more than 1 million years ago," Pappu says. Several previous excavations in different parts of India have also yielded Acheulian tools, but these finds lack firm age estimates.

No fossil remains of hominids — members of the human evolutionary family — turned up among the new tool finds.

H. erectus must have rapidly moved from East Africa to South Asia, proposes archaeologist Robin Dennell of the University of Sheffield in England. Pappu's new finds raise the possibility that 800,000-year-old hand axes found in southeastern China (*SN: 3/4/00, p. 148*) indicate the presence of *H. erectus* groups that came from South Asia — or at least exposure of Chinese hominids to Acheulian techniques, Dennell writes in a commentary in the same issue of *Science*.

Until now, scientific consensus held that Acheulian toolmakers, presumably *H. erectus*, reached the Middle East at least twice, about 1.4 million and 800,000 years ago, but went no farther. In this scenario, another species of Acheulian-savvy hominids, *Homo heidelbergensis*, then took Acheulian tools from Africa to both South Asia and Europe about 500,000 years ago.

A stone ax from India suggests African hominids moved east earlier than thought.

Harvard anthropologist Philip Rightmire isn't surprised by the sign of an earlier arrival of *H. erectus* in India. Other evidence suggests that *H. erectus* left Africa and reached several destinations in Asia beginning at least 1.8 million years ago, wielding simple chopping tools. "For now, it's enough to say that *Homo erectus* introduced Acheulian tools to India," Rightmire says.

The latest finds come from the Attirampakkam site, which has yielded more than 3,500 Acheulian artifacts, including 76 hand axes and cleavers. Measurements of radioactive isotopes in six quartz tools unearthed there indicated that these finds had been buried about 1.5 million years ago.

A new glimpse of early Americans

Artifacts show Texas site was occupied 15,000 years ago

By Rachel Ehrenberg

Everything's bigger in Texas, even the piles of debris and tools left near a stream 15,000 years ago by some of the earliest known inhabitants of North America.

The new trove of 56 stone tools and thousands of flaky rock bits from an archaeological site north of Austin is the largest and oldest artifact assemblage of its kind discovered to date, says Michael Waters of Texas A&M University in College Station. Waters and a large team of colleagues describe the collection of artifacts, dubbed the Buttermilk Creek Complex, in the March 25 *Science*.

Across North America, a distinctive type of fluted blade shows up in layers of dirt dating to between 13,100 and 12,800 years ago. This "Clovis point" has been called the first great American invention, a technology that spread quickly around the continent. Scientists used to think that the inventors and users of the point, which was probably fastened to wooden spears, were the first inhabitants of North America, arriving via an ancient land bridge with Siberia.

But a number of sites in North America and one in Chile have established that people were living in the Americas earlier than 13,000 years ago, and in the last decade the "Clovis First" hypothesis has gone the way of the woolly mammoth. The newly described finds, which date to between 13,200 and 15,500 years ago, add Buttermilk Creek to the scant but growing roster of pre-Clovis sites.

It isn't clear how many people camped at the Texas site or how long they lingered. No hearths or other areas indicative of day-to-day living have been found. But, in addition to 12 bifacial blades that may have been used as spear points, the archaeological team found five blade fragments, 14 bladelets and some clunkier adzelike tools that might have been used for carving or shaping wood.

Matter & Energy

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Diamonds could be data gold mine

Linking electron spin to nitrogen might aid quantum computing

By Devin Powell

Could be that diamonds are a geek's best friend.

Scientists have developed a new way to manipulate atoms inside diamond crystals so that they store information long enough to function as quantum memory. Quantum information is encoded not as the 0s and 1s crunched by conventional computers but in states that are both 0 and 1 at the same time. Physicists use such quantum data to send information securely, and hope to eventually build quantum computers that solve problems beyond the reach of today's technology.

For quantum memory, flawless diamonds — composed of pure carbon crystals — won't do.

"We want to build in defects," David Awschalom of the University of California, Santa Barbara said March 22.

One of the most common defects in diamond is nitrogen, which turns the stone yellow. When a nitrogen atom sits next to a vacant spot in the carbon crystal, the intruding element provides an extra electron that moves into the hole. Scientists have already learned how to change the spin of such electrons using microwave energy and put them to work as quantum bits, or qubits.

In search of a more stable way to store quantum information, Awschalom has now figured out how to link the spin of an electron to the spin of the nearby nitrogen's nucleus. This transfer, triggered by magnetic fields, is fast — about 100 nanoseconds, comparable to how long it takes to store information on a stick of RAM.

The technique has "a fidelity of 85 to 95 percent," Awschalom said.

Unlike a diamond itself, this quantum memory isn't forever. But it lasts for a very long time by quantum standards. The nuclear spin remains coherent for more than a millisecond, with the potential to improve to seconds.

> "If you have a lifetime of milliseconds, that lets you do millions of operations."
> SEBASTIAN LOTH

"You can only do your quantum magic as long as you have coherence," said physicist Sebastian Loth of IBM's Almaden Research Center in San Jose, Calif. "If you have a lifetime of milliseconds, that lets you do millions of operations."

And in contrast to some other quantum systems under development, which require temperatures close to absolute zero, this diamond memory works at room temperature.

Scientists study graphene sibling

Single-layer 'silicene' sheets might have electronic uses

By Devin Powell

Inspired by the Nobel Prize–winning carbon material graphene, physicists are now investigating atom-thick sheets of carbon's big brother, silicon.

Silicon shares many properties with carbon, which sits just above it on the periodic table. In 2007 Lok Lew Yan Voon and then–graduate student Gian Guzmán-Verri of Wright State University in Dayton, Ohio, proposed that silicon could form flat sheets similar to graphene.

The team coined the new term for this material: silicene.

"Silicon has the advantage of being more integratable in today's electronics," said physicist Antoine Fleurence of the Japan Advanced Institute of Science and Technology in Ishikawa.

Speaking March 24, Fleurence described a new silicene recipe. He and his colleagues grew a thin layer of silicon on top of the ceramic material zirconium diboride. X-rays shined on this thin layer of silicon revealed a honeycomb of hexagons similar to the structure of graphene.

This structure looks familiar to Guy Le Lay, a physicist at the University of Provence in Marseille, France. Last year, he created the first-ever silicene ribbons. Le Lay described these 1.6-nanometer-wide stripes of honeycombed atoms, grown on top of silver, in the May 3 *Applied Physics Letters*.

New data from Le Lay's group, also presented March 25, suggest that silicene and graphene share not only a similar structure, but possibly similar electronic properties. To prove silicene's worth, though, Le Lay will need to grow it not on electrically conductive silver but on an insulating material that won't interfere with the movement of electrons. Fleurence's ceramic material also conducts electricity and so does not solve that problem.

On an insulating platform, physicists will be able to test the material's electronic properties directly and do experiments to determine whether the same quantum effects that make graphene so remarkable are also at work in silicene.

For silicene to compete with graphene in the long run, however, the process of creating it must be comparably simple, says Sankar Das Sarma, a physicist who studies graphene at the University of Maryland in College Park. "Graphene really took off in 2004 because it was so easy to make," he says.

The Russian scientists who first made graphene in 2004 — and won the 2010 Nobel Prize in physics for their efforts — did it using only a piece of Scotch tape and a chunk of graphite similar to pencil lead.

Environment

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In Iraq, breathing can be unhealthy

Small particles in air add to dangers facing U.S. troops

By Rachel Ehrenberg

ANAHEIM, Calif. — As if enemy fire, IEDs and suicide bombers weren't enough, U.S. soldiers in Iraq also must contend with air laden with heavy metals and lung-ravaging particles, researchers reported March 30 at a meeting of the American Chemical Society. Exposure to particles of the size collected in the study can lead to chronic respiratory infections, aggravate asthma and increase cardiovascular risk.

Air samples collected over 90-minute intervals at several sites in Iraq since 2008 contained dust, lead, aluminum and other metals in quantities that often exceeded U.S. air quality standards, Jennifer Bell of the Geophysical Institute at the University of Alaska Fairbanks reported. Included were particles smaller than 2.5 micrometers, which can evade hairlike projections in the nose and trachea and penetrate deep into the lungs.

Dust storms like this one in Baghdad can expose troops to unsafe levels of dust and other particles, a study finds.

KEVIN GEISBERT

While levels varied daily, typical concentrations of lead particles ranged from 0.6 to 1 microgram per cubic meter of air, Bell and her adviser, Catherine Cahill, found. That's at least four times U.S. standards. During one dust storm, aluminum levels exceeded 1,400 micrograms per cubic meter.

The noxious air probably results from a mix of natural and man-made sources, said Bell. Iraq has clay deposits, sandstone foothills and other geologic features containing zinc, lead and silicate minerals that get swept up in enormous dust storms in the region many times a year. Leaded gasoline is still widely used in Iraq, which with open trash burning, oil fires and debris from explosions makes naturally dusty air even worse.

"My major concern would be for potential long-term health ramifications," said Robert Brook of the University of Michigan Medical School in Ann Arbor. Fine particles are the most strongly linked to adverse health effects, he said.

Environment

"It seems beaked whales may be more sensitive than other species to sound." — PETER TYACK

Japan nuke accident seen in Seattle

Clues to events at crippled plant found in traces of radiation

By Devin Powell

Radioactive particles wafting from Japan to Seattle have been used as a window on recent events inside the crippled Fukushima Daiichi nuclear power plant. Working backward from trace nuclear by-products, physicists have confirmed that contaminated steam is the source of this radiation, not spent fuel rods or material ejected into the atmosphere directly from the reactor core.

"We haven't seen any of the heavier stuff that would come right from the core, which people saw 30 years ago during the Chernobyl accident," says Andreas Knecht, a nuclear and particle physicist at the University of Washington in Seattle who, along with colleagues, published the new data online March 24 at arXiv.org.

Starting March 16, Knecht's team saved and analyzed filters that clean 100 million liters of air every day in the ventilation system of the University of Washington's physics and astronomy building. With a detector originally designed to spot neutrinos coming from outer space, the researchers searched for gamma rays originating in the by-products of nuclear fission. The first such by-products from Japan were detected on March 18.

The mix of elements found in the filters drives home the differences between the Chernobyl and Fukushima disasters. The total meltdown of the Chernobyl reactor in 1986, which exposed the core, belched tons of radioactive material from fuel rods directly into the atmosphere. At the time, scientists in Paris detected 20 different isotopes. The partial meltdown of Fukushima, in contrast, released only five isotopes measurable by the Seattle team: iodine-131, iodine-132, tellurium-132, cesium-134 and cesium-137.

The absence of iodine-133, an ephemeral isotope that breaks down in days, confirmed that the radiation spotted by Knecht had been traveling for at least a week or so. And the presence of tellurium-132, a fission by-product that degrades over weeks, suggests that the windblown radiation came from material that had recently seen fission inside a nuclear reactor. This rules out older, spent fuel rods as a source and points to the fuel rods that were generating power when the March 11 earthquake struck.

The lack of heavier elements ruled out the possibility that the material in these fuel rods was tossed directly into the atmosphere after the earthquake. Instead, radioactive cesium and iodine — which dissolve easily in water as the compound cesium iodide — probably contaminated steam released to control pressure inside the damaged reactors.

"This is what we expected to see," says Knecht. "But obviously it doesn't hurt to check."

The team's findings tell the same story repeated by scientists at the Environmental Protection Agency, the University of California, Berkeley and other institutions monitoring the West Coast: Only minute amounts of radiation are reaching the United States. Levels of radioactive iodine, a cause for concern in Japan itself, were in Seattle a mere hundredth of the safety level set by the EPA.

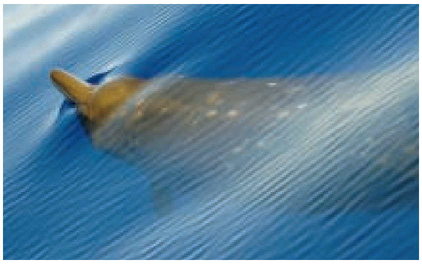
"We'd like to confirm that what's coming over here is at a level which is tolerable," says Ed Morse, a nuclear engineer at UC-Berkeley. "So far that's consistent with what we're seeing."

Beaked whales can't stand sonar

New study suggests species are highly sensitive to noise

By Rachel Ehrenberg

Navy sonar unquestionably disturbs beaked whales, concludes an analysis investigating how underwater sound affects these deep-divers. The results, published online March 14 in *PLoS ONE*, suggest that noise-exposure limits for beaked whales need to be lowered.



Beaked whales are especially sensitive to underwater sound, which can disrupt their behavior, a new study concludes.

COURTESY OF BRANDON SOUTHALL, NMFS/OPR/NOAA

During sonar exercises at the U.S. Navy's underwater test range in the Bahamas, beaked whales stopped their chirpy echolocations and fled the area, experiments employing a huge array of underwater microphones revealed.

"It seems beaked whales may be more sensitive than other species to sound," says study leader Peter Tyack of the Woods Hole Oceanographic Institution in Massachusetts. "At the very least we may need a special rule for these whales."

Some marine mammal species, such as harbor porpoises, are already known to be particularly sensitive to sound, while others seem unbothered.

"We treat porpoises differently, and now there's evidence that beaked whales respond differently as well," says marine conservation biologist Tara Cox of Savannah State University in Georgia.

Until beaked whales started showing up in unusual mass strandings, the elusive animals were rarely seen. Because the strandings often coincided with nearby naval sonar exercises, scientists suspected noise was somehow driving these whales to the beach.

350 billion Metric tons of carbon released by humans up to 1850

440 billion Metric tons of carbon released by humans from 1850 to 2000

Human climate meddling got start long before dawn of petroleum era

Clearing forests released greenhouse gases by the gigaton

By Alexandra Witze

SANTA FE, N.M. — People influenced the planet's climate for millennia before the industrial revolution's fossil fuel–burning machines began spewing carbon dioxide and other heat-trapping gases into the atmosphere, a new study suggests.

Clearing land — first to hunt and gather, and then to farm — removed trees that otherwise would have soaked up carbon dioxide. The new work estimates that humans working the land added about 350 billion metric tons of carbon into the atmosphere by the year 1850. (For comparison, between 1850 and 2000 people added 440 billion tons of carbon, mostly from burning fossil fuels — more than matching in a century and a half what humankind had taken the previous eight millennia to produce.)

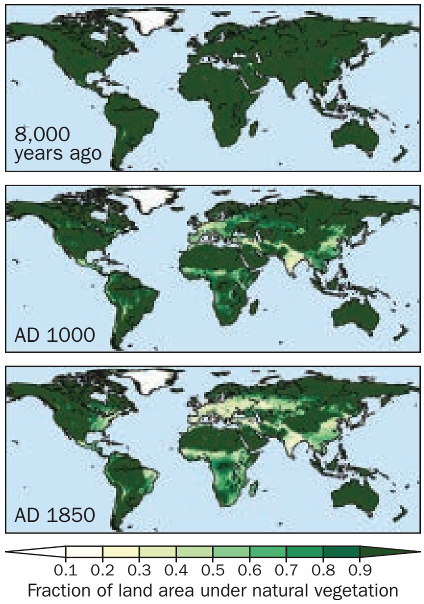
"Our data show very substantial amounts of human impact on the environment over thousands of years," says team leader Jed Kaplan of the Federal Polytechnic School of Lausanne in Switzerland.

Kaplan reported the work on March 25 at an American Geophysical Union conference on past civilizations and climate. He, Lausanne colleague Kristen Krumhardt and others also describe the findings in an upcoming issue of *The Holocene*.

Climate scientists often select 1850 as the start of industrial impact on the atmosphere. But the world in 1850 was not pristine. "I call it the 'virgin continent myth,'" says Kaplan.

People cut down forests and cleared land early on. Agriculture, for instance, arose in the Fertile Crescent some 8,000 to 10,000 years ago.

Previous research often assumed that as the world's population grew, the proportion of cleared land rose as well. But



Over millennia, humans cleared much of the planet's land area for farming and other uses, releasing carbon once stored in trees into the atmosphere.

J. KAPLAN *ET AL*/*THE HOLOCENE* 2011

the more people crowded onto a landscape, the more efficient they became at extracting dinner from it, says William Ruddiman, a retired geologist from the University of Virginia in Charlottesville. Irrigation, fertilizer, multicropping and new tools allowed farmers to increase crop yields, and per capita land use fell.

Kaplan and Krumhardt looked at how growing population and changing land-use trends affected carbon emissions. The scientists gathered population data for the past 8,000 years, then cataloged how land use changed over time. The result: a dramatic sequence showing a green-forested world giving way to a brown spread of deforestation.

The researchers then used a computer simulation to calculate the amount of carbon put into the preindustrial atmosphere. The 350-billion-ton estimate is roughly twice what the scientists found with a different, widely used computer simulation, and five times that reported in *Biogeosciences* in January by a University of Bern team. The differences, Kaplan says, trace in part to assumptions about how carbon is stored in the soil when forests give way to grasslands.

The new, higher estimates support a theory Ruddiman has espoused for years — that people were responsible for far more carbon emissions far earlier than most researchers have thought.

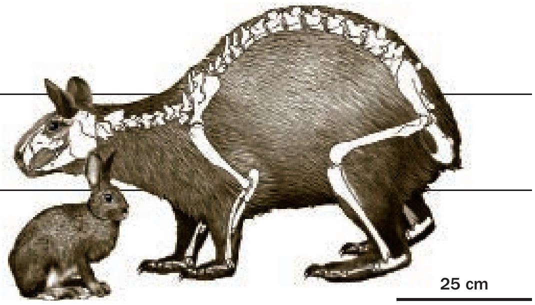
Critics have cited evidence like the chemical composition of carbon dioxide bubbles trapped in an ancient ice core, which don't show the changes in carbon type that would be expected if trees had been chopped down. But rapidly expanding peatlands could have counterbalanced some of those effects, says Ruddiman.

Julia Pongratz, a geographer at the Carnegie Institution for Science in Stanford, Calif., has done a more detailed study of how people's land use varied from place to place. For instance, when people first began growing rice in paddies in China, it took fewer acres to feed the same number of people than in Mesopotamia, because wet-grown rice produces more calories per acre than cereal crops.

Taking these regional patterns one step further, Pongratz is now calculating how prehistoric land use contributed to countries' total carbon emissions. "We find that when we include preindustrial emissions, the attribution of today's carbon dioxide increases goes up for countries like China and India and goes down for industrialized countries," she says.

Because of their long agricultural traditions, India and China emitted a lot of carbon millennia ago. In contrast, North America remained relatively pristine forest until the past couple of hundred years. In Europe, the fact that land was cleared thousands of years ago is outweighed by the sheer size of its modern-day carbon emissions. ■

Life



Fossils discovered on the island of Minorca reveal the largest rabbit species ever described (right, compared with a modern European rabbit at left).

The bunny that ruled Minorca

Fossil rabbit was six times the size of modern relatives

By Susan Milius

It may not be Harvey (it's visible), but paleontologists have found fossils of a giant rabbit — the largest ever described — on the Mediterranean island of Minorca.

Three to 5 million years ago, a rabbit species there grew about half a meter high with an estimated weight of 12 kilograms (about 26 pounds), researchers report in the March *Journal of Vertebrate Paleontology*. Six times the size of today's wild European rabbit, the hefty extinct species outweighed not only all known rabbits, but all species in the broader group of rabbits, hares and pikas, say paleontologist Josep Quintana Cardona of Minorca and his colleagues.

The new hunk of a rabbit, now named *Nuralagus rex*, shows the kind of unusual turn that evolution can take on islands. "Gigantism happens," says Brian Kraatz of Western University of Health Sciences in Pomona, Calif. When pioneer animals start colonizing an island, rates of evolution typically speed up at first, he explains. Small creatures can supersize, and big ones can shrink.

It's particularly exciting to see a huge rabbit, since rabbits and their kin are fairly similar to one another compared with the diversity of body forms in closely related groups like rodents, comments paleontologist Łucja Fostowicz-Frelik of the American Museum of Natural History in New York City.

So far no plausible rabbit-eaters have turned up among fossils from the same time period on Minorca, so the big bunnies could have evolved larger and larger body size without pressure to maintain speed and agility to escape predators. The relatively short, stiff spine of the fossils suggests that *Nuralagus* didn't hop much, if at all.

Data may point to monarch decline

Butterflies overwintering in Mexico appear to be on the wane

By Susan Milius

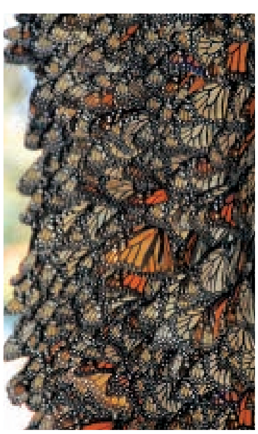
North America's beloved monarch butterfly may be sliding into long-term decline. While monarch numbers have fluttered up and down over recent decades, one research group now says that there's enough data to spot a downward trend.

Over the last 17 years, the area of Mexican forest patches covered by overwintering butterflies has been shrinking overall, says conservation biologist Ernest Williams of Hamilton College in Clinton, N.Y. He and his colleagues use the area occupied, which has averaged 7.24 hectares since the end of 1994, as a rough index of winter monarch population size.

"We have enough data now to say that we are seeing a long-term decline," Williams says.

Seven of the 10 below-average years in the study followed one another in a worrisome streak through the winter of 2010–2011, Williams and his colleagues report online March 21 in *Insect Conservation and Diversity*.

That trend in winter populations does pass a simple statistical test, says monarch researcher Karen Oberhauser of the University of Minnesota in St. Paul. She and other researchers are now working on a broader analysis of monarchs and the challenges the insects face throughout the year to get a better handle on whether the population is declining and, if so, why. "I am not arguing that monarch populations are not facing threats, nor am I saying I'm not concerned," she says. "I don't think the [wintering] trend data clarify the situation."



Monarch butterflies wintering in Mexico can cluster so densely that they hide the bark of a tree trunk.

Orange-and-black monarchs dart and waver over North American summer landscapes coast to coast and as far north as Canada, seeking milkweed plants as sites for laying eggs. The species' annual migration is perhaps its most dramatic feat, though. Butterflies that hatch during summer and fall — never having been to Mexico — find their way to the same patches of forest as earlier generations.

Winter monarch retreats are officially protected, but illegal logging chews away at Mexico's forests. Plus, looming climate changes may bring more episodes of severe weather, which can hammer the butterflies. Monarchs across North America are finding less breeding habitat than they used to as open land for milkweeds is falling to development. And researchers warn that a boom in genetically engineered crops is changing herbicide-use patterns and thinning the ranks of milkweeds.

FROM TOP: ARTWORK BY MEIKE KÖHLER; E. WILLIAMS

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Cosmic questions, answers pending

Throughout human history, great missions of exploration have been inspired by curiosity, the desire to find out about unknown realms. Such missions have taken explorers across wide oceans and far below their surfaces, deep into jungles, high onto mountain peaks and over vast stretches of ice to the Earth's polar extremities.

Today's greatest exploratory mission is no longer Earthbound. It's the scientific quest to explain the cosmos, to answer the grandest questions about the universe as a whole.

What is the identity, for example, of the "dark" ingredients in the cosmic recipe, composing 95 percent of the universe's content? And just what, if anything, occurred more than 13.7 billion years ago, when the universe accessible to astronomical observation was born? Will physicists ever succeed in devising a theory to encompass all the forces and particles of nature in one neat mathematical package (and in so doing, perhaps, help answer some of these other questions)? Will that package include the supposedly basic notions of space and time, or will such presumed preexisting elements of reality turn out to be mere illusions emerging from ur-material of impenetrable obscurity? And finally (fittingly), what about cosmic finality? Will the universe end in a bang, a whimper or the cosmic equivalent of a Bruce Willis movie (everything getting blown apart)?

In the pages that follow, *Science News* writers assess the state of the evidence on these momentous issues. In none of these arenas are the results yet firm. But as string theorist Brian Greene wrote in his book *The Elegant Universe*, "sometimes attaining the deepest familiarity with a question is our best substitute for actually having the answer."

—Tom Siegfried, Editor in Chief

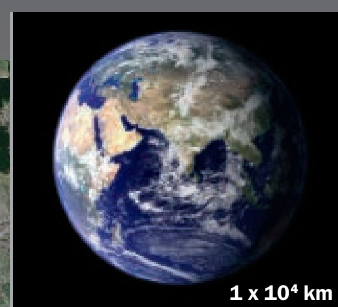
MISSION: REVEAL THE SECRETS OF THE UNIVERSE

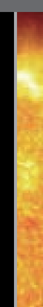
THE OBJECTIVE

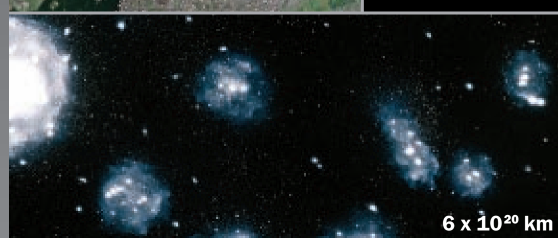
For millennia, people have turned to the heavens in search of clues to nature's mysteries. Truth seekers from ages past to the present day have found that the Earth is not the center of the universe, that countless galaxies dot the abyss of space, that an unknown form of matter and dark forces are at work in shaping the cosmos. Yet despite these heroic efforts, big cosmological questions remain unresolved:

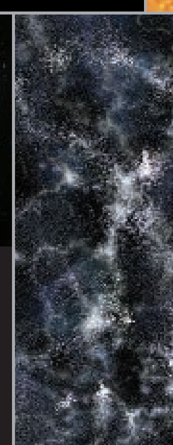
Find tools for the mission on Page 32. For pdfs of this section, and more resources, visit www.sciencenews.org/cosmicquestions

THE WHEREABOUTS









Understanding the universe requires recognizing its immense scale. Zooming out from Manhattan reveals the Earth, solar system, galaxies and then walls of galaxies separated by voids. At the most distant scales, the universe looks uniform.

THE VITAL STATISTICS

13.75 billion years (uncertainty +/–0.11): Time since the Big Bang, the creation of the universe.

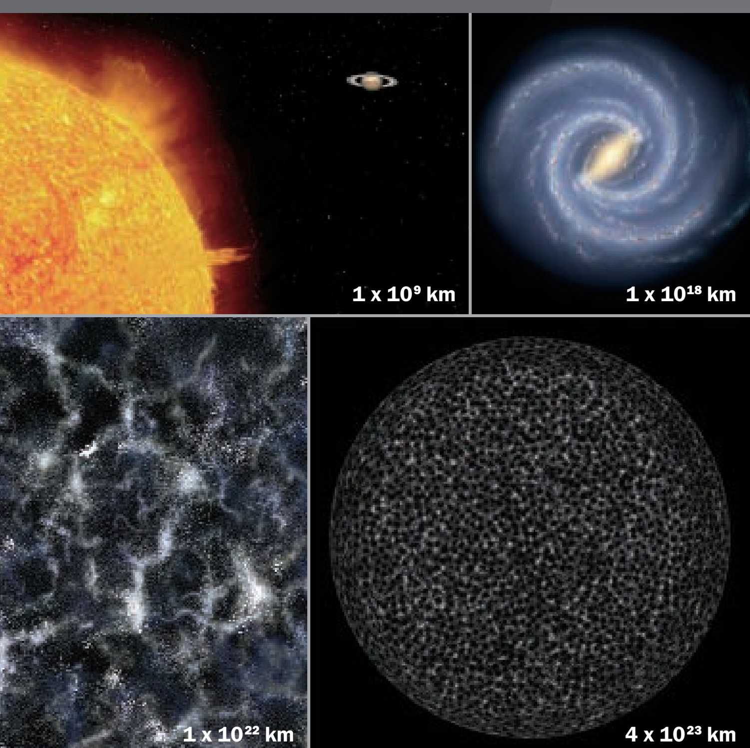
377,730 years (+3,205/–3,200): Time after the Big Bang when photons stopped interacting with charged matter and produced the relic radiation known as the cosmic microwave background.

70.4 kilometers/second/megaparsec (+1.3/–1.4): Expansion rate of the universe assuming its spacetime geometry is flat. Also known as the Hubble constant.

90 billion light-years: Rough diameter of the known universe.

–0.980 (+/–0.053): Equation of state, a measure of the (negative) pressure exerted by dark energy divided by its density. An unvarying value of –1 suggests that dark energy is Einstein's cosmological constant.

1.0023 (+0.0056/–0.0054): Value of omega, the total mass-energy density relative to the critical mass-energy density. Omega equal to 1 signifies a universe with flat spatial geometry.



PAST MISSION FINDINGS

1543 Nicolaus Copernicus publishes a mathematical description of planetary motion, assuming that the sun is the center of the solar system. Later work by Johannes Kepler, Galileo Galilei and Isaac Newton provides further evidence.

1666 Isaac Newton formulates the law of gravity and laws of motion, published in 1687.

1900 Max Planck formulates the first description of quantum theory, which will eventually explain the nature of matter and energy on the subatomic scale.

1917 Albert Einstein applies general relativity to the universe. Later work by Willem de Sitter and independently by Aleksandr Friedmann implies the possibility that the universe is expanding.

1924 Edwin Hubble announces that the "spiral nebulae" sit beyond the Milky Way and later that the Milky Way is just one of many galaxies.

1929 Hubble finds that the universe is expanding, after analyzing the redshifts of distant galaxies.

1933 Fritz Zwicky examines galaxies in the Coma cluster and determines that there is unseen mass, what scientists call "dark matter."

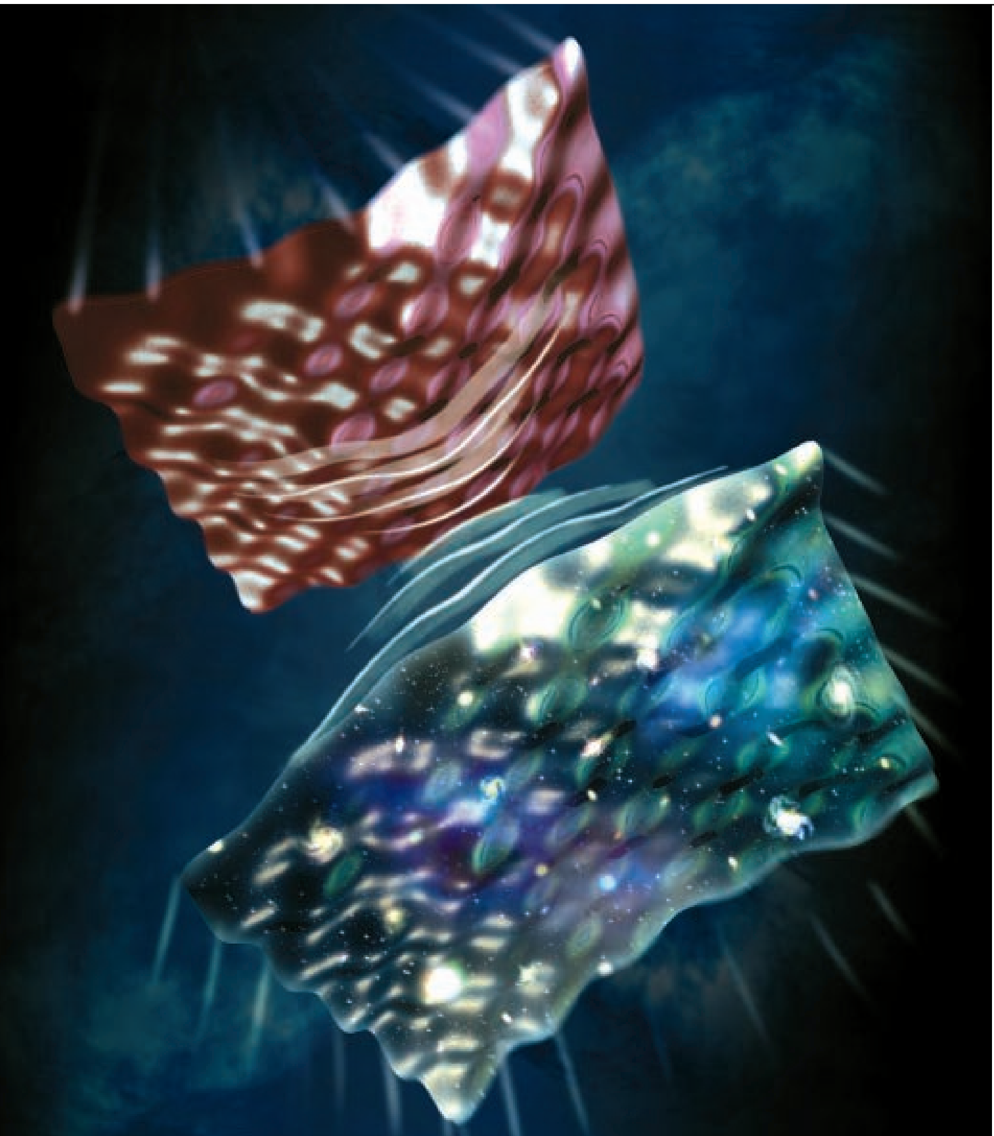
1960s Steven Weinberg, Abdus Salam and Sheldon Glashow independently propose a theory to unify electromagnetism and the weak nuclear force.

1964 Arno Penzias and Robert Wilson discover the cosmic microwave background radiation; in 1990 NASA's COBE mission confirms that the radiation's properties verify the universe's birth in a Big Bang.

1986 Astronomers Margaret Geller, John Huchra and Valérie de Lapparent map a section of the observable universe, revealing a structure that encompasses large walls and giant voids.

1998 Researchers discover that the universe is expanding at an accelerating rate, suggesting a mysterious force dubbed "dark energy" might be at work.

TOP, FROM LEFT: USGS, NASA EARTH OBSERVATORY; RETO STÖCKLI AND ROBERT SIMMON, MODIS/GSFC/NASA, USGS, DMSP; JPL-CALTECH/NASA, T. PYLE/SSC, ADAPTED BY T. DUBÉ; R. HURT/SSC, JPL-CALTECH/NASA; BOTTOM, FROM LEFT: DAVID PARKER/PHOTO RESEARCHERS; NICOLLE RAGER FULLER; NICOLLE RAGER FULLER; TABLET: VIKTOR GMYRIA/SHUTTERSTOCK.COM



WHAT HAPPENED BEFORE THE BIG BANG?

Pre-Bang branes and bubbles

By Ron Cowen ▪ Illustration by Nicolle Rager Fuller

If the universe occupies a sheetlike membrane, the Big Bang may have been just one in a series of collisions, each "Big Bounce" refreshing the cosmos.

Cosmologists Paul Steinhardt and Neil Turok liken the early history of the universe to a play in which the protagonists — matter and radiation — move across the stage according to the laws of physics. Astronomers are actors who arrived on the scene 13.7 billion years too late to know what happened.

But that hasn't stopped Steinhardt, Turok and other researchers from pondering whether the universe was born in a giant fireball around that time or might have existed before that.

The modern-day notion of the cosmos's tumultuous beginning — known as the Big Bang — has its roots in Edwin Hubble's 1929 discovery that the universe is expanding. At the time, scientists envisioned the universe explosively flying outward from a single point in space and time.

Though this simple version of the Big Bang idea can't fully explain what people see in the cosmos today, Alan Guth of MIT added a new ingredient in 1981. Early in its history, the universe underwent a brief period of faster-than-light expansion, known as inflation, he proposed. In the years since Guth's suggestion, inflation has been wildly successful in explaining the structure of the universe and its arrangement of galaxies.

Bubbling over

Some scientists think that if inflation happened once, it could happen many more times — hinting at a cosmos alive and well eons before the Big Bang. Rapid expansion, in these interpretations, isn't confined to just one neck of the cosmic woods, like a single expanding balloon. Instead, distant patches of space keep inflating, like a child continually blowing soap bubbles, says Alex Vilenkin of Tufts University in Medford, Mass.

Every inflated patch becomes a separate universe, with its own Big Bang beginning (*SN: 6/7/08, p. 22*). In this "eternal inflation" scenario, the fireball that begot the universe seen with today's telescopes was preceded by a multitude of others just as surely as it will be followed by many more, each popping off at different times in different parts of the cosmos, Vilenkin says.

Just as the sun is merely one of billions of stars in the Milky Way galaxy, the visible universe may be one of countless in the cosmic firmament. Cosmologists call this ensemble of universes the multiverse.

Not only might there have been a plethora of universes that came before the one people know, but each one may also have been different from the others. In combining eternal inflation with string theory, an idea that has become popular because it could help unify the four known forces in nature (see Page 26), each inflated universe would have its own set of physical properties. Although the known universe is chockablock with galaxies, for example, gravity in another, earlier universe could have been too weak to form galaxies.

Bounce not bang

String theory itself — which calls for a space with many rolled-up dimensions — may suggest a different type of pre–Big Bang picture. In a model developed by Steinhardt, now at Princeton University, and Turok, now director of the Perimeter Institute in Waterloo, Canada, the Big Bang is replaced with an endless cycle of contractions and bounces; 13.7 billion years is merely the time since the last "Big Bounce."

In this picture, the known universe resides on a three-dimensional version of a sheet, called a brane, which can travel along an extra dimension. Another brane resides a tiny distance away.

When they are separated, the two branes are perfectly wrinkle-free, representing a universe nearly devoid of matter. As the two branes pull closer, they develop tiny wrinkles. These wrinkles are the seeds of galaxies. When the branes finally collide and bounce apart, they unleash an enormous amount of energy, some of which is converted to matter and radiation. To an observer on one of the branes, this Big Bounce would look just like a Big Bang (*SN: 9/22/01, p. 184*).

While the branes are separated, they stretch and smooth out; the cosmos is expanding just as it is today. But eventually, the two branes are pulled back together for another round of collisions and bounces. Each cycle may last a trillion years or more.

In the Big Bounce model, the universe not only existed before the Big Bang, it retains the memory of what came before. All of the stars, galaxies, and large-scale structures now present owe their existence to the composition of the universe in the previous cycle. Though the details might be different, the underlying physical laws would remain the same.

Cosmic clues

Whether the Big Bounce or the multiverse captures reality — if either one does at all — remains a mystery. One observation, though, could distinguish between the Big Bounce and any inflationary scenario, Steinhardt notes. Gravitational waves, tiny ripples in the fabric of spacetime, are generated during each cycle of the Big Bounce. But in this scenario, the waves would be too weak to be detected. Inflation, in contrast, would produce a much more powerful set of the waves — strong enough to leave a noticeable imprint on the cosmic microwave background, the radiation left over from the Big Bang.

The European Space Agency's Planck spacecraft is now searching for the telltale signs that gravitational waves would leave in the cosmic microwave background (*SN: 4/11/09, p. 16*). If the imprint is found, "we're done," says Steinhardt. The Big Bounce would fall flat.

Whether or not inflation implies a multiverse is another story, but Planck may offer clues about that too.

As bubble universes expand, they can collide with each other. If another universe happened to have struck the one in which people reside, Planck might be able to detect a particular pattern of hot and cold spots in the microwave background.

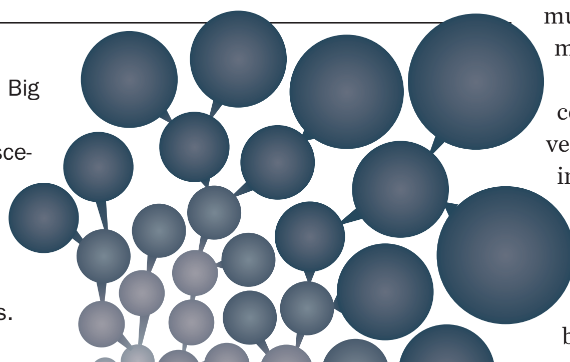
Even if no sign of a collision can be spotted, though, other bubble universes may still exist. Bumps could be so infrequent that observers might have to wait a millennium to find the pattern.

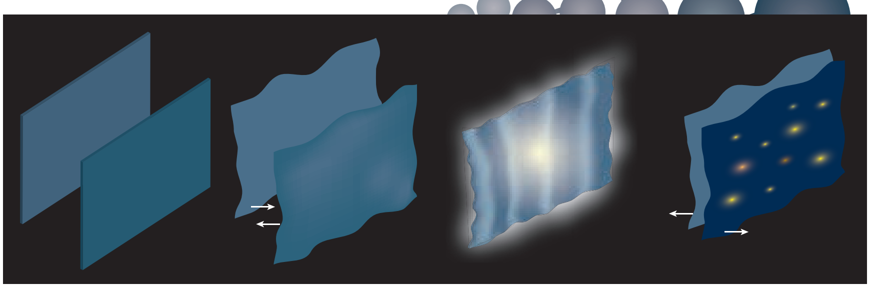
If that prolonged uncertainty about cosmic genesis sounds a bit like purgatory, consider the words of an unnamed man quoted in St. Augustine's *Confessions*. When asked what God was doing before making heaven and Earth, the man replied: "He was preparing Hell for those who pry too deep."

St. Augustine, himself, found the answer facetious: "More willingly would I have answered, 'I do not know what I do not know.' " ■

In the beginning

Not knowing what came before the Big Bang doesn't stop physicists from theorizing. In the eternal inflation scenario, the known universe bubbled out of a larger multiverse (right). Another model (below) suggests that the universe cycles through a series of contractions and bounces.





In the cyclic model, the known universe occupies a sheetlike surface, a "brane." Another brane sits a small distance away.

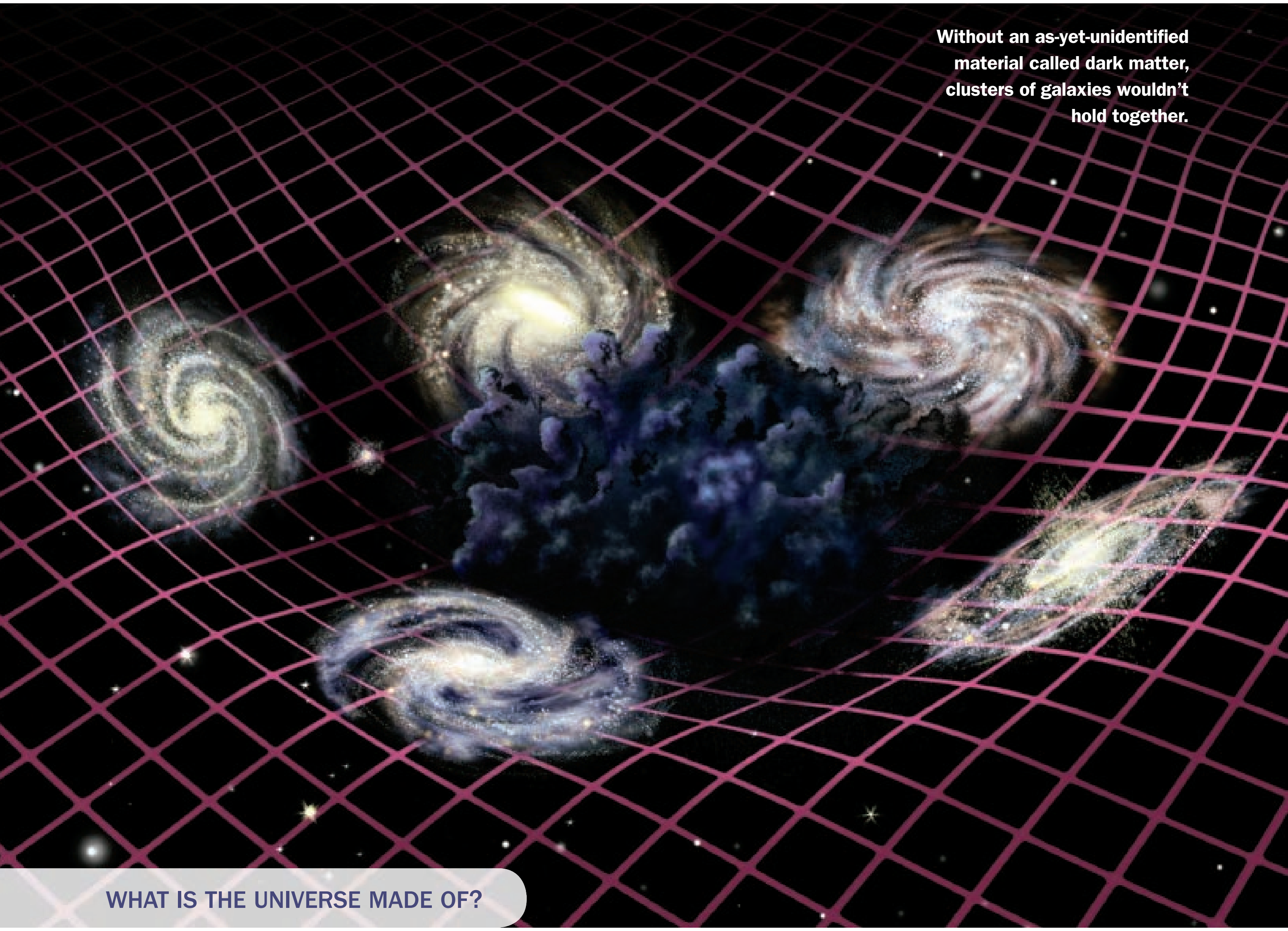
An interbrane force pulls the two sheets together, amplifying quantum ripples and creating wrinkles in the branes.

The branes collide and then rebound, releasing energy in what looks like a Big Bang.

Once the branes separate, galaxies and other cosmic structures form. The matter spreads out and the cycle repeats.

SOURCE: P. STEINHARDT

E. FELICIANO



Without an as-yet-unidentified material called dark matter, clusters of galaxies wouldn't hold together.

WHAT IS THE UNIVERSE MADE OF?

In the dark

By Alexandra Witze ▪ Illustration by Nicolle Rager Fuller

In ancient times, listing the ingredients of the universe was simple: earth, air, fire and water. Today, scientists know that naming all of that, plus everything else familiar in everyday life, leaves out 95 percent of the cosmos's contents.

From the atoms that make up an astronomer, to the glass and steel of a telescope, to the hot plasma of the stars above — all ordinary stuff accounts for less than 5 percent of the mass and energy in the universe. "All the visible world that we see around us is just the tip of the iceberg," says Joshua Frieman, an astrophysicist at the University of Chicago and the Fermi National Accelerator Laboratory in Batavia, Ill.

The rest is, quite literally, dark. Nearly one-quarter of the universe's composition is as-yet-unidentified material called dark matter. The remaining 70 percent or so is a mysterious entity — known as dark energy — that pervades all of space, pushing it apart at an ever-faster rate.

"Dark" is an appropriate adjective, as scientists have little insight into where dark matter and dark energy come from. But figuring out dark matter would illuminate what holds galaxies together. Figuring out dark energy might help reveal the universe's ultimate fate (see Page 30).

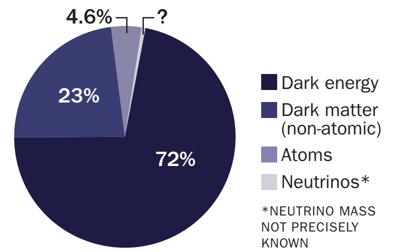
It's little wonder that scientists regard the identities of dark matter and dark energy as among today's biggest astronomical puzzles.

A different matter

Dark matter made its debut in 1933, when Swiss astronomer Fritz Zwicky measured the velocities of galaxies in a group known as the Coma cluster and found them moving at different rates than expected. Some unseen and large

Mostly unfamiliar The stuff that makes up people, planets, stars and interstellar gas accounts for just under 5 percent of the universe. The rest is made of mysterious entities dubbed dark matter and dark energy.

Mass-energy content of the universe



SOURCE: WMAP

amount of "*dunkle Materie*," he proposed in German, must exist, exerting its gravitational effects on the galaxies within the cluster.

Astronomer Vera Rubin confirmed dark matter's existence in the 1970s, after she and colleagues had measured the speeds of stars rotating around the centers of dozens of galaxies. She found that, counterintuitively, stars on the galaxies' outer fringes moved just as rapidly as those closer in — as if Pluto orbited the sun as quickly as Mercury. Rubin's work demonstrated that each galaxy must be embedded in some much larger gravitational scaffold.

Ever since, other lines of evidence have strengthened the case for dark matter. It resembles ordinary matter in that it interacts via the well-understood gravitational force; that's why it affected Zwicky's and Rubin's galaxies. But scientists know that dark matter is not ordinary; if it were, it would have affected ratios of chemical elements born in the early universe and thus thrown off the abundances of such elements observed today.

The leading candidate for a dark matter particle is the vaguely named "weakly interacting massive particle," or WIMP. Such particles would be "weakly interacting" because they rarely affect ordinary matter, and "massive" because they must exceed the mass of most known particles, possibly weighing in at as much as 1,000 times the mass of the proton. But nobody has yet definitively detected a WIMP, despite decades of experiments designed to spot one.

Results from dark matter experiments are mixed: One group in Italy claims to see a WIMP signal seasonally, with more WIMPs hitting detectors as the Earth moves into a stream of galactic dark matter debris, and fewer when Earth moves away. But other researchers haven't been able to confirm those results. Recent reports from other experiments, including one buried in Minnesota's Soudan mine, hint that WIMPs might be lighter than theorists had expected, on the order of 10 proton masses (*SN: 8/28/10, p. 22*).

The sensitivity of many long-running experiments is now improving to the point that WIMPs and other candidate particles should be either spotted or ruled out in the near future.

Mysterious forces

Spotting dark matter may prove to be easier than understanding dark energy, whose mysteries make scientists feel like mental wimps.

Albert Einstein unknowingly ushered dark energy onto the stage in 1917, while modifying his new equations of general relativity. Einstein wondered why gravity didn't make the universe contract in on itself, like a balloon with the air sucked out of it. He thus made up a "cosmological constant," a fixed amount of energy in the vacuum of space that would provide an outward push to counter gravity's inward pull.

In 1929, though, Edwin Hubble solved Einstein's problem by reporting that distant galaxies were flying away from each other. The universe, Hubble showed, was expanding. It had been zooming outward ever since the Big Bang gave birth to it.

Einstein happily ditched his cosmological constant, but in 1998 astronomers showed that it should have been recycled rather than trashed. That year, two research teams reported their studies of distant supernovas. These exploded stars can be calibrated to serve like standard light bulbs, shining with a particular brightness. The scientists reported that many distant supernovas were dimmer than expected, even accounting for an expanding universe. It was as if someone had quickly moved the light bulbs into a more distant room. The universe was not only getting bigger — it was doing so at an accelerating rate.

Something funny was going on, giving the cosmos a repulsive push. So Michael Turner, a cosmologist at the University of Chicago, dubbed the thing "funny energy" at first, before settling on "dark energy."

More than a decade later, scientists still don't have a concrete clue to what dark energy is (*SN: 2/2/08, p. 74*). Theorists have done their best to explain it, putting forward ideas including a seething "vacuum energy" created as particles pop in and out of existence, and "quintessence" — named after Aristotle's postulated fifth element — that changes its strength depending on its place or time in the universe.

Meanwhile, observers have spent the last decade dreaming up ways to probe dark energy from the ground and in space (see Page 32). In particular, precision measurements of many distant galaxies could help pin down the nature and distribution of dark energy. A new camera, optimistically called the Dark Energy Survey, will see first light this autumn at the Cerro Tololo Inter-American Observatory in Chile. Real light — insight into the dark — may take some time. ■

In this false-color image of galaxies colliding, the majority of the mass (blue) is separate from most normal matter (pink), direct evidence of dark matter.

TOP: T. DUBÉ; BOTTOM, X-RAY: M. MARKEVITCH *ET AL*, CXC/NASA, CFA, OPTICAL: STSCI/NASA, D. CLOWE *ET AL*, MAGELLAN/UNIV. OF ARIZONA, LENSING MAP: STSCI/NASA, ESO WFI, D. CLOWE *ET AL*, MAGELLAN/UNIV. OF ARIZONA

IS THERE A THEORY OF EVERYTHING?

Strung together

By Matt Crenson ▪ Illustration by Nicolle Rager Fuller

Physics is really two sciences. There's quantum mechanics, the weird tumultuous world where particles pop into and out of nothingness and cats can be simultaneously living and dead. And there's general relativity, Einstein's majestic vision of massive objects bending space and time.

Ever since these two very different views of the universe emerged early in the 20th century, generations of physicists have tried to unite them in a single theory that would ideally describe all four of nature's basic forces to boot. Even Einstein tried, and failed. Now, after an especially frustrating few decades with little new evidence to guide them, today's physicists may be about to get some tantalizing hints about how the forces fit together.

The clues are expected to come from the Large Hadron Collider, a ring of superconducting magnets in the Alps designed to smash protons together at energies never before seen on Earth. The collider began operating in March 2010 and is expected to reach full power in 2014, when it will attempt to smash its protons together with double the violence it does today.

Even then, the LHC will be far from powerful enough to re-create the single, unified force that physicists believe existed for a fraction of a second after the Big Bang — you'd need a collider as big as the universe itself for that. But the LHC might be able to test some of the predictions made by the leading theory that joins gravity and the other forces.

Superstring theory — string theory for short — ties all of physics into one neat package by reducing the bewildering taxonomy of particles in the current bestiary of physics, the Standard Model, to identical snippets of string, each less than a billionth of a billionth of a billionth of a centimeter long. According to string theory, the particles that carry the three forces included in the Standard Model — the photon (electromagnetism), the gluon (strong force) and the W and Z bosons (weak force) — are all just the same tiny dancers each following their own distinct rhythms.

And unlike the Standard Model, string theory has room for gravity.

Though proposals besides string theory attempt to explain how all the forces of nature might fit together, most of those other theories come with major flaws. Some predict the existence of particles that can't exist, for example.

String theory's primary drawback is that it requires there be much more to the universe than physicists can probe, making the theory very difficult to test.

For example, most versions of string theory require that the universe have 10 or 11 dimensions — nine or 10 of space and one of time, rather than the four that people experience: up-down, front-back, left-right and past-future.

"The forces are unified in 11 dimensions, but they split apart when you go to four dimensions," says Gordon Kane, a physicist at the University of Michigan in Ann Arbor.

Superstring theory attempts to unify gravity with quantum mechanics by describing particles and forces as tiny vibrating strands and loops.

For string theory to say anything about how the forces arise, physicists have to figure out how all those extra dimensions roll up, or "compactify," into the four familiar ones.

String theory also conjures up a shadow population of partner particles for all of the ones currently known to exist — a notion called supersymmetry. In fact, supersymmetry may be necessary to join the strong, weak and electromagnetic forces, so it is important even if string theory isn't correct.

When forces collide

Many physicists have high hopes that the LHC will find evidence for both supersymmetric particles and extra spatial dimensions.

"Even if we don't go out to the other dimensions, in some sense the other dimensions can come to us," says Harvard physicist Lisa Randall.

Working in the 1990s with colleague Raman Sundrum, now at the University of Maryland in College Park, Randall showed that it might be possible to detect the decay of a gravity-carrying particle coming from an extra dimension. Finding such a particle at the LHC would both verify the existence of extra dimensions and suggest why gravity is much weaker than the other three forces.

"I think it would be somewhat surprising," Randall says. "But this is one of the things we could find, and this is one of the things they should be looking for."

Most physicists think it's more likely that the LHC will find evidence for supersymmetric partners of the particles in the Standard Model. Which partners appear, and their properties, would put some helpful constraints on how the universe compactifies the 11 dimensions predicted by string theory.

For example, if the lightest superparticle turned out to be the wino, the superpartner of the weak force–carrying W boson, that would be consistent with a version of string theory known by the pithy moniker "M-theory compactified on 7-D manifold of G_2 holonomy."

Such supersymmetric particles may already have been observed, in fact — not on Earth, but in space. Some of the dark matter that is thought to make up more than 80 percent of the matter in the universe could be composed of supersymmetric particles left over from the universe's earliest moments (see Page 24). In the last few years two space-based instruments, the Fermi Gamma-ray Telescope and the Italian-led PAMELA mission, have seen evidence of dark matter in the Milky Way in the form of gamma rays and antimatter that could have been produced by supersymmetric particles colliding.

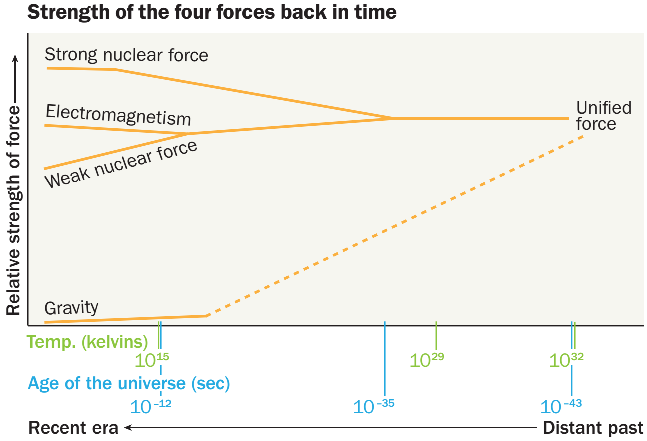
Because the LHC and any future colliders can carry physicists only so far back toward the moment just after the Big Bang, science's understanding of a unified theory is ultimately going to have to come from exploring the vastness of the universe. Some physicists wonder if such a strategy, which relies on finding and interpreting clues left behind by nature, can produce results comparable to the high-precision experimental data that led to the Standard Model during the 20th century.

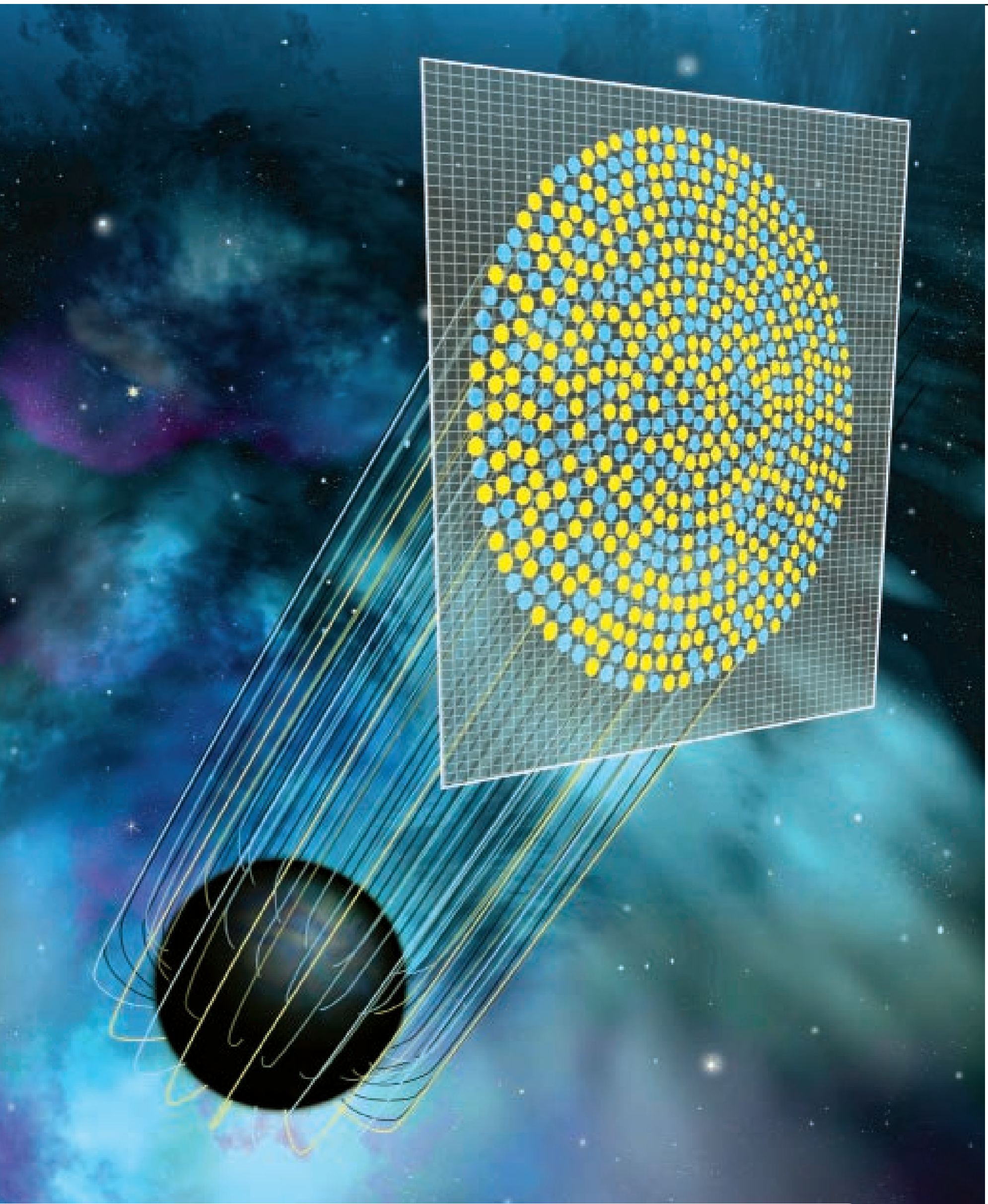
But string theory is not 20th century science — in fact, string theorist Edward Witten has described it as "21st century physics that fell accidentally into the 20th century." Now that the 21st century has arrived, it's string theory's time to be put to the test. ■

Back to one

One of the enduring puzzles in physics is why gravity — which guides matter on the scale of planets and galaxies — is so much intrinsically weaker than the other three forces. In the moments just after the Big Bang, some researchers think, the forces may have been united as one, separating into forces with differing strengths as temperatures decreased.

Strength of the four forces back in time





A 2-D projection contains all the details needed to map a 3-D black hole. Some physicists think space and time may emerge via a similar correspondence.

ARE SPACE AND TIME FUNDAMENTAL?

Out of the fabric

By Tom Siegfried ▪ Illustration by Nicolle Rager Fuller

Of all the mysteries of life and the universe, none resist the sleuthing of science's best private eyes more obstinately than the ultimate nature of space and time.

Every several centuries or so, profound insights do occur, immortalizing the names of the investigators who achieved them: Euclid (who cataloged the insights preceding him), Galileo, Newton, Einstein. Yet each advance left deeper questions unanswered. And now the 21st century's best brains still cannot say for sure whether space and time are fundamental building blocks of natural existence, or are themselves built from more primordial ingredients, so far unperceived.

Newton simply declared space and time as absolute and constant, providing a convenient arena for the operation of his laws of motion and gravity. Einstein saw, and showed, that space and time actually shift shape or speed as events unfold; mass and motion warp space and alter the flow of time.

Coping with these inconveniences required a merger, space and time becoming spacetime. From that merger emerged a bonus: a model for the evolution of the cosmos, from an initial speck of matter and energy to a gigantic ballooning multigalactic network.

Nowadays, though, spacetime's ability to accommodate nature's phenomena has begun to fade as physicists push their probes to the limits of distance and duration. Below a certain very tiny distance, the dimension of length can no longer be explored, or even defined. Time faces a similar limit when durations approach the very brief.

Today's leading theories for answering the greatest cosmic questions suggest that neither time nor space appear in reality's ultimate recipe. Somewhere between the stove and the table, space and time emerge, cooked up out of equations underlying an existence without rulers and clocks. At least that is "the widespread current belief," says physicist Joe Polchinski of the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara.

Space as society

To illustrate this, Fotini Markopoulou of the Perimeter Institute for Theoretical Physics in Waterloo, Canada, compares space to society. Space, like society, has features that can be described — geometry textbooks catalog space's properties and their implications. But space as reflected in geometry need not have been present at the beginning. It could have emerged from the interactions of matter and forces, just as society materializes from interactions among people.

"We have capitalist societies, agricultural societies, totalitarian societies," Markopoulou wrote in a 2008 paper (arXiv.org/abs/0909.1861). Nobody is confused by phrases such as "our society is addicted to credit." But that doesn't mean society is a fundamental feature of existence.

"A society does not exist independent of its members," Markopoulou pointed out. "We can see spacetime geometry as the analog to society, with the role of individuals played by matter and its dynamics."

As Polchinski notes, specifying spacetime's status in relation to matter is part of the quest for a theory of quantum gravity — the math that would unify Einstein's relativity theory, which describes spacetime in bulk, with the quantum physics that governs the microworld (see Page 26). A key clue in that quest is a correspondence between the surface of a black hole, a gravitational bottomless pit from which nothing can escape, and the space within it. It turns out that a mathematical description of the black hole's outer boundary (the point of no return for objects falling in) contains all the information needed to specify the three-dimensional interior. In essence, that means the 3-D space inside somehow emerges from the physics of the 2-D surface.

Time materialized

Generalizing the peculiarities of black holes to ordinary space and time remains a research challenge for quantum gravity physicists. But most agree that sooner or later space and time will have to go. String theory — the most-studied approach to quantum gravity — offers several examples of how space, rather than being fundamental, emerges into existence, as physicist Nathan Seiberg of the Institute for Advanced Study in Princeton, N.J., outlined in a 2006 paper (arXiv.org/abs/hep-th/0601234).

If matter at its most basic is made of tiny vibrating strings, for instance, it becomes impossible to probe space to any arbitrarily short distance, Seiberg observes. That's another way of saying that at distances less than some (very short) length, the idea of space becomes meaningless.

Further study of spaceless theories may help solve serious problems confronting physicists today, Seiberg believes. String theory implies countless possible vacuum states — that is, spaces of differing physical properties — with no obvious method for determining which one the visible universe should have chosen. Knowing how space emerges from spacelessness might help explain why humans exist in one particular space from among the countless possibilities.

Doing away with time poses more difficult problems, Seiberg acknowledges. Basic notions in physics, such as that of causes preceding effects, or predicting the outcome of experiments before the experiment is done, seem to lose their meaning if there is no time to define before and after. So some physicists, Markopoulou for one, have suggested that even if space is emergent, time may remain fundamental. In fact, she conjectures, time is needed to allow quantum processes to create the illusion of space. Space may not have been around at the beginning, but that beginning would be stillborn without time to get reality going.

Seiberg, though, believes time and space will both go down the cosmic drain together.

"My personal prejudice is that these objections and questions are not obstacles to emergent time," Seiberg writes. "Instead, they should be viewed as challenges and perhaps even clues to the answers."

More intriguingly, he observes, space and time's ultimate status in nature may have something to say about the practice of science. Much of modern science is based on the concept of reductionism — explaining large-scale phenomena from laws operating at smaller scales. That notion will eventually break down if there's a smallest scale below which space no longer exists.

"Therefore, once we understand how spacetime emerges, we could still look for more basic fundamental laws, but these laws will not operate at shorter distances," he writes. "This follows from the simple fact that the notion of 'shorter distances' will no longer make sense. This might mean the end of standard reductionism." And the beginning of a new view of not only space and time, but of science itself. ■

As small as it gets

Current theories are unable to describe space and time below certain limits defined by what are called "natural units." These units, proposed by the German physicist Max Planck, are derived from fundamental quantities such as the speed of light. A theory uniting quantum mechanics with gravity will be needed to reveal whether space and time are meaningful concepts at smaller scales.

Planck length: 1.616 x 10^{-35} meters

The Planck length is derived from Newton's gravitational constant, the speed of light and Planck's own constant from quantum theory. It is unfathomably small: Comparing its size to a bacterium is like comparing the size of a bacterium to the visible universe. Many physicists believe that at shorter lengths space cannot be probed and the concept of distance becomes no longer meaningful.

Planck time: 5.391 x 10^{-44} seconds

The Planck time is also calculated from the gravitational constant, the speed of light and Planck's constant in such a way that moving at one Planck length per one Planck time would be equal to the speed of light. Current theories are unable to describe the universe at an age younger than the Planck time; physicists hope that a theory of quantum gravity could illuminate that epoch.

WHAT IS THE FATE OF THE UNIVERSE?

Hanging in the balance

By Elizabeth Quill ▪ Illustration by Nicolle Rager Fuller

The fate of the universe was supposed to be sealed by the turn of the millennium.

"I imagined we'd be walking around holding a sign saying 'the world is coming to an end' or 'the world is not coming to an end,' " recalls astrophysicist Saul Perlmutter.

But as Y2K soothsayers readied for impending doom, Perlmutter and his colleagues delivered a surprising discovery suggesting that the world's fate would stay in limbo long after the Times Square ball dropped and any leftover champagne went flat. More than a decade later, scientists are still vigorously debating what their finding means not only for the universe's future, but also for all of cosmology.

Perlmutter, of the University of California, Berkeley, led one of two teams that set out in the early 1990s to get a grip on the far future by studying distant supernovas. These stellar explosions serve as distance markers to help astronomers measure how fast the universe is expanding — a key factor in determining if and when it will meet its end. But after analyzing the data, both teams reported in 1998 that the universe's expansion isn't just cruising along — it is accelerating. Some mysterious force, now known as dark energy (see Page 24), is driving space apart, faster and faster.

A dark twist

Before dark energy's discovery, the forecast was surprisingly simple. If the gravitational pull of all the matter in the cosmos was strong enough to rein in expansion — like the Earth's pull on a rocket that can't quite reach escape velocity — the universe would eventually come crashing in on itself. That ending, dubbed the Big Crunch, would mirror the Big Bang that started the cosmic expansion in the first place. If, though, the universe's expansion escaped the claws of gravity, it would go on growing forever. Expansion would slow but never halt, and instead of ending, the universe would

In one end-time scenario, the entire universe — from galaxies down to atoms — would rip apart at its seams.

become a cold, dark, lonely place where life could not survive — a Big Freeze.

But dark energy gives the fleeing rocket some extra oomph, making end-time predictions quite a bit fuzzier.

"A crucial issue is how the dark energy will behave in time," says cosmologist Rocky Kolb of the University of Chicago. "Until we have some way to grapple with that, the fate of the universe hangs in the balance."

If the strength of dark energy's extra push remains forever unchanging, it could be the cosmological constant — a term Albert Einstein added to his equations for general relativity in 1917 and later dismissed as his "biggest blunder." In this case, something like the Big Freeze would play out. But if dark energy's strength decays over time, then a Big Crunch of sorts remains an option.

If instead dark energy grows stronger, exceeding the repulsive force of Einstein's cosmological constant, a more painful scenario awaits: "In a finite amount of time, dark energy gets infinitely dense," says cosmologist Max Tegmark of MIT. "First denser than our galaxy, and our galaxy flies apart. Then denser than Earth, and that flies apart. Then denser than atoms, and atoms fly apart. In a finite time, everything is ripped apart."

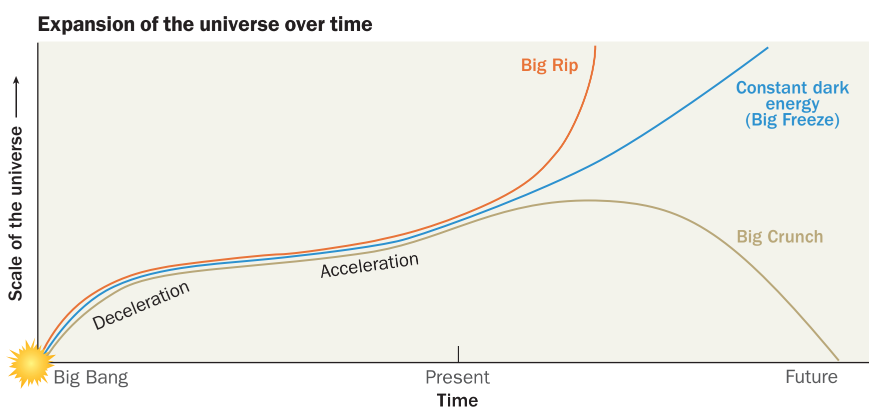
Figuring out whether the universe would end with this Big Rip, or a Freeze or Crunch, requires determining a property of dark energy called its equation of state. That quantity is the ratio of the pressure exerted by the dark energy to its density. The most recent findings, based on data that come from seven years of mapping the glowing radiation left over from the Big Bang, suggest that the equation of state is close to that expected for the cosmological constant, deviating by no more than 14 percent.

But over billions of years, even a much tinier deviation — undetectable with current instruments — could dramatically alter the universe's fate, especially if the dark energy's strength is not constant but can change over time.

"The million dollar question is an experimental question," Tegmark says. Scientists need better measurements to determine whether dark energy's equation of state is perfectly constant.

So some experimentalists are turning back to those very same stellar explosions that revealed dark energy's existence to begin with. A paper by Perlmutter and collaborators, appearing in 2009 in the *Astrophysical Journal*, describes an ongoing effort to compile the world's supernova datasets. Many scientists have their hopes set on a future observatory, WFIRST, which would look for the signal of dark energy in the appearance of distant galaxies and in the imprint of the cosmic equivalent of sound waves in the early universe. A proposed mission named Euclid, from the European Space Agency, and a camera mounted on a telescope in the Andes will further the efforts.

Cosmic Armageddon The discovery of dark energy made the fate of the universe much more difficult to forecast. Scientists typically talk about three possible endings (depicted below), depending on what this mysterious force actually is and how it behaves over time.



SOURCE: CXC/NASA, M. WEISS

Beyond the end

But others say that a theoretical breakthrough is necessary. Measuring the equation of state with enough precision, they argue, is impossible; a tiny deviation could always linger.

"We don't just want to measure a number," Kolb says. "We want to understand how this crucial piece of physics fits into the overall fabric of the theory of nature. And until we do that, I am not going to be comfortable with any explanation of dark energy."

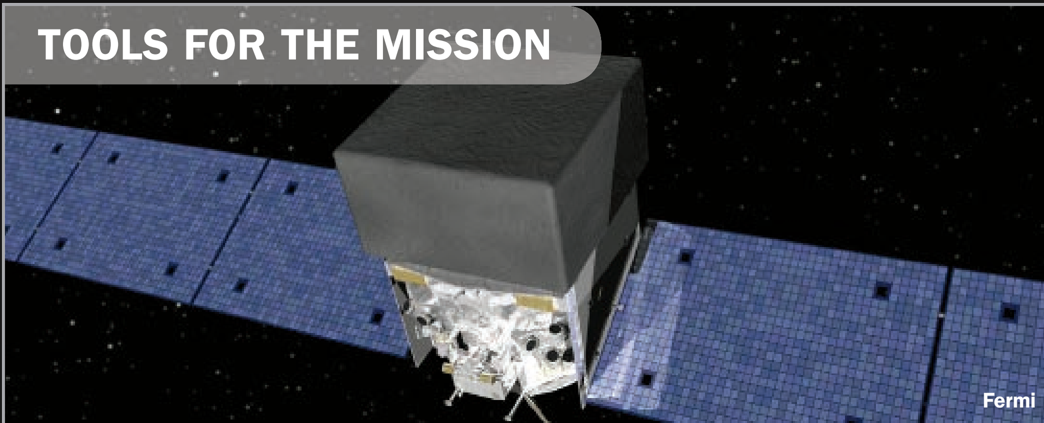
Kolb thinks no current proposal adequately explains dark energy, thus no proposal decides among a Freeze, Crunch or Rip scenario.

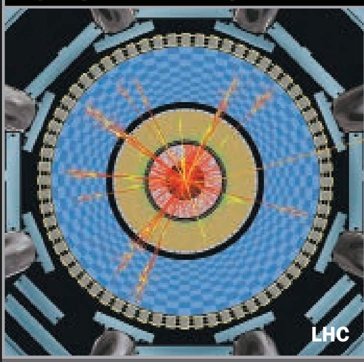
Of course, the right theory might even predict that the universe meets its doom by some other, unknown means. One such possibility presents itself if the observable universe is just one of many bubble universes constantly being created and growing in some larger space. In this "multiverse" scenario, bubble universes can collide. If another bubble encroached on the bubble that people occupy, it would be bad news, says Anthony Aguirre of the University of California, Santa Cruz. "We would just be sitting around," he says, "and this other bubble would smash into us at the speed of light with some huge energy and we would die."

Beyond predicting another possible end, the multiverse ushers in a new way of thinking about what an "end" actually means. "We'd have to be living in a lucky (for cosmologists) or simple universe for the part that we see to be telling us about the whole thing," Aguirre says.

Imagining the death of the observable universe as the ultimate end may be just as naïve as imagining that the destruction of the Earth, for that matter, means the end of all life in the galaxy. There might be much more out there. Even if the bubble occupied by people bursts, other universes could live long and prosper. ■

TOOLS FOR THE MISSION


Fermi


LHC


Planck

Hunting data

A number of instruments now operating or proposed can troll the skies or otherwise help to answer some of the most puzzling questions about the universe.

Planck A European Space Agency observatory launched in 2009, Planck is recording a more detailed picture of the cosmic microwave background, the relic radiation left over from the Big Bang, than its predecessors COBE and WMAP did. The mission is searching for primordial gravitational waves, which could provide a test for inflation theory, and looking for clues to the nature of dark matter and dark energy.

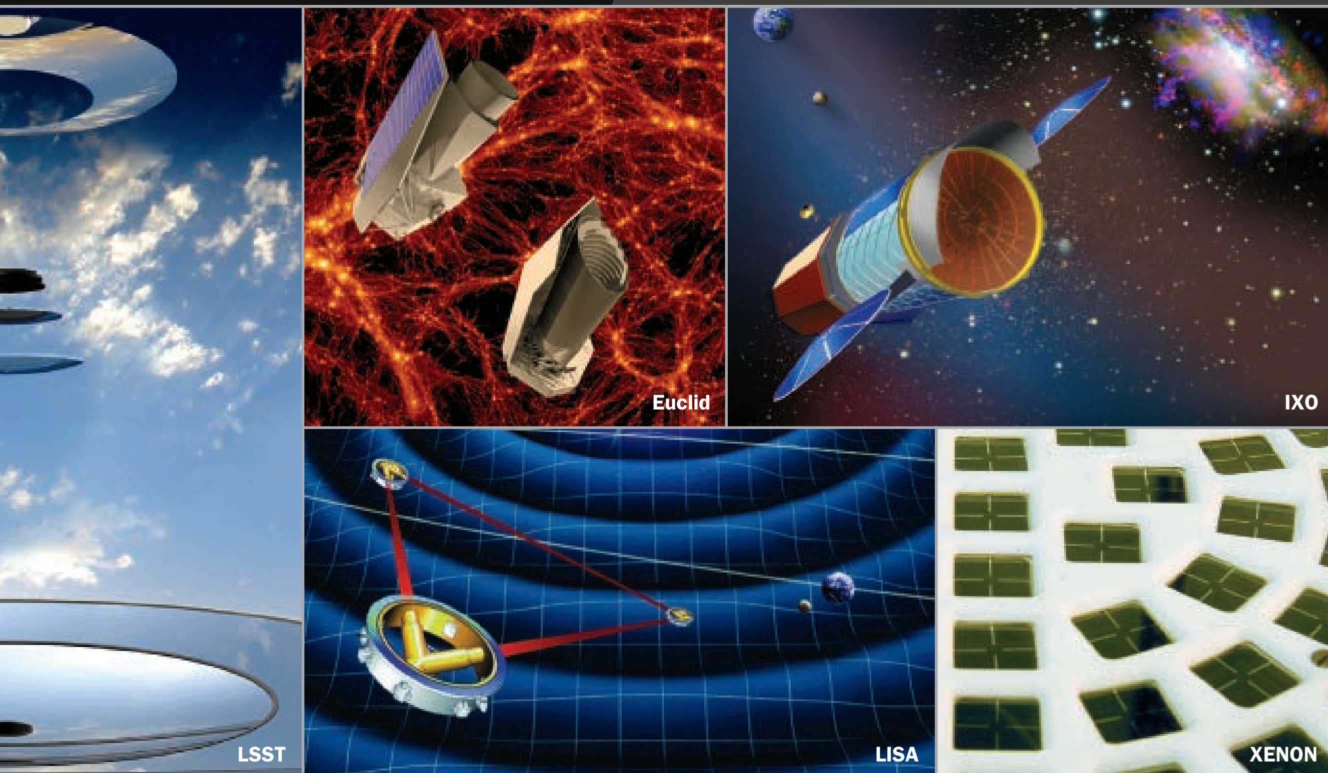
Fermi Launched in 2008, the Fermi Gamma-ray Space Telescope has opened scientists' eyes to astronomical objects that emit very high-energy radiation, including supermassive black holes and colliding neutron stars. Since its launch, Fermi has found evidence of antimatter above thunderstorms on Earth (*SN: 12/5/09, p. 9*) and captured unexpected changes in emissions from the Crab Nebula (*SN: 1/1/11, p. 11*). Fermi could offer clues to the identity of dark matter and to the birth of the universe.

WFIRST The Wide-Field Infrared Survey Telescope, a proposed NASA observatory, would probe a wide swath of the sky with two main goals: to settle key questions about dark energy by mapping large-scale structures and to look for signs of extrasolar planets in the Milky Way's central bulge.

LHC By smashing protons together at high speeds, the Large Hadron Collider is re-creating energies present just after the Big Bang. In the spew of particles emitted (computer-generated image shown), scientists hope to spot signs of supersymmetry and find evidence for string theory—possibly pointing to a theory that unifies the forces of nature. The collider, in a 27-kilometer tunnel straddling the border of Switzerland and France, began regular operations in 2010 but has yet to operate at full energy.

LSST Proposed to sit atop Cerro Pachón in the Chilean Andes, the Large Synoptic Survey Telescope (mirrors and lenses depicted) will capture the entire visible sky twice each week, helping astronomers better understand the large-scale structure of the universe throughout its history. Knowing how stars, galaxies and galaxy clusters are distributed can offer insight into cosmic ingredients, including dark matter's distribution and dark energy's strength.

Dark Energy Survey Atop another mountain in the Chilean Andes—Cerro



Tololo — researchers are mounting a sensitive digital camera on an existing 4-meter telescope in an attempt to uncover the nature of dark energy. The camera will survey a large swath of the southern sky over five years to gather information about more than 300 million galaxies. An effort that includes scientists from 23 institutions, the survey is expected to see first light in fall.

Dark matter experiments The XENON Dark Matter Project, operating underground at Gran Sasso National Laboratory in Italy, looks for signs of dark matter particles by recording scintillations in liquid xenon (detector shown above). The DAMA/LIBRA experiment, at the same lab, records seasonal variations in faint flashes of light from 25 sodium iodide detectors. And an experiment in a mine in northern Minnesota, the Cryogenic Dark Matter Search, tries to spot dark matter jostling germanium and silicon detectors. Though claims of detection have been made, dark matter's identity remains unknown.

JWST The James Webb Space Telescope will have a primary mirror 6.5 meters across and will orbit about 1.5 million kilometers from Earth. The observatory will probe how stars and galaxies first emerged and will look for Earthlike planets. Launch had been scheduled for 2014, but has been pushed back to no earlier than 2016 because of cost overruns (*SN: 4/25/11, p. 22*).

Euclid Named for the father of geometry, the proposed Euclid spacecraft (two concepts shown) would measure dark matter distribution and try to understand the nature of dark energy by looking back 10 billion years, before dark energy began to dominate over matter in the universe.

IXO Proposed by NASA, the European Space Agency and the Japan Aerospace Exploration Agency, the International X-ray Observatory would take in radiation emitted from neutron stars and from the vicinity of black holes. Searching in the X-ray regime would allow the observatory to peer through dust and gas clouds that might otherwise obscure its view. IXO may reveal how matter behaves in extreme conditions and help reveal the nature of dark matter and dark energy.

LISA The Laser Interferometer Space Antenna, a proposed NASA-ESA mission, would actually be three identical spacecraft that form a triangle. By recording how the craft move in relation to each other, scientists hope LISA will detect gravitational waves. Background undulations left over from the early universe could offer clues to its origin and expansion history.

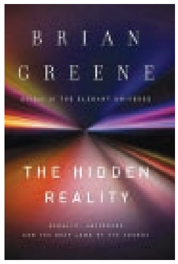
FERMI IMAGE: NASA; LHC: ©CERN GENEVA; PLANCK: C. CARREAU/ESA; LSST: TODD MASON/MASON PRODUCTIONS INC., LSST CORPORATION; EUCLID: ESA; IXO: NASA; LISA: ESA; XENON: FRANCESCO ARNEODO/INFN, XENON COLLABORATION; TABLET: VIKTOR GMYRIA/SHUTTERSTOCK.COM

The Hidden Reality: Parallel Universes and the Deep Laws of the Cosmos
Brian Greene
Anyone with a passing interest in cosmology knows by now that the universe isn't what it used to be. In fact, it isn't even the universe anymore.

A century ago, the "universe" was supposedly everything that existed, mainly just the Milky Way galaxy and some fuzzy nebulae at an unknown distance. But soon Edwin Hubble, with help from many others, showed that the Milky Way was merely one of billions of "island universes," eventually referred to simply as galaxies so "universe" could be retained as the name for everything.

In recent years this scenario has repeated itself in the theoretical realm, as physicists now speak seriously about parallel universes, rendering the one that humans inhabit just one of countless (literally) others. But this time, remaking the universe isn't as simple as it was with galaxies. Parallel universes of many different flavors have been conceived by physicists pursuing the implications of modern theories. There are the "many worlds" of quantum physics, the "brane worlds" of string theory and the multiple "bubble universes" of inflationary Big Bang cosmology, to name just a few.

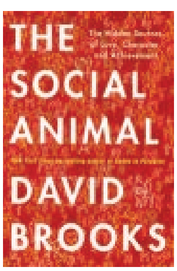
Greene, a prominent string theorist well known for two previous popular



books, provides the best guide available (in this universe at least) to the various forms that parallel universes might take and the science underlying them. Most speculative, and most intriguing, is his discussion of the parallel worlds that might exist within advanced computer simulations — *The Matrix* with a vengeance.

One small complaint: Much of the best material is found in the extensive notes at the back of the book. So don't forget to read them. And don't even think about touring other universes without packing this book. *— Tom Siegfried*
Knopf, 2011, 372 p., $29.95.

The Social Animal: The Hidden Sources of Love, Character, and Achievement
David Brooks
In his new book, *New York Times* columnist Brooks describes human nature as shaped by a search for mates and other relationships, guided by unconscious feelings about oneself and others that develop early in life. Fair enough. That idea has plenty of scientific supporters

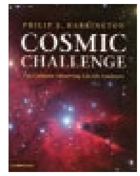


and dates back more than a century, even if it ignores how conscious deliberations fit into the mix.

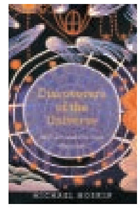
But Brooks' narrative fails to pick up steam. First, he ushers in two fictional characters, Harold and Erica, but the eventual spouses never develop into fully realized characters. As a young Erica tries to adjust to college and the legacy of an emotionally unstable mother, Brooks veers into a discussion of research on self-control. As Harold discovers the joys of English, Brooks takes an extended detour into experiments on how people acquire knowledge and achieve insights. And so on.

As Harold and Erica's lives play out, Brooks hilariously dissects the lifestyles of the rich and overeducated types that the pair encounter. The book begins with Harold's parents meeting at a resort frequented by what Brooks dubs the Composure Class. These effortless achievers have looks, wealth and perfect families. They are also ceaselessly annoying.

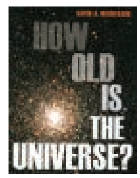
Brooks also succeeds at describing research on social norms and cultural differences. On the other hand, his portrayal of decision making as an integration of countless past emotional judgments is a stretch, based on what's currently known. *— Bruce Bower*
Random House, 2011, 424 p., $27.



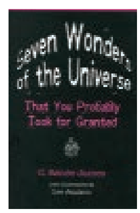
Cosmic Challenge
Philip S. Harrington
This guide to observing the heavens beckons backyard astronomers to find 187 targets using instruments ranging from binoculars to monster scopes. *Cambridge Univ. Press, 2011, 469 p., $45.*



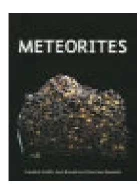
Discoverers of the Universe
Michael Hoskin
An in-depth account of the lives of sibling astronomers William and Caroline Herschel, who discovered Uranus, comets galore and much more. *Princeton Univ. Press, 2011, 237 p., $29.95.*



How Old is the Universe?
David A. Weintraub
An astronomer outlines the research showing that the universe is 13.7 billion years old. *Princeton Univ. Press, 2011, 370 p., $29.95.*



Seven Wonders of the Universe That You Probably Took for Granted
C. Renée James
A lighthearted tour of everyday phenomena like light, time and gravity that also explores what makes Earth special and the evolution of life. *Johns Hopkins Univ. Press, 2011, 240 p., $25.*



Meteorites
Caroline Smith, Sara Russell and Gretchen Benedix
A well-illustrated overview of the science and (literal) impacts of these space rocks. *Firefly Books, 2011, 112 p., $19.95.*

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Science not in the zone

It makes no sense to analyze basketball shooting streaks ("In the zone," *SN: 2/12/11, p. 26*) as though they were similar to slot machines or video games, which are supposed to be random. Basketball shooting, and other sports activities, are definitely not random events.
Walt Gray, Richland, Wash.

I was very surprised to hear the model that statisticians use to try to measure "streaks" in basketball. I would say that it is clearly wrong, and throws away very important information about time. Humans do not see streaks as mere repetition. They see them as *rapid* repetition. Throwing away the time information loses half the ball game, as it were.
Bruce Ewing, Eugene, Ore.

Based on my participation in sports (many decades ago), I believe there is a mind-body symbiosis that temporarily allows the player to concentrate on the play at hand and blot out distractions that often adversely influence the outcome. This has nothing to do with statistical clumps or patterns. It is peculiar to the human brain and its effectiveness in controlling the muscles involved. Quite often it is characterized by players as being "loose" or "dialed in" — their actions become instinctive and they no longer have to think as much about the moves involved. They are in a "zone."

This is the same phenomenon involved when a field goal kicker, for example, can make every kick in practice but may miss in a game due to becoming "tight" when the kick has great importance. The 3-point shot contest associated with the NBA All-Star game is another example where one often sees shooters becoming dialed in (or not). A similar effect may be present when sports teams manage to develop extraordinary winning streaks. Success breeds success, as they say, and the collective team spirit becomes focused on the next game and thereby achieves better performance.
George Sutherland, Sammamish, Wash.

I have played competitive basketball for most of my 50-plus adult years, so I read Bruce Bower's piece on the "hot hand" with great interest. I believe the problem with the research into performance streaks is that they have been done from the outside looking in. As an athlete who has been "in the zone" occasionally, I can testify that the phenomenon does indeed exist. This state can continue for part or all of a single game, but in my experience, it does not, unfortunately, stay around for subsequent games.
John Dee German, via e-mail

Strong placebo

The study described in "Possible relief for an irritable bowel" (*SN: 1/29/11, p. 9*) found that 41 percent of those receiving rifaximin for irritable bowel syndrome improved, while 32 percent of those on a placebo improved. The article then discusses pros and cons of the drug and possible FDA licensing. It seems to me that the real story here is that the placebo is 78 percent as effective as the drug being tested, not a ringing endorsement for the drug. Either the psychological effect of taking any pill is very significant for this condition, or there is some ingredient in the placebo that is unexpectedly effective against IBS.
Clark Waite, San Miguel de Allende, Mexico

The study authors offered no explanation for the placebo effect in this trial. They did note that adverse effects were roughly equal in the two groups. Placebo effects are common in medical trials; this one was just greater than usual. — *Nathan Seppa*

Dumbing down vs. easier learning

As quoted, Conrad Wolfram ("Scientific Observations," *SN: 1/29/11, p. 4*) stated that math problems used in educational classes are "dumbed-down" and involve lots of calculations, and therefore are not "real world" mathematics. As an educator of mathematics I frequently hear this criticism. While true to some degree, we should remember that most science experiments done in classrooms are vastly simpler than those done in "real world" labs; most classroom computer programming is far less complex than that of most business/industrial software; and most literature read by our grammar and high school students is more structured and works on far fewer levels than modern award-winning fiction (works by David Mitchell and William Gibson, for example). "Dumbed-down" artificial problems and models can help reinforce key math concepts without overwhelming students with complexity. Calculations are used as a way to learn how to manipulate more abstract expressions. Overreliance on software to perform math operations in class can impede the learning of abstraction skills.
Jerry Malczewski, Lancaster, N.Y.

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Ila Cote

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Better risk assessments through molecular biology

As director of the U.S. Environmental Protection Agency's NexGen Program, toxicologist Ila Cote leads a collaboration that brings together data, methods, skills and brains from diverse fields to better understand how chemicals interact with living things and the environment. In doing so, scientists hope to answer questions about potential risks from chemical exposure more quickly and cheaply. Cote, who recently hosted a conference about NexGen in Washington, D.C., discussed the effort with Science News *chemistry writer Rachel Ehrenberg.*

What is risk assessment?

Risk assessment is a process of evaluating information to determine how likely you think some event is; in the case of the EPA, the likelihood of public health or environmental damage. One example is air pollution regulations: We ... would take all the information that's available on the health effects and environmental effects of air pollution, organize it, synthesize it and interpret it and then provide that information to decision makers at EPA.

What does molecular biology bring to risk assessment?

It really got a big leap forward with the Human Genome Project and the invention of robots that can do lab work. Now you can generate data both faster and cheaper, and it's a different kind of data. Molecular biology is really the study of the machinery of cells and how they function, particularly in regard to these important molecules in the cell like DNA, genes and proteins. So with those new ways of looking at the function and the machinery of the cell, we're gaining new insights.

What are some of these insights?

Understanding how chemicals cause disease, how individuals might differ from one to the other in terms of their response to the same exposure. To go back to [air pollution]: We know that about 30 percent of the population is much more sensitive to ozone. For a long time we didn't know why. Now we know that part of that is some specific genes that make you more susceptible. That's probably not the whole story, but that's one piece. There are differences in metabolism — big differences in the population in how you metabolize things. So any drug where metabolism is involved in an important way, we know that individual responses can differ. We all know people who smoke. And not all of those people will get lung cancer or a smoking-related disease, and it's been a perplexing question for many years as to why that is. These new methods are providing some insight.

ROBERT E. WALLINE

One could take a sample of spit ... to understand what people had been exposed to and how that changed their risk for some specific disease.

What methods are most promising?

It's very hard to figure out how to use data in the abstract, so we're developing some case studies in collaboration with other agencies. We're taking chemicals that we know a lot about — we know what the public health risks are for these chemicals as well as we know it for anything ... — and we want to take the matching molecular biology data and see if we can reverse-engineer to the right answer.... For ozone, we're looking at lung injury and how that happens through an inflammatory process. So we know, at a chemical level, most of the steps that lead to inflammation. And what we want to do is look at the genes that turn on and off that are associated with inflammation. By looking at the patterns of those genes can you predict the health effects and the magnitude of the response for that individual?

One of the prototypes we're doing is with benzene, in collaboration with a University of California, Berkeley lab that's done epidemiology studies of benzene-exposed workers in China. So they can measure how the genes turn on in those people and accurately predict how much benzene they've been exposed to and how likely they are to get cancer. So potentially in the future, if we were concerned about a school or a community, one could take a sample of spit or a cheek scraping ... and be able to understand what people had been exposed to and how that changed their risk for some specific disease. The technology is just now coming online, and we don't have enough examples to be able to reliably do it now, but I don't think it's that far off in the future.

What are the challenges to implementing a molecular biology approach to toxicology?

In some ways this new data is not very intuitively obvious. In the good old days, you exposed a bunch of rats and half died and half didn't, and you could say, "That doesn't look good." Now what you get is these little bright lights of readouts of a bunch of genes that get up-regulated or down-regulated. And you show that to somebody and they go "What does that mean?" ... It requires people who understand biology and computers to understand all these data. ■

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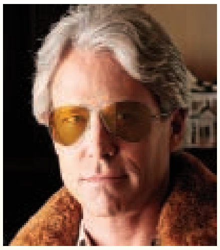

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