Oxygen-Free Animals | Moonless Space Plan | 9/11's Lung Effects

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ MAY 8, 2010

SPECIAL ISSUE

The Beam Goes On

50 years of lasers

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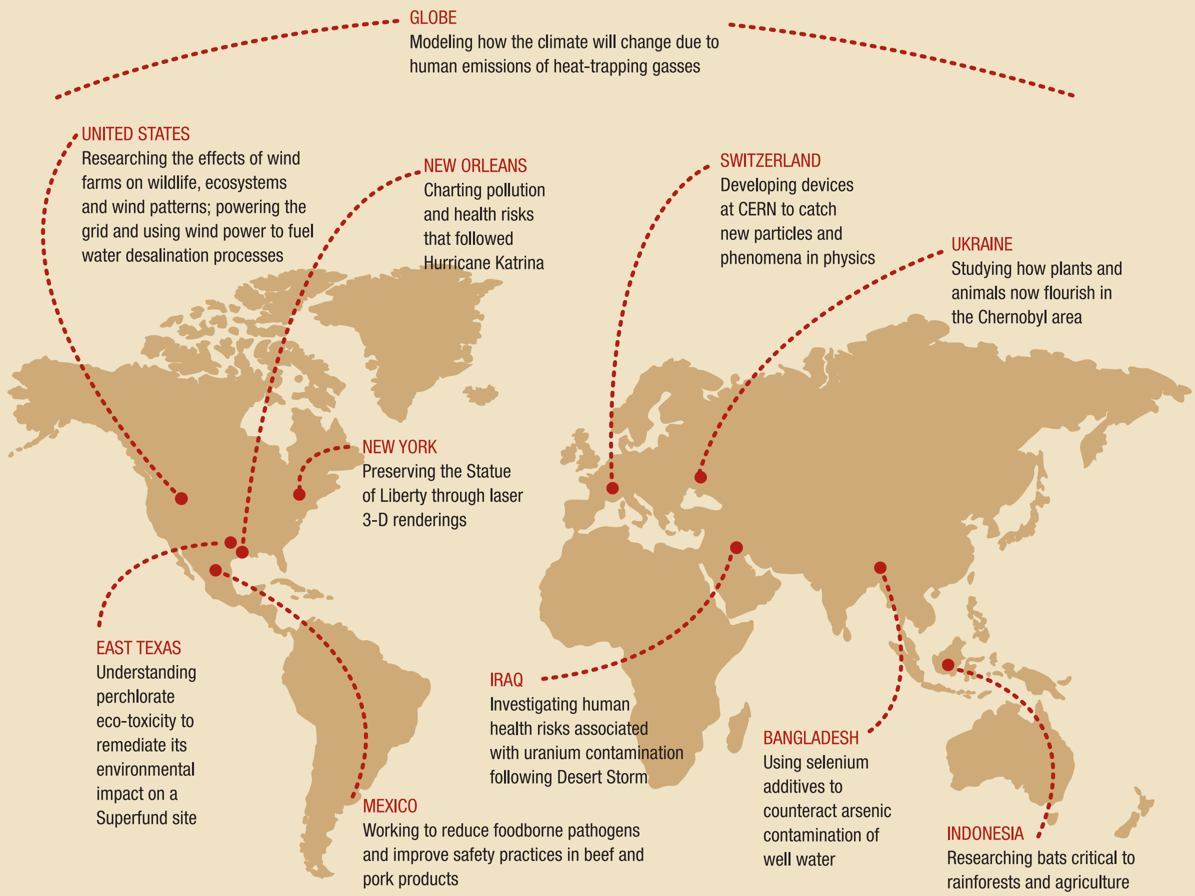

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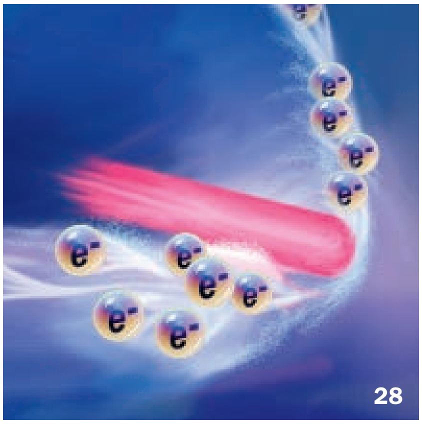

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ScienceNews

In The News

Special Issue
Celebrating the Laser

Departments

COVER A fish-eye view of the Gemini Observatory shows its laser system creating an "artificial star" as a telescope reference. *Kirk Pu'uohau-Pummill, Imiloa Astronomy Center of Hawai'i*

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

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FROM THE EDITOR

Lasers illuminate benefits of basic science research

Basic science's advocates are always encountering people obsessed with practical applications. Research without practical purpose, seeking knowledge for knowledge's sake, somehow never seems to escape being labeled a luxury by budget cutters and skeptical naysayers.

But for the past half century, scientists confronting the critics of basic research funding have had at their disposal a piercing one-word rejoinder: lasers.

From the purest of scientific reasoning, pondering the intricate interplay of atoms, electrons and light, Albert Einstein conceived the principle behind the laser and published a paper about it in 1917. He had no thoughts of death rays, CD players or supermarket cash registers. He simply sought scientific insight. But the ultimate payoff was eminently practical: Einstein's idea eventually led to one of the 20th century's grandest technological tours de force.

Five decades ago, as Ron Cowen recounts in this issue (Page 18), Theodore Maiman made Einstein's idea real, initiating the age of the laser — a new tool for science and a new technology for society. Building on the maser, the microwave version of Einstein's idea, Maiman demonstrated that light could mimic the sharp beam of microwaves developed a few years earlier by Charles Townes (see Page 36) and others. In the 50 years since Maiman's surprising accomplishment (*SNL: 7/23/60, p. 53*), lasers have become the shining example of useful technology born of natural curiosity. From laser printers and bar code readers, chemical sensors and special microscopes to multiples uses in medicine and industry (fiber-optic communication, welding, eye surgery), the laser's applications have paid basic science's debt to society several times over.

Beyond their practical and valuable technological uses, lasers have enabled advances in many realms of basic research, from allowing physicists to trap and study individual atoms to powering experiments for testing the foundations of quantum physics. And as Lisa Grossman reports (Page 28), scientists continue to create new versions of lasers and to find novel applications for old ones. It's safe to say that in the decades to come, lasers will continue to play a starring role in both the practice of science and in science's service to society.

—Tom Siegfried, Editor in Chief

Scientific Observations

"Even if we eventually come up with a computational account of how the social brain works that is truly aligned with the neuroscience data, it remains an open question what such an account would look like. It is possible that it would be so different from our intuitive categories for social behavior that it would literally be something that we could not presently understand.... We may end up with a theory of social behavior very different from the one we currently use in everyday life. On the other hand, the picture of the physical world that quantum mechanics provides shares these same considerations, and it is an intriguing possibility that a future social neuroscience would literally allow us to understand ourselves in an entirely different way." **—CALTECH NEUROBIOLOGIST RALPH ADOLPHS IN A REVIEW OF THE BURGEONING FIELD OF SOCIAL NEUROSCIENCE IN THE MARCH 25 *NEURON***

Science Past | FROM THE ISSUE OF MAY 7, 1960

WHISTLING SWANS DYED TO STUDY MIGRATION ROUTE — The U.S. Fish and Wildlife Service has been dyeing whistling swans vivid colors to learn more about their migratory movements. With their wings, tails or other body parts colored blue, yellow, green or red, the swans are easier to observe both when flying and resting on the ground. The Service is interested in determining over which states the birds fly in their annual migrations.... Actually only a very small sampling of the whistling swan population is being dyed. This is because of the difficulty in trapping the four-foot-long birds. Mass dyeing, however, is not considered necessary. The dyes used normally do not remain on the swans for very long.

Science Future

May 12
Students can visit scientists or conduct their own experiments to celebrate National Lab Day. Find local events at www.nationallabday.org

May 27–30
The Association for Psychological Science hosts its annual meeting in Boston. See www.psychologicalscience.org

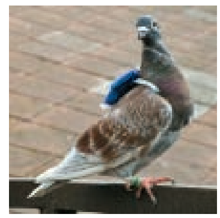
June 4–8
The American Society of Clinical Oncology meets in Chicago. See www.asco.org

SN Online

www.sciencenews.org

DELETED SCENES BLOG
The hardest part of finding element 117 might have been the paperwork to ship radioactive test materials from the United States to Russia. See "The backstory behind a new element."

LIFE
Pigeon navigation is largely a meritocracy. See "Pigeons usually let best navigator take the lead."



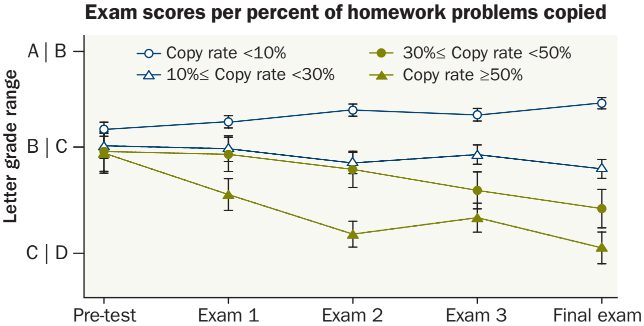
BODY & BRAIN
Top jaw, bottom jaw, the brain responds similarly to toothaches in both places. Read "Why a rotten tooth is hard to find."

ATOM & COSMOS
The spacecraft Cassini has snapped the first images of lightning on Saturn. See "Stormy weather on Saturn" for story and video.

Science Stats | CHEATERS NEVER LEARN

A study of MIT students found that those who copied others' homework more frequently did worse on exams over the course of a semester.

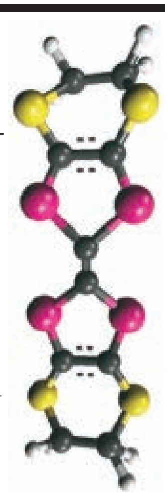
Exam scores per percent of homework problems copied



SOURCE: D. PALAZZO *ET AL.*/*PHYSICAL REVIEW SPECIAL TOPICS – PHYSICS EDUCATION RESEARCH* 2010

The (-est)

Researchers have identified how a few molecules beat the heat to form the smallest known superconductors. Defined as materials with no electrical resistance below certain temperatures, superconductors were thought to exist only in the macroworld; at microscopic scales, materials would get too hot. But an analysis of a known organic superconductor found that the special property was preserved in just four pairs of its molecules (shown), an international team reports online March 28 in *Nature Nanotechnology*.



CLOCKWISE FROM TOP LEFT: CALTECH; ZSUZSA ÁKOS; K. CLARK *ET AL.*/*NATURE NANOTECHNOLOGY* 2010

“Essentially these insects are swimming through the air.” —ITAI COHEN, PAGE 8

In the News

STORY ONE

Briny deep basin may be home to animals thriving without oxygen

New species would extend the limits of multicellular life

By Susan Milius

Marine creatures resembling something out of a Dr. Seuss book may be the first multicellular animals known to live their whole lives without oxygen.

If further work bears out the remarkable powers of these organisms, part of a group known as loriciferans, the discovery could shake up thinking about the limits of animal life, says study coauthor Roberto Danovaro of the Polytechnic University of Marche in Ancona, Italy.

Previously loriciferans have been reported scattered around the globe living in sediment grains beneath regular, oxygenated water — and the creatures were thought to be rare.

Now Danovaro, Reinhardt Kristensen of the Natural History Museum of Denmark in Copenhagen and colleagues report that abundant loriciferans belonging to three new species turned up in sediment cores pulled from the bottom of a briny, acidic and sulfurous basin of oxygen-starved water deep in the Mediterranean Sea.

Molecular tests indicate the animals were alive when collected, and investigations under microscopes suggest the species may be especially adapted to life without oxygen, the researchers argue online April 6 in *BMC Biology*.

“This discovery is truly exceptional,” says invertebrate biologist Gonzalo Giribet of Harvard University, who was not part of the study. Biologists know of animals living in extreme places, with alarming amounts of salt or scorching heat, “but not of any other animals that live without oxygen,” he says.

Loriciferans look like tiny cups with tentacles sticking out. Because they are so different from other animals, these oddballs have their own phylum, on a par with mollusks and arthropods. Kristensen described the phylum in 1983 (*SN: 10/8/83, p. 229*).

Before the team pulled up these cores, scientists had found only single-celled organisms living in oxygen-free zones, Danovaro says. These residents include bacteria and some protozoans, such as ciliates.

R. DANOVARO

Loriciferans are so different from other animals that they have their own phylum. Researchers now suggest that some species (one shown) live entirely without oxygen.

So far work has suggested that multicellular animals showing up in places without oxygen are just visitors passing through. Thus, biologists have thought that developing an anoxic lifestyle is hard for such organisms.

Finding a full-time multicellular resident of oxygen-free zones “would be a watershed for how we can think about where animals live,” says Tim Shank of Woods Hole Oceanographic Institution in Massachusetts. He studies tubeworms and other animals that thrive around deep ocean vents releasing sulfide-choked plumes of water too hot to hold oxygen. Even there, Shank says, the animals need cooler water swirling in to provide oxygen.

If animals really can live totally oxygen-free, Shank says, it would be “a step beyond” even the marvels of vents.

Deep-sea researchers may have many more surprises ahead of them, too. “The bottom of the sea is one of the least known ecosystems we have,” says biologist Jim Barry of the Monterey Bay Aquarium Research Institute in Moss Landing, Calif.

It was during three expeditions to survey life in such deep waters that Danovaro and his colleagues found the loriciferans, 3.5 kilometers or so below the Mediterranean Sea’s surface in the hostile L’Atalante basin.

Salt was concentrated in the Mediterranean when it became closed off from the Atlantic about 6 million years ago. Upon reconnection hundreds of thousands of years later, pools of concentrated brine remained trapped in the L’Atalante and other deep basins. Conditions in the

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

sampling spots are harsh enough to corrode sensors, Danovaro says.

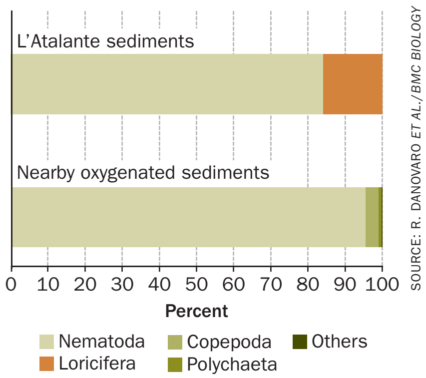
When the researchers first found the loriciferans in the sediment, "we thought they were cadavers," he says.

To see if the loriciferans had just wafted down after dying elsewhere, researchers brought up more sediment cores and tested them in nitrogen-filled incubators on ship. In molecular tests, the animals appeared to be alive and metabolizing. For example, an amino acid injected into the mud turned up in loriciferan tissues after four hours.

The presence of cast-off skins in the cores also suggests that the loriciferans are growing on location. They may be reproducing there too: Two individuals' bodies carried eggs, Danovaro says.

Also, he points out that the loriciferans, not even a millimeter long, have limited mobility, so it's unlikely that they'd move out of the sediment and through the 50 meters of anoxic water above them to take a breath in the oxygenated zone. Thus, the researchers argue, it's most likely that the loriciferans in the muck are not just visiting the basin but have made it their full-time home.

Mediterranean sediment residents



Loriciferans were relatively abundant in the sediment pulled from beneath the salty, oxygen-deprived L'Atalante basin, but they didn't show up in sediment from nearby oxygenated waters.

The evidence may be indirect, but "I think they're right," says Lisa Levin of Scripps Institution of Oceanography in La Jolla, Calif.

Electron microscope images show that loriciferans' cellular innards look adapted for a zero-oxygen life, says Danovaro. The cells don't appear to have mitochondria, which use oxygen to generate energy. Instead, images of loriciferan tissue reveal what look like hydrogenosomes, organelles that help power some known anaerobic single-celled creatures.

And near the hydrogenosome-like bits, the loriciferans have rod-shaped structures that could be symbiotic organisms. Some one-celled creatures depend on such organisms to take the hydrogen, along with other products, from the hydrogenosomes and turn it into user-friendly metabolites for the host cell (*SN: 4/18/98, p. 253*).

The research team may indeed have found multicelled creatures living in anoxic conditions, but the evidence for those creatures having hydrogenosomes still looks preliminary, cautions Johannes Hackstein of Radboud University Nijmegen in the Netherlands, who studies the organelles. Electron micrographs of tiny structures aren't enough, he says, without physiological experiments and staining of cell parts.

Figuring out how loriciferan biology works is the next step, Danovaro says. ■

Back Story | TOUGH CREATURES

Some oxygen-reliant animals find a way to get the gas even in hostile environments.

Tardigrades
Tiny, tubby invertebrates sometimes called "water bears" or "moss piglets" are the only animals so far to have lived through experimental exposure to the vacuum of space. When deprived of oxygen, the creatures survived in a dormant state—as they do on Earth when their wet homes become barren of oxygen or supersalty. And the creatures can withstand another crisis, too: They shrivel up to resist drought and revive themselves unharmed.

Hydrothermal vent clams
Clams that survive near hydrothermal vents position themselves in very particular ways to get both food and oxygen. The creatures extend a foot into the oxygen-starved streams of sulfide flowing from the vent. (The streams nourish the symbiotic microbes in the clams' gills, which in turn nourish the clams.) The clams also sit in a way that keeps their siphons extended into oxygenated water; the siphons direct the water over the creatures' gills.

Humboldt squid
Also called jumbo squid, these predators grow to 2 meters in length and can travel at 25 kilometers per hour. Off the coast of California, they routinely dive down to hunt in oxygen-poor water and spend all day there, outlasting other visiting hunters including sharks. Lab experiments from ships have revealed that the squid can slow their oxygen consumption rate down by 80 to 90 percent, quite a feat for an active and muscular predator.

Polychaete worms
These marine relatives of earthworms and leeches come in a variety of forms. Some have adapted to zones of oxygen-starved ocean water and sport outsized structures that increase their body surface area for gas exchange. The species of terebellid polychaete shown above has enlarged, branched curlicues, or branchiae, that help it flourish in an oxygen-minimum zone 412 meters deep on the Pacific side of Costa Rica.

FROM LEFT: ANDREW SYRED/PHOTO RESEARCHERS, INC.; © PETER BATSON, DEEPSEAPHOTOGRAPHY.COM; IMAGE COURTESY OF NOAA, MBARI 2006; GREG ROUSE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Life

To view a video of the fruit fly's nimble turns, visit **www.sciencenews.org/fly_turn**

Fruit flies maneuver on autopilot

High-speed video reveals clues to insect aerodynamic skills

By Lisa Grossman

Fruit flies turn in midair with a shrug of their shoulders and nary a thought.

Flies' aerial gymnastics are driven by wing joints that act like windup toys, letting the bugs use air drag to whirl around almost automatically, a new analysis shows. Insights from the study, published online April 5 in *Physical Review Letters*, could someday help build better flying robots.

Fruit flies beat their wings about once every four milliseconds — faster than their neurons can fire electrical signals — and can turn 120 degrees in 18 wing beats. Such skills made physicists at Cornell University wonder how much of the wing motion is controlled by the insect and how much is controlled by aerodynamics.

To investigate, the researchers set up three high-speed cameras trained at the center of a box holding about 10 flies. A fly crossing the center of the box triggered the cameras to start rolling at 8,000 frames per second. At the same time, LED lights projected a rotating striped pattern on the inside of the box to trick the flies into making a U-turn.

"The flies see this, and it makes them dizzy," says study coauthor Attila Bergou of Brown University in Providence, R.I., who worked on the study as a Cornell graduate student. "It generates very reliable and repeatable turns in these flies."

The physicists analyzed the videos to extract detailed information on the wings' positions with respect to the body.

"I was surprised that they were able to get it to work as well as they did," comments Ty Hedrick of the University of North Carolina at Chapel Hill. "Getting the uncertainty of these measurements low enough that you can see what you need to see is difficult."

When a fruit fly turns, one wing tilts more than the other, the team found, similar to the way a rower pulls one oar harder than the other to make a boat turn. Thanks to aerodynamics, a wing-tilt difference of just 9 degrees is enough to send a fly off in another direction.

Studies combining a computer model and high-speed images show how flies "swim" in air, using drag forces to turn.

"Essentially these insects are swimming through the air, using drag forces to row themselves in whichever direction they want," says study coauthor Itai Cohen of Cornell.

Computer models of the fly and aerodynamic simulations showed that the fly's wing joint acts like a torsional spring, the kind found in windup toys or old clocks. To change its wing tilt and set up a turn, all the fly has to do is twitch the muscle that controls the spring.

"The insects don't have to do any thinking whatsoever," Cohen says. "They have a natural system that provides just the right amount of torque to the wing."

Cohen hopes these findings and further studies of other insects could help in designing flying robots that take advantage of insect aerodynamic skills.

"We're in the dark ages as far as building anything like that," Cohen says. "We're nowhere in the ballpark."

Scientists name elusive new lizard

Scientists couldn't see the lizard for the trees. But now they've tracked down and named *Varanus bitatawa*, a skittish reptile that grows up to 2 meters long and sports bright yellow speckles. On the Philippine island of Luzon, the monitor lizard hauls itself up into trees in search of fruit and melts into the vegetation if humans approach, says herpetologist Rafe Brown of the Biodiversity Institute at the University of Kansas in Lawrence. He and colleagues name the species in a paper published online April 7 in *Biology Letters*. The species is "new to us," Brown clarifies, because the Agta and Ilongot peoples living in the Sierra Madre mountain range know the lizard well — as a delicacy. Western scientists first glimpsed the monitor in 2001 but could not secure a full-grown specimen. Then, in 2009, a team led by Brown and graduate student Luke Welton got its hands on an adult. DNA tests confirmed that it differs from a previously identified fruit-eating monitor living on a different part of the island. —*Susan Milius*

FROM TOP: A. BERGOU *ET AL*./*PHYSICAL REVIEW LETTERS* 2010; ARVIN DIESMOS

Matter & Energy

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When dust swirls and lightning zaps

How swarming particle clouds can build up electrical charge

By Alexandra Witze

It's the ultimate love-at-first-sight story: In the middle of the desert, hundreds of miles from anything else, lonely sand grains meet up in a crowd and decide to electrify each other. Sparks fly.

Physicists have long wondered how sand grains and other small particles can build up electrical charges as they collide with one another, sometimes to the point of discharging lightning in dust storms or plumes of volcanic ash. Now, a paper appearing online April 11 in *Nature Physics* suggests that particles transfer electrical charge vertically during a smashup, such that positive charges move downward and negative charges move up in the cloud.

The findings could help combat a wide variety of practical problems, such as the adhesion of charged dust to solar panels on a Mars rover or the generation of dangerous electrical discharges that can occur when a helicopter takes off in the desert. Dust clouds can create problems in grain silos, where charge sometimes builds up and leads to explosions, and in the pharmaceutical industry, where powdered drugs can become charged and not mix properly, says Hans Herrmann, a materials researcher at ETH Zurich.

Herrmann says he became interested in the problem after watching lightning in the swirling sands over dunes at night. "Normally when particles collide, they neutralize," he says. "How could it be that charges increase?"

Working with ETH colleague Thomas Pähtz and Troy Shinbrot of Rutgers University's campus in Piscataway, N.J., Herrmann developed a model to explain the charging. Before colliding, the grains have an overall neutral charge but are polarized by a background electric field, with a negative charge toward the top of the grain and a positive charge toward the bottom, relative to the ground. Upon colliding, the particles neutralize each other at the point of contact. But when they separate again they become further polarized, with additional charges building up on the grains' edges.

"Every time there's a collision you end up pumping charge from the top to the bottom," Shinbrot says. The researchers ran computer simulations and then a series of experiments with glass beads to confirm the theory.

Daniel Lacks, a materials physicist at Case Western Reserve University in Cleveland, says the new study might not be the whole story.

Lacks has shown that electrical charging depends on particle size, with smaller grains tending to charge negatively and larger particles positively.

"The bottom line is that something is needed to break the symmetry when two particles of identical composition collide, in order for one particle to charge negatively and the other to charge positively," he says. For particles of different sizes, he says his mechanism might be in play; for identically sized particles, the new model may be the explanation. ■

Flying ash sparked lightning during this volcanic eruption in Indonesia in 1995.

OLIVER SPALT/WIKIMEDIA COMMONS

Martian meteorite's age reduced

But famous rock is still oldest known sample of Red Planet

By Lisa Grossman

The Mars rock ALH84001 made headlines in 1996 when scientists reported that it might contain fossil bacteria.

Though it's still the oldest chunk of Mars ever found, the Allan Hills meteorite — officially known as ALH84001 — is about 400 million years younger than previously estimated, new research suggests.

An analysis in the April 16 *Science* pegs the rock's age at a mere 4.091 billion years. Previously it was thought to have formed 4.51 billion years ago, when the planet's surface was still solidifying. The new age indicates that the rock would have formed during a later, more chaotic period when Mars was being pummeled by rocky space debris.

ALH84001 has been a lightning rod for controversy since scientists announced in 1996 that the meteorite might hold fossils of Martian bacteria. The scientific community has since mostly abandoned that idea, as one by one every line of evidence for life has been given a nonbiological explanation.

The older age was calculated by measuring radioactive isotopes of samarium and neodymium, found mostly in phosphate minerals that succumb relatively quickly to weathering and geological processes, says study coauthor Thomas Lapen of the University of Houston. Like hair dye or a fake ID, weathering disguised the rock's age, but only superficially.

Lapen's group looked at different elements, lutetium and hafnium, which are found in more change-resistant components of the rock. This method gave the meteorite a younger age.

Rocks from the early solar system are valuable for understanding the planet's composition at that time. "This is the only sample in that age range," Lapen says.

Surprisingly, the researchers also found that several younger meteorites have essentially the same composition as ALH84001, meaning that some of the same basic geologic processes have been at work on Mars for almost its entire history.

"That connection is perhaps the most amazing outcome of this research," Lapen says. "Mars is a very steady state planet. Igneous processes were happening the same way 4 billion years ago as they are happening right now."

The new age places the rock's birth during a time when the inner planets in the solar system were being bombarded with rock chunks. That provides a new explanation for why parts of ALH84001 show signs of having melted and reformed, says Allan Treiman of the Lunar and Planetary Institute in Houston. At the older age, it was a puzzle how the rock got its scars if the damage happened before the bombardment. "There's not a lot of time for that," Treiman says.

Not your father's space program

Obama leaves the moon off his new road map for NASA

By Ron Cowen

Speaking at NASA's Kennedy Space Center April 15, President Obama outlined a new plan for the space agency that would forgo sending astronauts back to the moon. Instead, NASA would send humans to an asteroid in 2025 and into orbit around Mars a decade later.

The strategy would rely on private aerospace companies to ferry crew and supplies into space. It would also cancel a program known as Constellation, which was to develop a heavy-lift rocket and vehicles to carry astronauts back to the moon, in favor of pursuing a new rocket that would take humans much farther.

"I am very happy about the introduction of new innovative commercial approaches in human spaceflight, because we've been trapped into a very bad cul-de-sac for 40 years," says planetary scientist and former NASA associate administrator for science Alan Stern of the Southwest Research Institute in Boulder, Colo.

In Obama's blueprint, NASA would get an additional $6 billion over the next five years to develop new space technologies, refocusing efforts away from designing space transportation vehicles. The plan would, however, keep plans to develop the Orion crew vehicle, which would be the only U.S. space transport vehicle once the shuttle is retired later this year. And in 2015, the agency would evaluate plans for a rocket that would carry astronauts into deep space.

Journeys to Mars orbit in the mid-2030s would be followed by a landing, "and I expect to be around to see it," the president told the cheering crowd.

Space-policy analyst Howard McCurdy of American University in Washington, D.C., says he's intrigued by Obama's willingness to leapfrog smaller goals and aim for Mars. "It's a high-risk proposition," McCurdy says.

NASA

Stellar neighbor is a cool slacker

Nearest brown dwarf barely hot enough to bake a potato

By Ron Cowen

The solar neighborhood is riddled with abject failures, a new study suggests.

Astronomers have found the nearest known brown dwarf, or failed star, residing about nine light-years from Earth.

That places this brown dwarf among the 10 nearest stellar or substellar systems, researchers report in an article posted online April 5 at arXiv.org. The object's temperature, about baking temp in a home oven, makes it not only the nearest but also the coolest brown dwarf known.

"Everyone is going to want to jump on this finding," says brown dwarf observer J. Davy Kirkpatrick of Caltech, who was not part of the discovery team.

Astronomers calculate that brown dwarfs should be at least as common as stars in the Milky Way. The new finding, combined with recent discoveries of other nearby brown dwarfs, suggests that the solar neighborhood is rife with these dim bodies. The nearest body to the solar system may be a brown dwarf rather than a bona fide star, says theorist Gibor Basri of the University of California, Berkeley.

Philip Lucas of the University of Hertfordshire in England and his colleagues discovered the dim body, dubbed UGPSJ0722-05, in a sky survey conducted with the United Kingdom Infra-Red Telescope atop Hawaii's Mauna Kea. Follow-up spectra recorded by the Gemini North Telescope, also on Mauna Kea, revealed that water vapor and methane in the object absorbed light more strongly than the coolest known brown dwarfs, an indication that the newfound body is even cooler. The team estimates its temperature is 125° to 225° Celsius.

Like all brown dwarfs, the object isn't heavy enough to sustain the nuclear burning that occurs in the cores of stars. Yet brown dwarfs are thought to form in the same way that stars are born, from the gravitational collapse of a molecular cloud of gas.

Lucas declined to comment on the study because he and his colleagues have submitted their paper to *Nature*.

Backward planets flipped into place

Earthlike bodies likely to have been kicked out in the process

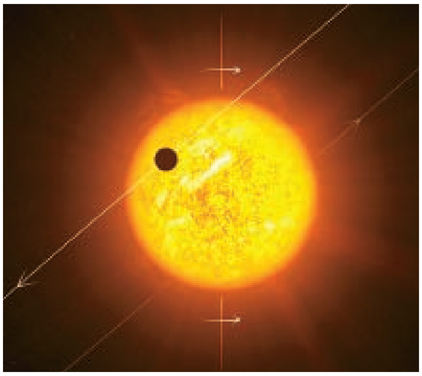
By Lisa Grossman

A recently discovered bevy of backward-orbiting exoplanets decreases the odds of finding Earthlike bodies near them, says astronomer Andrew Collier Cameron of the University of St. Andrews in Scotland.

That's because the wrong-way planets probably got where they are through a process that also would have hurled any incipient terrestrial-type planets into deep space, he proposed April 13 at a meeting in Glasgow, Scotland, of the Royal Astronomical Society.

Planets are thought to form from the disk of gas and dust around a young star. Because both star and disk coalesce from the same cloud of material, theory holds that both should spin in the same direction — as should any planets that arise.

Last summer, astronomers first discovered a handful of planets that orbit opposite the direction of their stars' spin (*SN: 9/12/09, p. 12*), as well as a number of others that have "forward" orbits tilted 20 degrees or more with respect to the stellar disk in which the planets were born. These exoplanets belong to a class called hot Jupiters — giants that sit scorchingly close to their stars.



ESO

Earthlike planets are unlikely to coexist with backward-orbiting "hot Jupiters."

The presence of so many slanted and reversed orbits among hot Jupiters is the hallmark of a scenario known as the Kozai mechanism, Cameron said. In this scenario, a second, distant large body like a planet or a companion star gravitationally perturbs a planet's orbit, tilting it with respect to the star's rotation. The planet's orbit can tilt so much that it flips over the top of the star like a jump rope. When the orbit is flipped more than 90 degrees, the planet actually orbits backwards.

Earthlike planets are unlikely to survive such a process. The giant planets can take hundreds of millennia to settle down, "during which you have a rampaging Jupiter on a cometlike, crazy tumbling orbit, which would simply fling any remaining debris out of the system," Cameron said.

Earlier research predicted that most orbits of giant planets perturbed by the Kozai mechanism should end up tilted around either 40 degrees — a forward but slanted orbit — or 140 degrees — a backward and tilted orbit.

"That looks very much like what we're now observing," Cameron said. "It looks almost too good to be true."

Some critics think he's right — it is too good to be true. "Their data isn't that definitive to eliminate any other possibilities," says Adam Burrows of Princeton University.

Body & Brain

For longer versions of these and other Body & Brain stories, visit **www.sciencenews.org**

Health effects of 9/11 continue

Emergency workers are still having breathing problems

By Nathan Seppa

Many rescue workers who responded to the 2001 World Trade Center attack in New York City continue to show breathing difficulties that haven't improved in the years since the dust cleared, researchers report in the April 8 *New England Journal of Medicine*.

Inhalation of the thick dust has caused bronchitis, asthma and symptoms of chronic obstructive pulmonary disease such as shortness of breath, says study coauthor Thomas Aldrich, a pulmonologist at Albert Einstein College of Medicine in New York City.

Aldrich and his colleagues analyzed results of lung function tests of 10,870 firefighters and 1,911 emergency medical service workers examined both before and after the attack. The sample included 92 percent of all rescue workers who arrived at Ground Zero between September 11 and September 24.

Lung function remains below normal for many September 11 rescue workers.

Of nonsmoking firefighters, 3 percent had below-normal lung function before 9/11, but that rose to 18 percent in 2002 and has since stabilized at 13 percent. Among nonsmoking EMS workers, 12 percent fell below normal range before the attack compared with 22 percent in 2002, a percentage that has been constant since then. Firefighters who arrived on the morning of 9/11, when dust was densest, were most likely to have diminished lung capacity within the first six months to a year.

"In the first 24 hours, there weren't many respirators there," says environmental scientist Paul Lioy of the Robert Wood Johnson Medical School in Piscataway, N.J. In any case, Lioy says, "these people went in to save lives; they weren't thinking about the dust."

Since there have been few biopsies of lung tissue in these workers, the precise nature of the lung disease is unclear. But inflammation probably plays a role, Aldrich says.

Insulin-producing cells regenerate

Mouse experiments suggest potential diabetes treatment

By Tina Hesman Saey

Replacements for some diabetics' missing insulin-producing cells might be found in the patients' own pancreases, a new study in mice suggests.

Alpha cells in the pancreas can spontaneously transform into insulin-producing beta cells, researchers report online April 4 in *Nature*. The study is the first to reveal the pancreas's ability to regenerate missing cells. Scientists were surprised to find that new beta cells arose from alpha cells in the pancreas, rather than from stem cells.

If the discovery translates to people, scientists may one day be able to coax type 1 diabetics' own alpha cells into replacing insulin-producing cells. Type 1 diabetes, also known as juvenile diabetes, results when the immune system destroys beta cells in the pancreas. People with the disease must take lifelong injections of insulin in order to keep blood sugar levels from rising too high.

Researchers treated mice to destroy their pancreatic beta cells and kept the mice alive by giving them insulin. After six months, the mice no longer needed the injections because their pancreases had regenerated between 4 percent and 17 percent of the beta cells present before the treatment — enough to maintain nearly normal blood sugar levels.

"It's very early and very basic research right now, but it opens up the idea that reprogramming is not just something we have to force cells to do, that it's an intrinsic property," says Andrew Rakeman, a scientific program manager for the Juvenile Diabetes Research Foundation in New York City who was not involved in the study.

The researchers found that some of the insulin-producing cells also made glucagon, a hormone that is normally made by alpha cells. The finding suggested that the beta cells in the mice had once been alpha cells.

To test that hypothesis, the researchers tagged alpha cells in mice, then killed their beta cells. Newly generated beta cells carried the alpha cell tags, indicating that a switch had occurred.

If humans can perform the conversion, says study coauthor Pedro Herrera of the University of Geneva, controlling the immune system attack in type 1 diabetics could give their pancreases a chance to recover at least some function. "The life of diabetics would change even if the pancreas is only able to produce 1 or 2 percent of normal insulin levels," he says.

JIM WATSON/U.S. NAVY

“These people went in to save lives; they weren’t thinking about the dust.” —PAUL LIOY

Eating seaweed gives gut a boost

Bacteria enable some Japanese to digest the indigestible

By Susan Milius

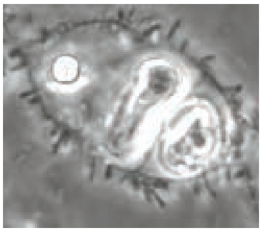
Eating seaweed appears to give some Japanese people digestive superpowers.

Bacteria in the guts of some Japanese people can break down porphyran, a compound in seaweed that is normally indigestible, scientists report in the April 8 *Nature*. The microbes may provide nutritional benefit to these people, says study coauthor Gurvan Michel, a biochemist at the Biological Station of Roscoff in France.

After discovering genes for a pair of porphyran-digesting enzymes in the marine bacterium *Zobellia galactanivorans*, Michel’s team searched for similar DNA sequences in other species. The team found a partial match in a gene from a human gut bacterium and eventually showed that porphyran-digesting bacteria were in samples from Japanese subjects but not in samples from Westerners.

The human gut bacteria probably acquired the gene centuries ago from marine microbes hitchhiking through the intestines on the seaweed abundant in the Japanese diet, Michel says.

“To our knowledge, it’s the first time there has been a demonstration of gene transfer from bacteria outside the gut to bacteria within the gut in connection with food,” he says.



DELPHINE SCORNET

Zobellia galactanivorans **bacteria look like eyelashes growing on the outside of a brown alga.**

Ruth Ley of Cornell University notes that there has been speculation about whether such gene transfer occurs. But she can’t think of any other work that has showed this and done it “so beautifully.”

All people rely on gut microbes for the tricky parts of digesting land plants, such as breaking down polysaccharides, a family of compounds that includes marine algae’s porphyran. “When you digest a salad, it’s not you that breaks down the vegetables; it’s the bacteria in your gut,” Michel says.

Land plants don’t make porphyran, but it shows up in seaweeds such as the dried, dark nori in sushi. Japanese people have eaten seaweed for centuries and today on average consume 14 grams daily.

Humans

For longer versions of these and other Humans stories, visit **www.sciencenews.org**

Hobbit fuss goes out on some limbs

Debate over pint-sized fossils turns to arm and leg bones

By Bruce Bower

ALBUQUERQUE — Two fossil "hobbits" have given what's left of their arms and legs to science.

But that wasn't enough to quell debate over hobbits' evolutionary status at the annual meeting of the American Association of Physical Anthropologists.

Since 2004, the discoverers of these unusual fossils on the Indonesian island of Flores have attributed their find to an ancient pint-sized hominid, *Homo floresiensis*, that survived there until 17,000 years ago — a shockingly recent date in human evolutionary terms.

Critics say the finds represent nothing more than human pygmies like those still living on Flores. If so, the centerpiece hobbit find — a partial female skeleton known as LB1 — is what's left of a woman who suffered from a developmental disorder that resulted in an unusually small body and brain.

But arm and leg bones from LB1 and another hobbit appear healthy, concludes a study led by William Jungers of Stony Brook University in New York. The bones display normal thickness in the tissue that forms the outer shell of most bones, as well as symmetry that signals healthy growth, said Stony Brook anthropologist and study coauthor Frederick Grine, who presented Jungers' paper on April 17.

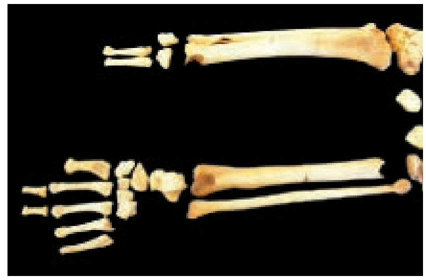
The scientists also found that *H. floresiensis* limb strength rivals that estimated for ancient hominids such as the 3.2-million-year-old *Australopithecus afarensis*, a.k.a. Lucy. That suggests hobbits could engage in arboreal acrobatics and other vigorous activities that humans generally can't manage. Hobbits may have spent much time climbing trees, as Lucy's kind did, the researchers propose.

In a separate presentation, Robert Eckhardt of Pennsylvania State University in University Park conjured an entirely different animal from the very same bones. He argued that a developmental disorder produced a suite of skeletal abnormalities in LB1 (*SN: 11/18/06, p. 330*), including irregularly shaped hip joints and tube-shaped upper leg bones.

A variety of developmental disorders produce skeletal traits in people today that Jungers has labeled as exclusive to *H. floresiensis*, Eckhardt argued. He described the case of a woman with a developmental disorder that resulted in an S-shaped collar bone, which Jungers' team lists as a hobbit-specific feature.

This new twist in the hobbit controversy follows the March 17 online publication of a paper in *Nature* concluding that hominids reached Flores before 1 million years ago. Excavations on Flores yielded stone tools from sediment dating to that time, reported Adam Brumm of the University of Wollongong in Australia.

Brumm's contention has been challenged by colleagues who believe natural processes may have moved the artifacts from younger to older sediment layers.



The limb bones of the LB1 hobbit, shown in cast, can be read two ways.

Hominid species named

Nearly 2 million years ago, an adult and child walking in the South African landscape fell through an opening in an underground cave and died. That plunge has now led to the identification of a new hominid species. In the April 9 *Science*, anthropologist Lee Berger of the University of the Witwatersrand in Johannesburg and colleagues assign the fossils to a new species, *Australopithecus sediba,* and propose that it served as an evolutionary bridge from apelike *Australopithecus* to the *Homo* genus, which includes living people. In a local African tongue, *sediba* means fountain or wellspring. "*Australopithecus sediba* could be a Rosetta Stone for anatomically defining the *Homo* genus," Berger says. But others doubt that the newly discovered fossils will illuminate *Homo* origins. "There's no compelling evidence that this newly proposed species was ancestral to *Homo*," says Bernard Wood of George Washington University in Washington, D.C. — *Bruce Bower*

FROM TOP: MAMORITAI/FLICKR; BRETT ELOFF, COURTESY L. BERGER/UNIV. OF WITWATERSRAND

8000 B.C. Date of oldest known preserved human hair with traces of lice

430 B.C. Herodotus describes Egyptian priests' lice-control methods

MEETING NOTES

Thumbs-up on precision grip

A tiny fossil thumb bone provides a gripping new look at the early evolution of human hands. An upright gait and relatively sophisticated ability to manipulate objects apparently evolved in tandem among the earliest hominids at least 6 million years ago, Sergio Almécija of the Autonomous University of Barcelona reported April 16. That's well before the earliest evidence of stone toolmaking, which dates to about 2.6 million years ago, countering the idea that skills for toolmaking drove the evolution of opposable thumbs. Almécija and colleagues studied a bone from the tip of a thumb belonging to *Orrorin tugenensis,* which at an estimated 6 million years old is the second oldest reported hominid genus. The fossil indicates that *Orrorin* had a long enough thumb to meet the tips of the other fingers, allowing fine manipulation of objects. By comparing *Orrorin*'s thumb bones with those of other hominids, ancient apes and living people, Almécija found a pattern that argues against the notion that hominids first evolved handier hands as they learned to make stone tools. In Almécija's view, early hominids inherited hands capable of fine manipulation from small-bodied apes that lived in Africa and Europe between 25 million and 5 million years ago. Russell Tuttle of the University of Chicago, who had predicted that early hominids would have had a relatively sophisticated grip, called the new analysis unsurprising. —*Bruce Bower*

Lice make the clothes, and man

For once lice are nice, at least for scientists investigating the origins of garments. DNA evidence suggests that body lice first evolved from head lice about 190,000 years ago—soon after people first began wearing clothing, researchers propose. The new estimate, presented April 16, sheds light on a development that allowed people to settle in northern, cold regions, said Andrew Kitchen of Pennsylvania State University in University Park. His team examined mitochondrial and nuclear DNA from head and body lice to estimate when body lice appeared. Because body lice thrive in the folds of clothing, they probably appeared not long after clothes were invented, many scientists believe. —*Bruce Bower*

Genes & Cells

100 billion Estimated neurons in a human brain

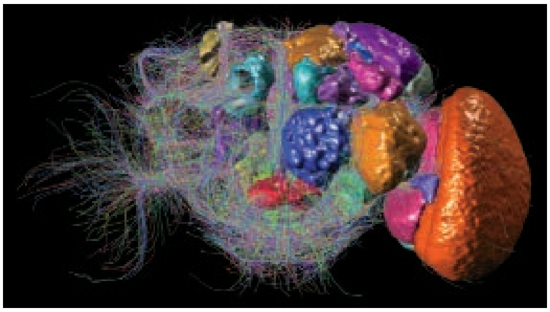
100 thousand Estimated neurons in a fly brain

302 Neurons in the lab nematode *C. elegans*

Making connections in the fly brain

New digital atlas will show how 100,000 neurons fit together

By Laura Sanders



Detailed maps of the fly brain can help reveal how networks of neurons interact to control behavior.

WASHINGTON — A new computer-based technique is charting the fruit fly brain, tracing a detailed network that researchers intend to build into a complete master plan of the organ. Mapping the estimated 100,000 neurons in a fly brain, and seeing how they interact to control behavior, could be a powerful tool for figuring out how the billions of neurons in the human brain work.

The program has already found some new features of the fly brain, said study coauthor Hanchuan Peng of the Howard Hughes Medical Institute's Janelia Farm Research Campus in Ashburn, Va. Peng presented the results April 9 at the 51st Annual Drosophila Research Conference.

He and his colleagues developed a method, also described in the April *Nature Biotechnology*, that incorporates many different images of brains from fruit flies that are genetically programmed so that select neurons glow when struck with a particular type of laser light. By combining thousands of these digital images from different flies, the researchers can create maps of how groups of neurons fit together.

Large-scale studies that focus on how neurons are connected are "very important for the future," commented geneticist Wei Xie of Southeast University in Nanjing, China. Understanding how all of the neurons work together is much more meaningful than studying how a single brain cell connects to another cell: "Just a neuron is not enough," Xie said.

Peng likened the process to a Google Earth resource. "What we want to do in the next few years is to add more and more neuron reconstructions into this map," he said. "If you think about the fruit fly brain as the Earth, the little neurons will be the streets. We want to map a lot of neuron streets onto the Earth."

For the most part, neuron-connecting pathways don't vary much from brain to brain, the researchers found. But the shapes of cells in the same brain structure can differ dramatically. For example, the variety of neuron shapes found in a wheel-shaped structure called the ellipsoid body "are just amazing," Peng said.

The results are preliminary, but such unexpected variation could mean that these neurons — which were thought to be nearly carbon copies of each other — have important functional differences.

Repairing a cell's faulty batteries

New method could prevent certain inherited disorders

By Tina Hesman Saey

Researchers have developed a technique that could help prevent incurable genetic diseases affecting an estimated one in 6,000 people.

The method targets diseases stemming from genetic mutations in mitochondria, energy-producing organelles that are akin to cellular batteries. Mitochondrial mutations can lead to diabetes, deafness and diseases that affect the nervous system, heart and muscles.

Mitochondria are the only organelles in animal cells that have their own genetic material separate from the DNA in the nucleus. The new technique, reported online April 14 in *Nature*, transplants nuclear DNA from human embryos with faulty mitochondria into embryos that have healthy cellular batteries.

Last year, researchers showed that swapping nuclear DNA from one rhesus monkey egg to another could separate genetic information in the nucleus from diseased mitochondria (*SN: 9/26/09, p. 8*). Douglass Turnbull of Newcastle University in England and his colleagues extended that work to humans, using frozen embryos that were not viable because they had been fertilized either by two sperm or by single sperm that did not carry DNA. Such embryos would normally be discarded.

Researchers plucked nuclei from embryos 18 hours after fertilization. At this stage, the DNA is packaged into structures known as pronuclei. The scientists then transferred the pronuclei to embryos from which the nuclear DNA had been removed. Undetectable or very low levels of defective mitochondrial DNA were found in the recipients, raising the possibility that the technique could be used to move nuclear DNA from the embryo of a mother carrying diseased mitochondria into another embryo.

The method is technically difficult, says biologist Shoukhrat Mitalipov of the Oregon National Primate Research Center in Beaverton. But embryos created in fertility treatments are often frozen at precisely the stage the technique uses, so there may be a large pool of potential donor embryos that people with mitochondrial diseases could draw from.

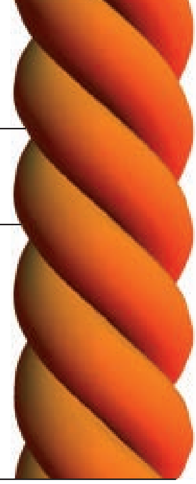
H. PENG

Numbers

For a longer version of this and other Numbers stories, visit **www.sciencenews.org**

Physicists untangle rope's twists

Twine, string, cord or cable, it all winds up the same way



A triple-stranded rope, like the one shown here, reaches a "zero-twist" configuration when its individual strands are rotated to their maximum.

J. BOHR AND K. OLSEN/TECHNICAL UNIV. OF DENMARK

By Alexandra Witze

Researchers have unraveled the math that keeps ropes from unwinding.

The trick lies in the number of times each strand in a rope is twisted, say Jakob Bohr and Kasper Olsen, physicists at the Technical University of Denmark in Lyngby. Their paper was posted online April 6 at arXiv.org.

In a traditional rope, each individual strand is twisted as much as possible in one direction. The twisted strands are then wound together in a spiral shape called a helix, which itself rotates in the opposite direction.

The interlocking of these twists and countertwists gives the rope strength so that when yanked, it does not unwind.

By plotting a rope's length against the number of times each strand is twisted, Bohr and Olsen discovered that there is a maximum number of twists — resulting in what is called the "zero-twist point" for the overall rope. A good rope — one that won't unravel when pulled or pushed — is always in the zero-twist configuration.

A triple-stranded rope in the zero-twist configuration, Bohr and Olsen found, is 68 percent the length of its untwisted component strands. That figure stays the same no matter what material the rope is made of, says Bohr.

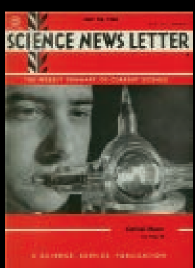
"If you have an old Egyptian rope or one made by modern petrochemical industries, they all look the same," he says. "It is beyond material — it is geometry."

Physicist Henrik Flyvbjerg, also of the Technical University of Denmark, agrees: The rule of the zero-twist point is universal. "If there is life on other planets in other solar systems, their rope makers must follow the same rules," he says.

The work also explains why rope makers need to feed in the strands at a splayed-out angle, Bohr says; the tensile stress in the rope will automatically adjust the newly added portion to the zero-twist configuration.

Celebrating the laser

Half a century ago, science took a step into science fiction when Theodore Maiman demonstrated that a method for making sharp beams of microwave radiation could be adapted to visible light. Those microwaves had been amplified by stimulated emission of the radiation, inspiring the acronym "maser." Maiman showed how to do the same thing with optical radiation — visible light — hence the obvious parallel label of "laser" (although the Science

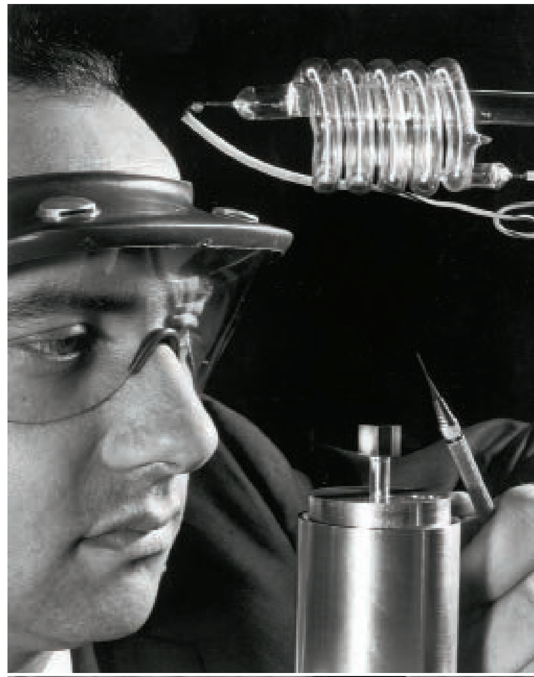


News Letter *cover story from July 23, 1960, referred to the "optical maser"). Eventually laser became the term applied to all similar devices emitting coherent radiation of various wavelengths. From death rays to bar code readers to light-beam scalpels for eye surgery, the laser has engaged the public's attention and inspired popular awe like few other inventions. Its anniversary marks not merely a time to remember its history, but also an occasion to celebrate its many roles in everyday life and scientific research. From probing the inner workings of molecules to detecting gravity waves from deep space, lasers remain today a vital tool in the advance of science. — Tom Siegfried*

In this section

Web edition

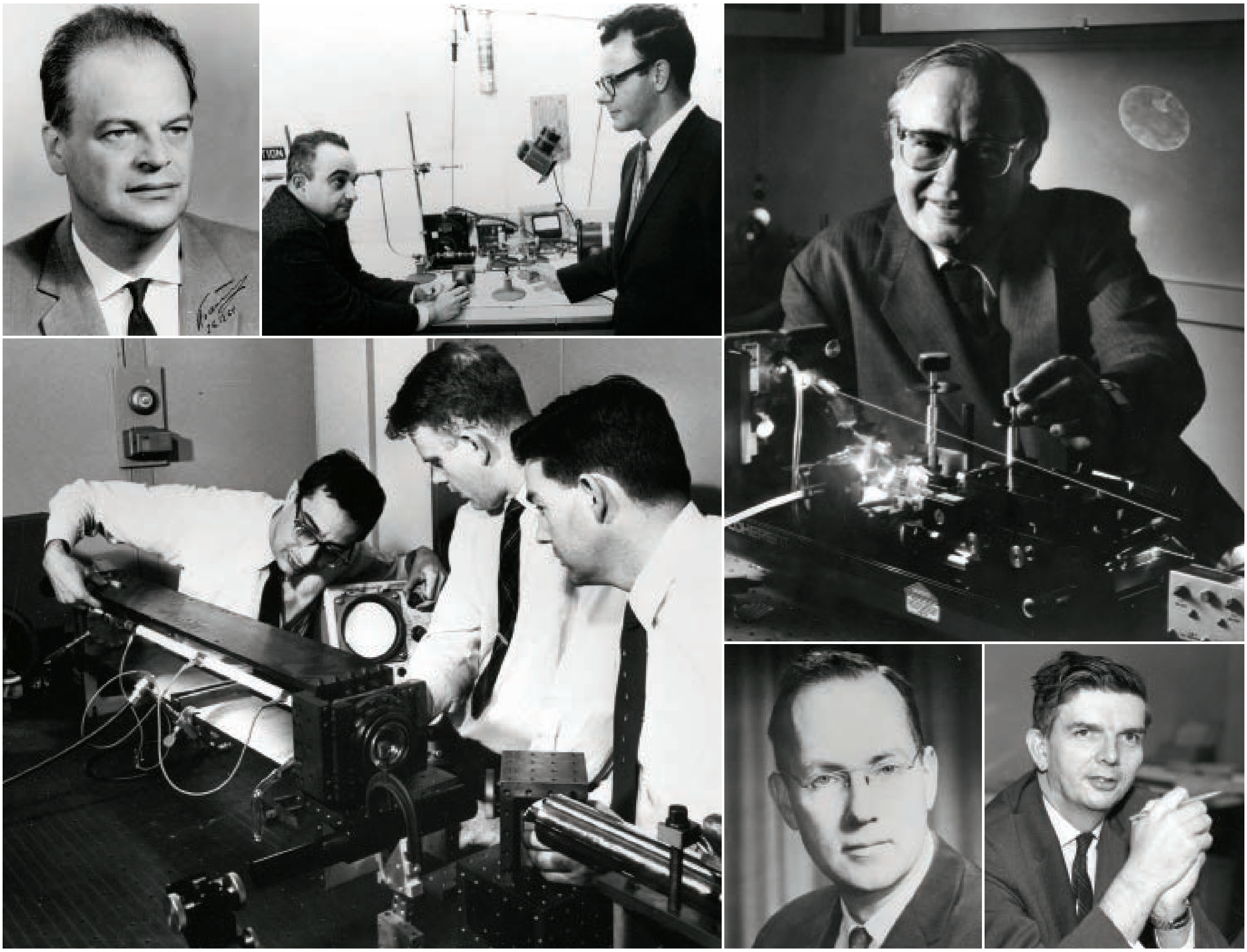
For a slide show of images, links to past *Science News* coverage of lasers and a PDF of the entire special section, visit www.sciencenews.org/laser



Inventing the Light Fantastic

Ideas behind laser born long before device itself

By Ron Cowen



Though Theodore Maiman is widely credited with inventing the laser (he is shown at top left in a publicity photo that exaggerated the size of the device), he was not alone. Others who made major contributions to its development include (clockwise from Maiman) Nikolai Basov, Gordon Gould (right, with Ben Senitzky), Arthur Schawlow, Robert Dicke, Charles Townes, Ali Javan (left, with Bell Labs' William R. Bennett Jr. and Donald Herriott) and Aleksandr Prokhorov.

INTRO: © ROMAN SMITKO/DREAMSTIME.COM; CLOCKWISE FROM TOP LEFT: COURTESY OF HRL LABORATORIES, LLC, MALIBU, CALIF.; AIP EMILIO SEGRE VISUAL ARCHIVES, W. F. MEGGERS GALLERY OF NOBEL LAUREATES; AIP EMILIO SEGRE VISUAL ARCHIVES, HECHT COLLECTION; BELL LABS, AIP EMILIO SEGRE VISUAL ARCHIVES, HECHT COLLECTION; AIP EMILIO SEGRE VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION; MIT, AIP EMILIO SEGRE VISUAL ARCHIVES, W. F. MEGGERS GALLERY OF NOBEL LAUREATES; BELL LABS, AIP EMILIO SEGRE VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION; O. KUZMIN, FOTOKHRONIKA TASS, MOSCOW, USSR, AIP EMILIO SEGRE VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

After nine months of intensive study, physicist Theodore Maiman was hoping for a flash of brilliance.

It was spring 1960, and Maiman had been working with an assistant, Irnee D'Haenens, at the Hughes Research Laboratories in Malibu, Calif., to see if he could generate a new type of light by blasting a tiny pink ruby crystal with radiation from a powerful photographic flash.

Using off-the-shelf parts, Maiman was racing against six other research teams, all vying to be the first to produce an intense, pencil-thin beam of visible-light waves perfectly matched in energy and in the alignment of their peaks and troughs. Other scientists had already proclaimed that pink ruby couldn't generate such radiation. But Maiman was convinced otherwise.

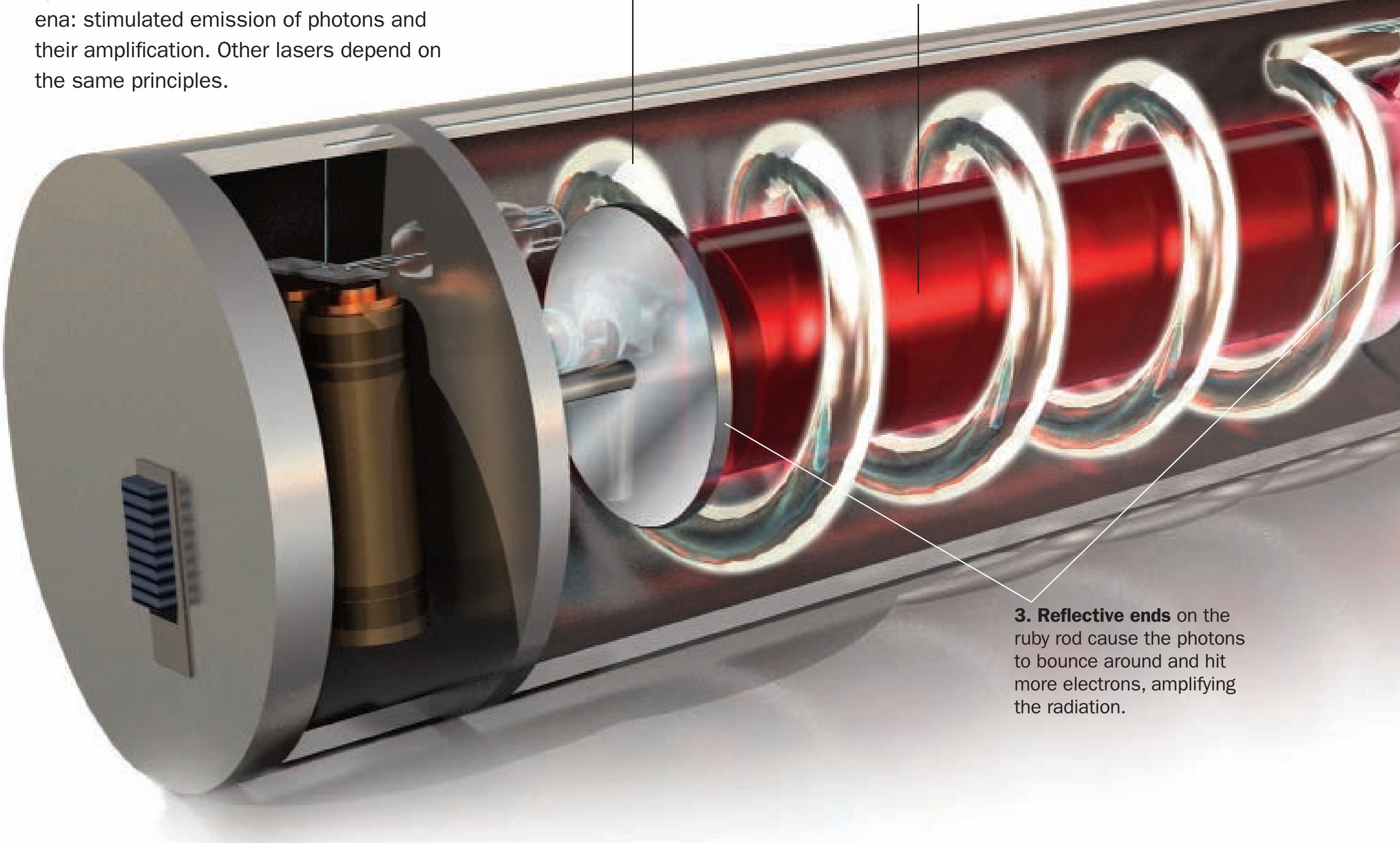
On May 16, 1960, he and D'Haenens watched their oscilloscope as they increased the voltage to a flashlamp coiled around a small ruby rod. A sharp upturn in intensity, followed by a sharp drop, revealed that the ruby was indeed shooting out brilliant, coherent pulses of light.

Exhilarated, Maiman, D'Haenens and several colleagues decided to repeat the experiment and examine the beam as it struck a white cardboard screen. D'Haenens was color-blind and at first couldn't see the color of the crystal's light. But after the voltage to the flashlamp was cranked up, the light pulses from the ruby rod became so intense that everyone else's eyes, with normal sensitivity to red, were too dazzled to register the signal.

Only D'Haenens could see the brilliant,

Making light lase

A modern version of the ruby laser, first built by Theodore Maiman, relies on two phenomena: stimulated emission of photons and their amplification. Other lasers depend on the same principles.



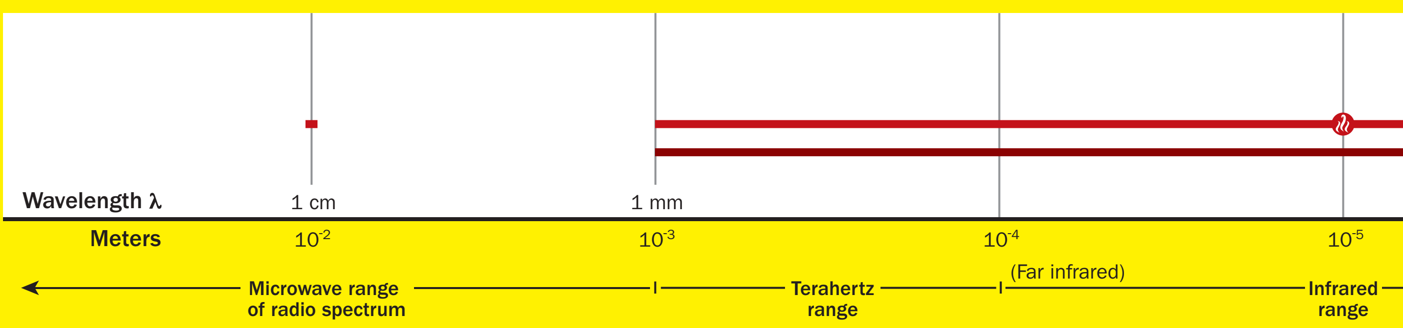
Beyond the ruby laser

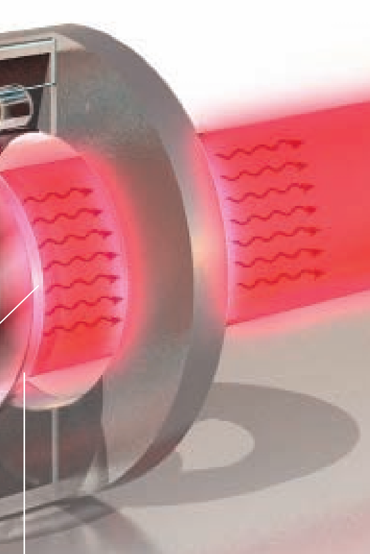
By swapping out the lasing material, scientists can build lasers that emit radiation at different wavelengths. Some examples are shown below.

Solid-state laser: The first ruby laser was an example of a solid-state laser. In this case, the ruby crystal emitted wavelengths of red light at 694 nanometers. Solid-state lasers today are often made from a glass or crystal that is doped with a rare earth element. One such laser, made from neodymium-doped yttrium aluminum garnet crystals, can emit infrared light with a wavelength of 1,064 nanometers.

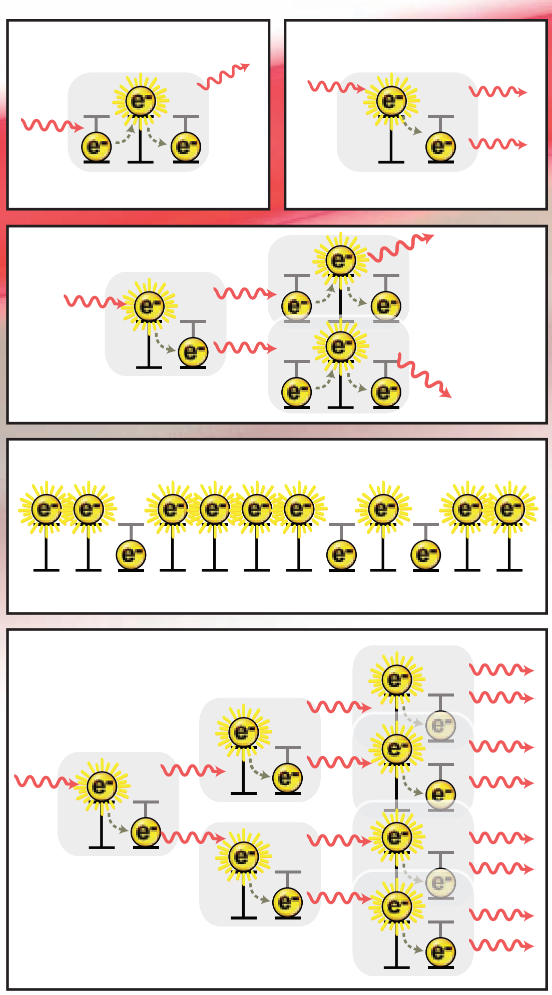
Semiconductor lasers: Small chips of semiconductors take the place of the ruby rod in these lasers. Two outer semiconductor layers are separated by a middle layer, and radiation is generated when oppositely charged particles meet in that middle layer. Often employing gallium arsenide or gallium phosphide as the lasing material, these devices operate in the near-infrared and red light region of the electromagnetic spectrum. Their small size and low power requirements make them ideal for data transmission and for spectroscopy. These lasers are also found in CD players and laser pointers.

Dye laser: Using organic dye, typically in a liquid solution, these lasers generally operate from the ultraviolet to the near-infrared. Rhodamine 6G is a widely used dye because it is one of the most highly fluorescing materials. Though most of the original work on generating short laser pulses relied on these lasers, they are used primarily for spectroscopy today.





4. **An opening** at one end allows radiation to shoot out in the form of a laser beam.



In a process known as spontaneous emission (left), an ordinary electron hit by a photon (arrow) will jump to a higher energy level and then reemit the photon. An already excited electron hit by a photon can produce two photons of identical energy that travel in lockstep, a process called stimulated emission (right).

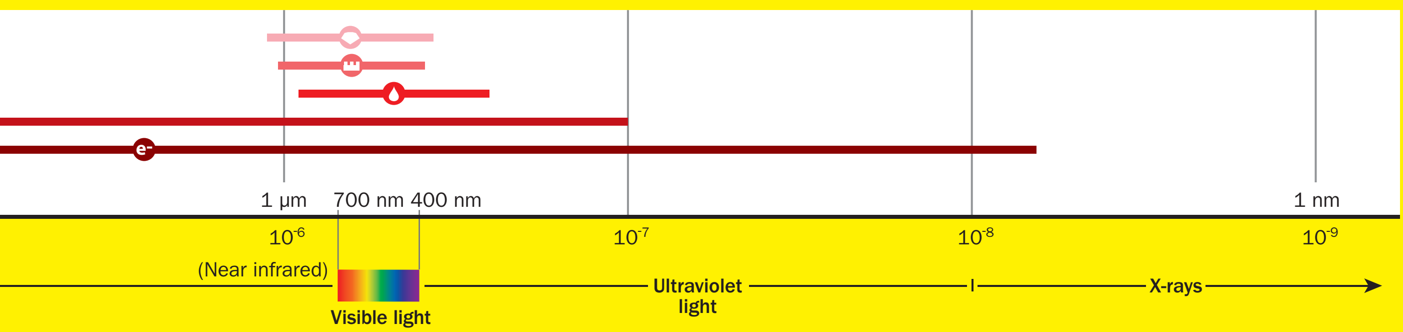
In a typical material, the matched (or coherent) photons will be absorbed by unexcited electrons, since there are more of them, and those electrons will emit wayward photons via spontaneous emission.

In a lasing material, such as the ruby rod, amplifying light requires getting more electrons to occupy the excited state than the unexcited state, a condition known as population inversion.

Once population inversion is achieved, coherent photons bouncing around the cavity will be more likely to hit excited electrons and produce more coherent photons (a process called amplification), creating the laser beam.

Gas laser: Relying on an electric current discharged through gas to produce light, various versions of this laser type can operate in vastly different radiation regimes. Helium-neon lasers, for example, produce red light at 632.8 nanometers — but can also be made to emit green light. The first maser (microwave version of the laser) used ammonia gas to produce radiation at wavelengths around 1.25 centimeters. Carbon dioxide–based lasers generate radiation around 10.6 micrometers, while argon-ion lasers can produce light with wavelengths as short as 351 nanometers. Excimer lasers, which combine an inert gas and a reactive gas as the lasing medium, produce ultraviolet light, typically between 157 and 351 nanometers, and are used for delicate surgeries.

Free-electron laser: Here, the lasing medium is a beam of electrons that has been accelerated to near light-speed. The beam passes through an undulating magnetic field that causes photons to be emitted in a coherent way. Such lasers are the strongest in terms of power and have the widest frequency range; different types can produce radiation that spans the far-infrared, visible light, ultraviolet and X-ray ranges. Wavelengths down to 6.5 nanometers have been achieved. These devices can be used in isotope separation, plasma heating and particle acceleration. Unfortunately, their setup is large and expensive.



ILLUSTRATIONS/ICONS: NICOLLE RAGER FULLER; CHART: T. DUBÉ horseshoe-shaped red glow that indicated the team had created a powerful beam — achieving light amplification, D'Haenens recalled in a 1985 interview for the American Institute of Physics.

It was indeed a new vision. D'Haenens had witnessed the birth of the laser.

Fifty years later, the laser's importance in daily life may be second only to that of the computer. From welding detached retinas to optically transporting telephone calls around the world, from the heart of every CD player to the treatment of life-threatening diseases, the laser has insinuated itself into nearly every technological aspect of modern society.

Microbiologists routinely use low-power lasers as tweezers to gently nudge bacteria, cells and even DNA. Physicians send laser light through flexible cables to kill cancer cells, pulverize kidney stones and destroy other unwanted growths in the human body. On a more cosmic scale, laser light beamed into space enables ground-based telescopes to produce crystal-clear images of the heavens.

Einstein's idea

Like many key 20th century discoveries in the physical sciences, the laser traces back to Albert Einstein. Although he had no conception of a laserlike device in 1916, he had an abiding interest in the interaction between light and matter. In those days, many scientists studying light were concerned with two processes, spontaneous absorption and spontaneous emission.

Spontaneous absorption happens when light of just the right energy shines on atoms. The atoms' outermost electrons absorb the energy (in the form of photons — particles of light), spontaneously jumping to the next higher energy level. In the absence of some external source of energy, however, electrons are like couch potatoes — they will fall back to the lowest possible energy, spitting out a photon in the process. So about as quickly as an electron absorbs a photon, it spontaneously emits it. The sun's visible surface, the filament of a lightbulb and the wick of a burning candle all shine because of spontaneous emission.

But Einstein showed that to be consistent with quantum theory and thermodynamics, another type of emission must also exist — stimulated emission, which laid the groundwork for the laser. If light striking an atom can excite electrons, then it can also force already excited electrons to radiate light and drop back down to a lower energy level, Einstein reasoned.

Imagine a bunch of atoms whose electrons are in an excited state because they have absorbed a photon. Tickle those atoms with a second pulse of light that has exactly the same energy as the original light absorbed by the electrons. That second pulse, Einstein showed, prompts the electrons to emit photons identical to each other in energy and momentum. For each incoming photon that tickles an atom, there are now two outgoing ones.

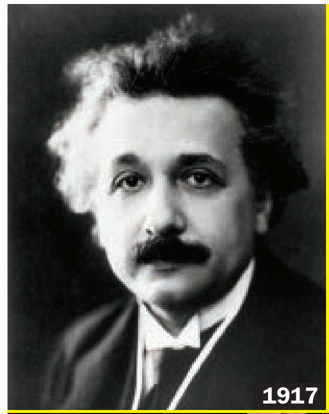
"A splendid light has dawned on me about the absorption and emission of radiation," Einstein wrote to his friend Michele Besso in 1916.

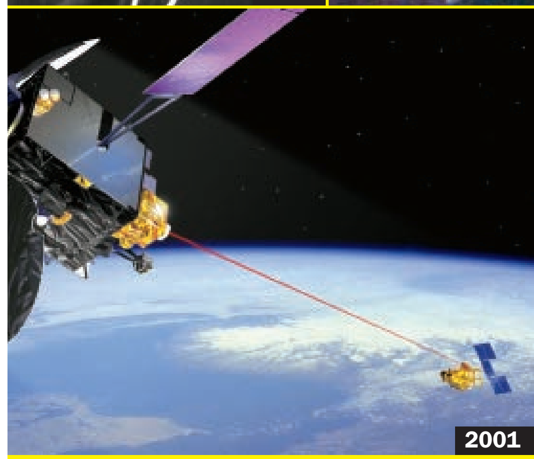
Over the next two decades, several physicists flirted with the idea of using stimulated emission to produce a high-intensity, coherent beam of radiation. Each emitted photon would tickle other still-excited electrons, creating a flood of photons with the same wavelength traveling in the same direction, like a battalion marching in unison. But no one knew how to put that theory into practice.

It wasn't until the 1950s that stimulated emission was harnessed in the development of the maser — the laser's microwave cousin.

Emergence of the maser

Studies of microwave radiation and its interaction with molecules got a big boost from the military. During World War II, physicists developed radar that used ordinary radio waves to detect enemy aircraft. Because radar was pushed to shorter and shorter wavelengths for ease of use, by the time the war ended the military had a surplus of sophisticated microwave equipment that scientists were happy to accept. One of these scientists, a young physicist named Charles Townes, had joined Columbia





The long road to lasers

1917 Albert Einstein publishes work predicting that an electron tickled by a photon could drop to a lower energy level and release additional radiation, later dubbed stimulated emission, the "se" in laser.

1924 Richard Tolman hints that stimulated emission could produce radiation in a way that would reinforce incoming radiation, hinting at the "light amplification of radiation" in laser.

1928 Rudolf Ladenburg and Hans Kopfermann demonstrate stimulated emission.

1951 Charles Townes describes how ammonia gas can emit radio waves, laying the theoretical groundwork for the maser (the microwave version of the laser).

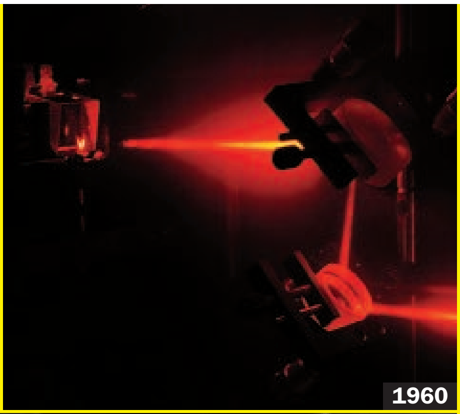
1954 A working maser is demonstrated by Townes and colleagues and independently by Nikolai Basov and Aleksandr Prokhorov.

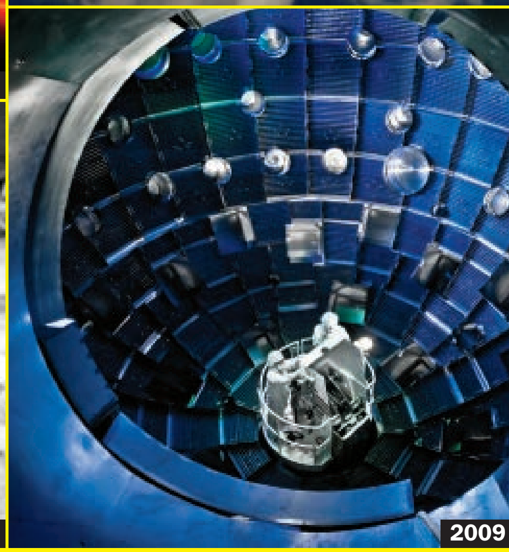
1956 Robert Dicke files a patent that claims to describe how to build an infrared laser, but the patent gets little publicity.

1958 Townes and Arthur Schawlow publish a paper describing the principles of the optical maser (now called the laser).

1959 Gordon Gould, who coined the term "laser"a year before, files a patent application.

1960 Theodore Maiman develops the first working laser, the ruby laser, at Hughes Research Laboratories.





1960 Ali Javan demonstrates a continuously operating helium-neon gas laser. (A similar beam between a prism and two mirrors is shown above.)

1961 Columbia-Presbyterian Hospital uses a ruby laser on a person for the first time, destroying a retinal tumor.

1963 Zhores Alferov and Herbert Kroemer independently propose semiconductor lasers, later used in fiber optics, CD players and laser pointers.

1964 Townes, Basov and Prokhorov (shown) receive the Nobel Prize for work that led to the maser and the laser.

1965 James Russell invents the CD, though it doesn't become popular until it is mass manufactured in the 1980s.

1966 Charles Kao and George Hockham show that glass fibers can efficiently transmit laser signals if the glass is pure.

1970 Corning Glass Works makes a low-loss optical fiber.

1970 Arthur Ashkin describes the manipulation of microparticles with laser light, laying the groundwork for optical tweezing.

1971 Xerox develops the first laser printer.

1974 A Wrigley's 10-pack of gum is the first item purchased via a UPC bar code scanned by a laser.

1976 John Madey and Stanford colleagues demonstrate the free-electron laser, which passes near–light-speed electrons through magnetic fields to produce a photon stream.

1977 General Telephone and Electronics sends the first live telephone traffic through fiber optics in Long Beach, Calif.

1981 Schawlow and Nicolaas Bloembergen share half the Nobel for contributions to the development of laser spectroscopy.

1982 The first music CD is manufactured, "The Visitors" by ABBA (cover shown).

1983 President Ronald Reagan calls for a laser-based defense system in his "Star Wars" speech.

1985 Steven Chu leads the first work that cools and traps atoms with laser light.

1987 Laser is first used in corrective eye surgery.

1988 First transatlantic fiber-optic cable is put down.

1995 The Kuiper Airborne Observatory detects the first natural laser in space. (KAO, a converted military cargo plane with a reflecting telescope, is shown.)

1996 Lawrence Livermore National Laboratory produces a laser with a peak power of more than a petawatt, exceeding the entire electricity-generating capacity of the United States.

1997 Researchers at MIT create the first atom laser. The device produces a coherent beam of atoms.

1997 Chu, Claude Cohen-Tannoudji and William Phillips share the Nobel for methods to cool and trap atoms with laser light.

2000 Alferov and Kroemer share half the Nobel Prize for their contributions to high-speed- and opto-electronics.

2000 John L. Hall and Theodor Hänsch develop the optical frequency comb technique, in which ultrashort pulses of light create frequency peaks that can serve as a ruler.

2001 A long-distance laser communication link is established for the first time between Earth-orbiting satellites (illustration shown).

2004 First laser-powered computer mouse is introduced.

2005 Hall and Hänsch share half the Nobel for contributions to spectroscopy.

2009 Kao shares the Nobel Prize for advances in optical communication.

2009 The National Ignition Facility produces a laser shot with an energy of more than one million joules (target chamber shown).

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University and had become fascinated with how molecules absorb and emit energy. At that time the military, mindful of the many scientific payoffs during the war, was pouring money into physics research with relatively few strings attached. "Military funding wasn't so targeted as it is now," Townes recalls.

Townes had become obsessed with the study of short-wavelength microwaves known as millimeter waves because they interacted more strongly with atoms and molecules than longer wavelengths did. He was convinced that such radiation, if it could be generated at high intensities, would lead to better probes of atomic and molecular structure. But no one knew how to produce a stable, intense source of the millimeter waves. And pressure was mounting because Townes had been appointed chair of a Navy committee on millimeter-wave research and had no advances to report.

A breakthrough came on April 26, 1951. The Navy committee had convened in Washington, D.C., and Townes, a father of young children, was used to waking early. Careful not to disturb his roommate at the Franklin Park Hotel, collaborator and future brother-in-law Arthur Schawlow, Townes crept out of the room and sat on a bench in an adjoining park. Red and white azaleas were in full bloom, Townes recalls, but his full attention was on the millimeter-wave puzzle.

As he was familiar with Einstein's theory of radiation, Townes knew that a source of photons — including microwaves — could stimulate atoms or molecules to emit light at exactly the same frequency, thereby boosting the intensity of the outgoing signal. But there was a major stumbling block. He needed to find a way to keep more electrons at higher energy levels than at lower ones.

A group of atoms in thermal equilibrium (having reached the same temperature as its surroundings) tends to have more atoms with unexcited electrons than excited ones. So any temporary boost in the signal from stimulated emission would soon be soaked up by electrons at the lowest energy levels. Instead of a net gain in a microwave signal, there would be a net loss.

"I cannot reassemble exactly the sequence of thought that pushed me past that conundrum, but the key revelation came in a rush," Townes wrote in his 1999 memoir. "The second law of thermodynamics assumes thermal equilibrium; but that doesn't really have to apply! There is a way to twist nature a bit."

If a device could be built to keep a collection of atoms or molecules out of equilibrium — with more of them in the higher energy state than the lower one — then Einstein's stimulated emission could lead to a true amplification of an incoming signal.

Townes' idea was too undeveloped to talk about at the Navy committee meeting. But soon after returning to Columbia, he pursued the notion at full tilt. He focused his efforts on molecules of ammonia gas made with deuterium, a heavy isotope of hydrogen.

Townes' strategy was twofold. First, using a changing electric field, he would separate ammonia molecules in the higher energy state from those in the lower energy state. Then he would trap the higher-energy molecules in a cavity designed to keep the microwave radiation they emitted bouncing back and forth through the gas. That radiation would stimulate even more electrons to emit microwaves and generate a larger and larger amplification of the original microwave signal.

Townes recruited two young researchers at Columbia, Herb Zeiger and Jim Gordon, to develop the device. The work took three years, and not everyone in Columbia's physics department was patient. One day in 1953, one of the university's physics Nobel laureates, I.I. Rabi, and department chair Polykarp Kusch (who became a Nobel winner two years later) paid Townes a visit. They told him to stop wasting his time.

Townes listened, but ignored the advice of the two heavyweights. "Luckily, I had tenure," he says.

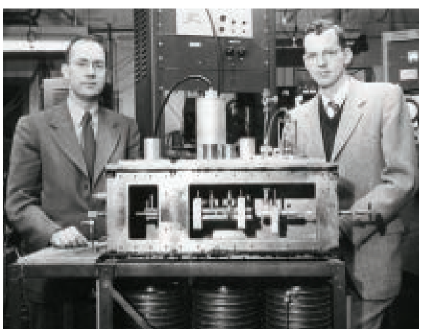
Besides, he and his students had reason to be optimistic: Almost immediately, they had gotten indications of stimulated emission. And in early April 1954, Gordon burst into a seminar that Townes was holding to announce that amplification had been achieved. Gordon and Townes had developed the first device demonstrating "microwave amplification by stimulated emission of radiation" — the maser (*SNL: 2/5/55, p. 83*).

Unbeknownst to Townes, several other researchers had begun contemplating similar ideas about a maser. At the University of Maryland in College Park, Joe Weber had published a short paper proposing to use stimulated emission as an amplifier of radiation. And in 1954, Aleksandr Prokhorov and Nikolai Basov of the Lebedev Physical Institute in Moscow wrote an article about using a beam of alkali halide molecules to generate a microwave oscillator.

Steps to the laser

While most other researchers marveled at the concentrated beam produced by the maser and worked to refine its design, Townes leapfrogged to much shorter wavelengths — the infrared and visible-light portions of the electromagnetic spectrum.

"I wanted to develop an infrared [version of the maser] because I saw there were new ways to probe atoms and molecules at infrared wavelengths," Townes says. "When I sat down and tried to understand how we could get down to these wavelengths, writing down the equations and examining my notes," he says, "I realized, 'Hey, it looks like we can go right down to even shorter wavelengths — light waves.' "



Charles Townes, left, and Jim Gordon stand with a version of their ammonia-beam maser. The device's side has been removed to reveal the inner structure.

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Because of the shorter wavelengths, an optical version of the maser posed new design challenges. Some physicists even claimed, based on their understanding of quantum theory, that it could never be done.

But, as Townes pointed out, scientists were familiar with the interaction of light and atoms at infrared and visible-light wavelengths.

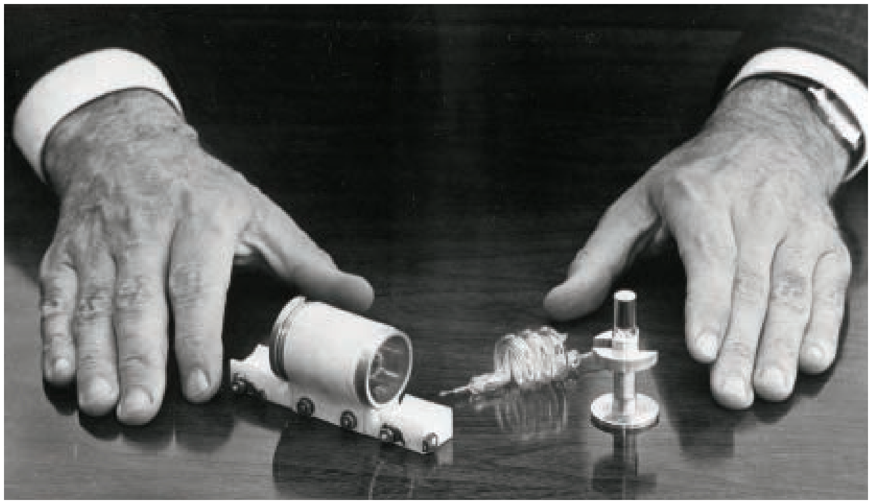
With Gordon Gould of Columbia, Townes discussed an experimental arrangement for a visible-light version of the maser. Instead of the maser's microwave cavity, a system of reflecting mirrors would pass a source of light back and forth through a carefully chosen material to stimulate excited atoms and amplify the radiation.

Gould realized that such a design, for which he coined the term *laser* (for light amplification by the stimulated emission of radiation), could create sharply focused beams of high intensity that would carry much more energy than the beam produced by a maser. Keenly aware of potential applications, Gould had his notes, which date from 1957, notarized at a local candy store. Later those notes would be part of a 30-year patent war, in which Gould would finally get recognition for his ideas.

In the meantime, Townes and his colleague Schawlow, who had moved to Bell Laboratories in Murray Hill, N.J., detailed their own concept and design in a landmark 1958 paper titled "Infrared and Optical Masers" (*SNL: 2/7/59, p. 83*).

After reading the paper, several teams joined Townes and Schawlow in the race to be the first to construct the device. Each group attempted to use a different material, or source of atoms, to amplify visible light. "You rarely get a case like this, when there's sort of a starting gun and everyone tears off at the same time," notes physical sciences historian Spencer Weart, who is affiliated with the American Institute of Physics.

At Bell Labs, Schawlow investigated a solid material as the lasing medium, while colleagues Ali Javan, William R. Bennett Jr. and Donald Herriott were examining neon gas. Gould, who had left Columbia to join a private research company, TRG, had submitted a proposal to the military to use a metal vapor in a laser.



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The first laser, consisting of a flashlamp, a ruby rod and a cavity to confine the light, was smaller than the version depicted in a 1960 publicity photo (see Page 18).

In September 1959, at a quantum electronics conference in New York's Catskill Mountains, it was clear that other teams had joined the competition, including Maiman and the Soviet researchers Basov and Prokhorov. At that conference Schawlow reported his analysis that pink ruby would not make a good lasing medium for visible light.

Schawlow's claim was one reason that Maiman's success in May 1960 surprised so many (*SNL: 6/23/60, p. 53*). Some scientists, many of whom had barely heard of Maiman, at first refused to believe the California-based researcher had scooped everyone on the East Coast, who had garnered most of the money and equipment for building a laser.

"It's like some horse coming up from the outside in the home stretch," Weart says. "They didn't even know he was in the race."

From the beginning, Maiman had adopted a strategy different from his competitors, aiming to develop a pulsed laser rather than a device that would emit a steady beam of amplified light, which allowed him to use more basic equipment. His device was small and deceptively simple-looking: a rod-shaped ruby, its ends silvered to reflect light, sitting inside a coiled flashlamp.

When the lamp flashed at the right energy, its photons stimulated chromium ions in the ruby to emit identical visible-light photons. Those photons, reflected back into the ruby, in turn stimulated the production of even more identical photons, until a luminous stream of clones never before achieved in the laboratory burst through a half-silvered mirror at one end of the device.

The physicists knew the laser was much more than a visible-light analog to the maser. It could probe and manipulate much tinier subatomic structures than the microwave device ever could (*SNL: 1/20/62, p. 42*).

Winner and losers

Maiman had extraordinarily bad luck publishing his findings. Although he quickly submitted an article to *Physical Review Letters*, it was just as quickly rejected by editor Samuel Goudsmit, a well-known theoretical physicist, who mistakenly believed that Maiman's device was merely an unimportant variant of the maser. A scant, four-paragraph description of Maiman's work did appear in *Nature* in August 1960.

That July the Hughes Corp. publicized Maiman's invention with a press conference in New York City, but the public relations photographer didn't think Maiman's laser looked substan-

Lasers, lasers everywhere

Once called a "solution looking for a problem," lasers have now infiltrated many areas of life.

1 Communications: Laser diodes send pulses of light through bundles of fiber-optic cables (shown). Lighter, stronger, faster and more efficient than electrical cables, fiber optics transmit telephone, Internet and cable TV data worldwide. Lasers have also been used for communication between satellites in space. Back on Earth, lasers write and read digital information on CDs and DVDs.

2 Security: Just like in spy movies, crisscrossing laser beams can blow the whistle on intruders—though in real life, the beams are invisible. Lasers can also verify the authenticity of documents such as ID cards and passports and can make communication more secure by encoding eavesdropping-resistant messages in single photons.

3 Entertainment: Lasers have been used for special effects in movies, to impress crowds at concerts and as their own main event at laser light shows. Laser tag gaming locations have also popped up across the country.

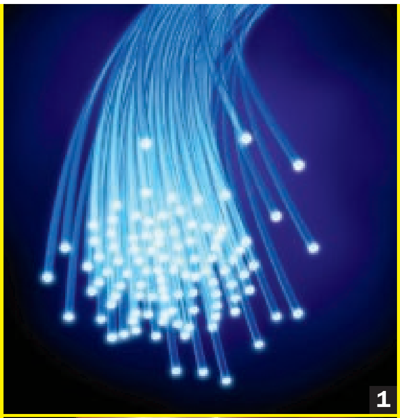
4 Military: Lasers are used in range finders and to indicate targets for guided bombs. Lasers can confuse heat-seeking weapons and have been developed to destroy ballistic missiles (U.S. Air Force airborne laser shown shooting down one such missile).

5 Medicine: Lasers can correct vision by remolding eyeballs, make surgical incisions, cauterize wounds, treat cancer (shown) and take clear images of the body's insides. With dropping costs, lasers are becoming as common in hospitals as blue scrubs.

6 Measurement: By bouncing laser light off distant objects and timing how long the light takes to return, LIDAR (for Light Detection and Ranging) can measure distances with great precision (lower Manhattan shown in September 2001). The technique has mapped ice flows, monitored erosion on beaches, measured chemicals in the atmosphere and caught speeding cars. It has also detected snow in the atmosphere of Mars.

7 Industry and commerce: Thanks to their high-power, tightly focused beams, lasers can cleanly cut everything from paper to fabric to metal (shown)—and weld the pieces together. Lasers are also used to mark such pieces with ID numbers. After final products make it to the store, bar codes, read with lasers, tag items to keep track of inventory and make checkout a breeze.

8 Basic discovery: Lasers have also led to new tools for basic research. Lasers can help take sharp pictures of space by canceling out atmospheric smearing (lasers from the Starfire Optical Range in New Mexico are shown), can hold and manipulate microscopic objects (including living bacteria) and can cool atoms to nearly absolute zero.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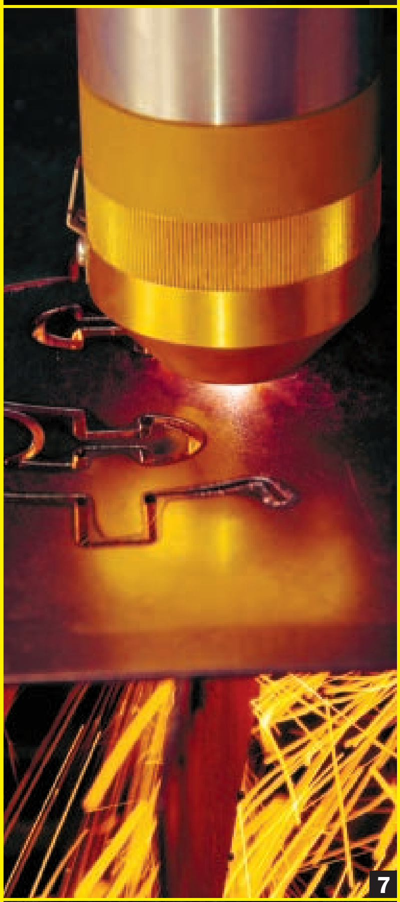
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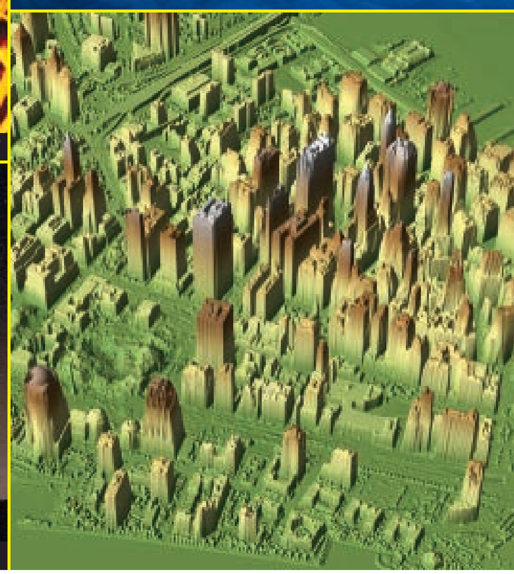


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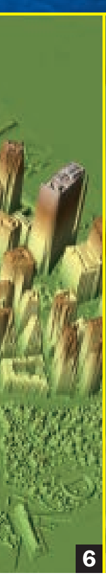
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tial enough. He convinced Maiman to pose with a bigger flashlamp and ruby rod than he had actually used. Without a published paper to analyze, many researchers relied on that misleading publicity photo, still being distributed today, to replicate Maiman's discovery.

By late summer, Bell Labs researchers did manage to build their own ruby laser. Once again, public relations folks got into the act, convincing the scientists to haul their apparatus, which was considerably larger than Maiman's, up to an old radar tower at Bell's main headquarters in Murray Hill and beam laser pulses to another Bell tower in Crawford Hill, N.J., some 40 kilometers away (*SNL: 10/15/60, p. 245*). That publicity stunt garnered some press, and many reporters didn't seem to realize that the Bell device wasn't the first laser.

It probably didn't help matters that the Bell research paper on the ruby laser, which Goudsmit did agree to publish in *Physical Review Letters*, didn't give Maiman credit for building the first laser.

In December 1960, another team of Bell scientists, including Javan, Bennett and Herriott, did achieve a new milestone, succeeding in making the first gas-based laser (which generated a steady, rather than pulsed beam), using helium and neon as the lasing material. Over the years, more sophisticated versions of steady-beam lasers would transform electronic communications and a host of other technologies.

In the end, the first physics Nobel prize for the laser went to Townes, Basov and Prokhorov in 1964 for their theoretical and experimental work in developing the device (*SNL: 11/7/64, p. 295*). Schawlow shared the 1981 physics Nobel for his contributions to laser spectroscopy (*SN: 10/24/81, p. 261*).

In all, the Nobel Prize has been awarded to more than a dozen researchers for laser-related studies. Maiman never did receive a Nobel, although he was inducted into the National Inventors Hall of Fame and won several international awards. Gould, too, was passed over for a Nobel, but his court battle eventually won him millions in patent fees.

"I think probably everyone but Townes thinks they didn't quite get their fair share" of credit, Weart says. "It's like an inheritance; everybody thinks they ought to have gotten a little larger share, but there's only 100 percent to go around."

Looking back, it's obvious that the whole world benefited from the laser — though not quite as the public first imagined it.

Some of the reporters who covered the unveiling of Maiman's invention at the July 1960 press briefing hyped the laser as a death ray. As lasers became more powerful, researchers would jokingly refer to them as "one-Gillette" or "eight-Gillette" devices, depending on how many razor blades a beam could pierce. And in 1964, the James Bond blockbuster film *Goldfinger* featured a laser that sliced through a metal table and threatened to slice through Bond as well.

Regardless of the potential for destruction that garnered initial publicity, the laser has made major inroads in the fields of medicine, communications and industry. And biologists and physicists continue to use lasers in the pursuit of basic science.

Given Einstein's role in developing the theoretical underpinnings of the laser, it may be only fitting that one of its applications is ultraprecise lunar laser ranging to test another of Einstein's theories — general relativity. If gravity is weaker than he calculated, it may show up as variations in the Earth-moon distance.

In saluting Einstein and the laser's other scientific fathers on its 50th birthday, says historian Weart, it's perhaps also appropriate to acknowledge another important player — light itself.

"We should give credit to light for being such an amazing phenomenon," he says. It's the nature of photons "that allows lasers to use these wavelengths in such wonderful ways." ■

Explore more

- For information on a yearlong laser celebration, visit www.laserfest.org
- C.H. Townes. *How the laser happened*. Oxford University Press, 1999.

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Lasing Beyond Light

Physicists focus on whole new types of waves

By Lisa Grossman

Lasers and light seem as inseparable as snow and cold: If you have one, you have to have the other. From presentation pointers to Darth Vader's lightsaber, lasers have become synonymous with brightly colored beams of visible light.

But it wasn't always that way.

Lasers began as a special variety of the maser — short for microwave amplification by stimulated emission of radiation — that swapped "light" for "microwave." Soon after the invention of these devices, scientists proposed other "-asers" for waves across the electromagnetic spectrum, like "uvasers" for ultraviolet light or "grasers" for gamma rays. These acronyms never caught on. But laser became a household name.

And now, at age 50, the laser has extended its dominion far beyond the realm of light. Physicists have succeeded in building lasers that emit different kinds of waves. Laserlike "hard" X-ray pulses, for example, can freeze atoms in their tracks, providing a ringside view of chemical reactions. And phonon lasers vault the technology out of the electromagnetic spectrum altogether, creating coherent beams of sound.

Light-based lasers themselves play prominent roles in the exploration of other wave types. Laser-induced plasma ripples can accelerate particles to breakneck speeds in the space of a meter. And a proposed space telescope will use lasers to look for subtle shudders in spacetime invisible to conventional telescopes.

Everywhere they go, lasers show that they're about more than just light.

Superfast strobes

A torrent of proposals for other-wavelength devices followed the first laser flash. But it took a while for some of those ideas to mature. Lasers that emit the shortest type of X-rays, for instance, have been built only in the past few years.

These hard X-rays, electromagnetic waves with energies up to 10,000 times that of visible light, have proved their mettle as powerhouses of diagnostic medical imaging. Because they have wavelengths close to the width of an atom, these rays have the potential to capture the motions behind basic chemistry.

"If you want to look at small things, the nanoworld, what do you need?" asks Keith Hodgson of the SLAC National Accelerator Laboratory in Menlo Park, Calif. "You need a wavelength that is roughly the same as the objects you want to study," he answered in a talk in San Diego in February at the annual meeting of the American Association for the Advancement of Science. "If you want to study atoms, and the distances between atoms, that means hard X-rays."

But there's a problem: Old-school X-ray sources take blurry pictures because the radiation produced is not uniform. These sources are "more like a flashlight than a laser," said physicist Margaret Murnane of the University of Colorado at Boulder in another talk at the AAAS meeting.

JIANGANG ZHU, LAN YANG

An array of phonon lasers, which use pairs of drumhead-like devices (shown) to produce and amplify vibrations, could steer coherent sound waves.

By generating X-rays that march in lockstep, as the light waves in a laser do, scientists should be able to get rid of that blur. Pulses of such X-rays could serve as a strobe light to take snapshots of atoms and molecules in motion.

Scientists got just such a strobe last year in the form of SLAC's Linac Coherent Light Source, which revved up on April 10, 2009. The light source uses the last third of SLAC's 2-mile-long accelerator to speed up electrons and then send them wiggling through a toothlike series of undulating magnets. As the electrons pass through, they toss off exceptionally bright X-rays. Although those X-rays are still spread out, they create electromagnetic fields that force the electrons into small, compact bunches. Those bunches emit bursts of bright, unified X-rays.

With beats less than 100 femtoseconds (a tenth of a trillionth of a second) apart, this strobe can expose proteins unfolding and bonds breaking — chemistry in action at the atomic scale.

"We really have the ability to capture any motion, electron or atom, that is relevant to our natural world," Murnane said.

A joyful noise

Like the hard X-ray laser, the phonon laser — which doesn't produce electromagnetic waves at all — was a long time coming. In April 1961, Charles Kittel of the University of California, Berkeley proposed lasers that shoot phonons, quantized "particles" of sound. An optical laser builds a beam of light by making electrons release identical photons through a process called stimulated emission; a phonon laser would build a beam of sound by driving a drum to release identical vibrations.

Since phonons and photons are both a type of particle called a boson, the translation from light to sound should be easy, Kittel argued. One of the defining qualities of bosons is that several with the same quantum properties can pile together at the same energy. The coherent beam of light streaming out of a laser is a physical manifestation of bosons being bosons.

It turns out that making a pileup happen with phonons in the lab wasn't so easy, and Kittel's dream wasn't realized until 2008. The breakthrough came when a group at the Max Planck Institute for Quantum Optics in Garching, Germany, produced a laserlike stream of coherent phonons from a vibrating magnesium atom trapped in a laser field. A paper on the results appeared in *Nature Physics* in August 2009 with a simple title, "A phonon laser."

A phonon laser would build a beam of sound by driving a drum to release identical vibrations.

"That was a big spur for me," says Caltech physicist Kerry Vahala, who was visiting the Max Planck Institute when the device was built. Within a year of returning to California, he had built his own version of a phonon laser.

Though the German group's laser resembled a type that uses atomic vibrations to produce photons, Vahala says his team's is "nearly identical to the way the first optical lasers were realized."

Vahala's setup includes two glass drumheads, called whispering-gallery–mode resonators, about 63 micrometers in diameter. When a traditional light-based laser shines on the drumheads, they hum at a tunable frequency, an effect Vahala exploited to create the phonon laser.

The resonators are named for whispering galleries, the spaces under domes where words softly spoken at one wall can be heard clearly at another, such as the one in St. Paul's Cathedral in London. Just as a domed ceiling guides sound waves around a room with almost no loss of volume, the whispering-gallery–mode resonators guide the laser light in a circle without losing any brightness.

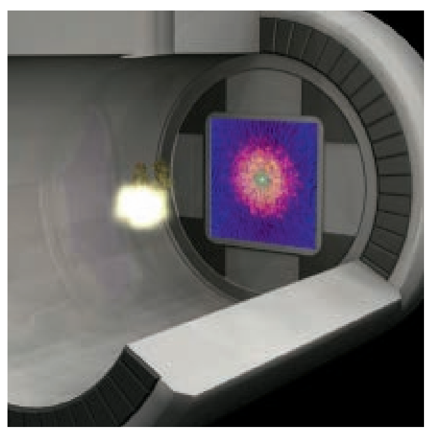
When there are two resonators, the circles touch to form a figure eight. As the light glides around, it exerts a force on the resonators, making them vibrate to produce phonons. That emission, Vahala says, is analogous to a flashbulb making electrons eject photons in a traditional laser. He and his colleagues sent more and more laser light whizzing around the resonators to make more phonons of the right frequency, amplifying the signal to create a coherent beam of sound.

Vahala's phonon laser, reported in *Physical Review Letters* in February, produces sound waves with a frequency of just over 20 to 400 megahertz — too high for humans to hear, but not high enough for medical imaging, etching or other proposed applications. "In terms of where phonon lasers can go," he says, "it's just the beginning."

Catch a wave

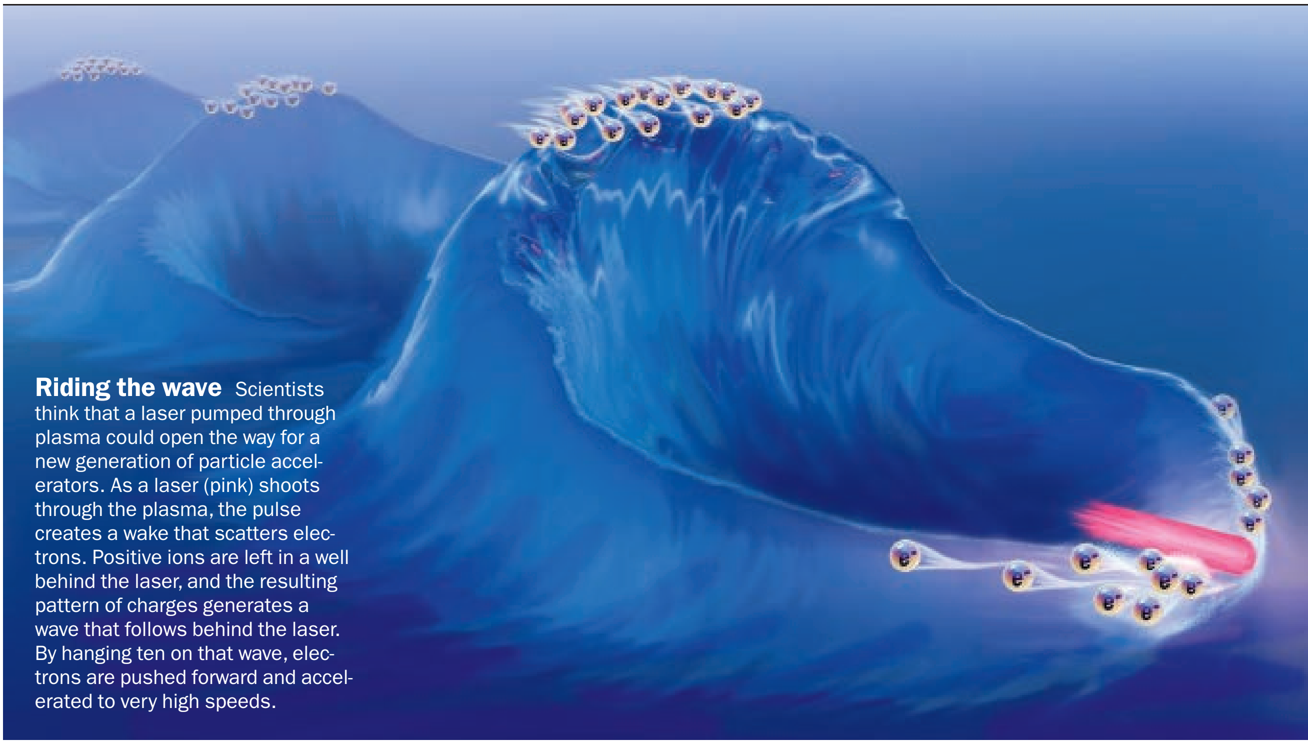
Light-based lasers aren't helping just to make sound waves. The devices can produce another type of wave that may usher in the next generation of accelerators: plasma waves.

Particle physicists, driven to decipher the fundamental nature of matter, have built bigger and bigger accelerators to smash particles together at higher and higher energies. These efforts have culminated in the Large Hadron Collider, a subterranean monster straddling the border between Switzerland and France. But some worry that the LHC may be pushing the limit on what resources and real estate can support.



X-ray pulses from SLAC's Linac Coherent Light Source could be used to take holographic images (purple square in this artist's illustration) of single molecules.

COURTESY OF SLAC NATIONAL ACCELERATOR LABORATORY



Riding the wave Scientists think that a laser pumped through plasma could open the way for a new generation of particle accelerators. As a laser (pink) shoots through the plasma, the pulse creates a wake that scatters electrons. Positive ions are left in a well behind the laser, and the resulting pattern of charges generates a wave that follows behind the laser. By hanging ten on that wave, electrons are pushed forward and accelerated to very high speeds.

"Accelerators have made the incredible transition from something that's handheld to something that's the size of a small European country," Wim Leemans of Lawrence Berkeley National Laboratory in California said in a talk at the AAAS meeting. "What do we do for an encore?" To explore new realms, accelerators have to reach ever higher energies. "How do we build this thing?" Leemans asked.

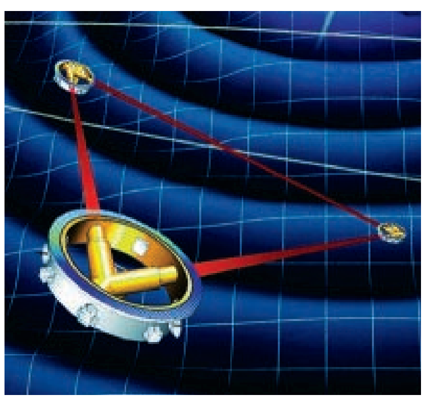
A new idea that could both shrink accelerator size and boost energy relies on lasers. Shining a laser into plasma, a gaslike state of matter where electrons float freely away from their atoms, could make a wave for electrons to surf.

Although no one has built such an accelerator yet, plasmas have been made many times in the lab and the laser-plasma acceleration concept has been making waves in the physics community. In October in Washington, D.C., at the Accelerators for America's Future symposium, six accelerator physicists were asked what they would do if they had $10 million a year for the next 10 years to devote to basic research and development. Four of them mentioned laser-driven acceleration.

Here's how it works: A pulse of laser light crashes through the plasma, pushing free-floating electrons out of the way, like the prow of a boat scattering seagulls. Positive ions are left behind and electrons congregate in a negatively charged clump behind the laser pulse. The resulting pattern of charges forms a plasma wave, which contains a strong electric field.

"What's special about the electric field is it's just like the wake behind the motorboat — it's following the laser pulse," Leemans said. "As this laser pulse barrels through the plasma, behind it is this nice accelerating structure."

Like surfers catching a wave at just the right moment, electrons can hang ten, riding down the plasma wave and picking up energy as they go. In this way, the particles can reach energies similar to those attained in conventional accelerators in a fraction of the distance.



LISA (shown in this illustration) will consist of three spacecraft that use lasers to look for gravitational waves.

A cascade of advances in laser-plasma accelerators has come in the past decade. Leemans' group holds the record for the most energy in the least distance. In 2006, with the help of Simon Hooker of the University of Oxford in England, the team pushed electrons to a billion electron volts in just 3.3 centimeters — a fiftieth the energy of SLAC's linear accelerator in a hundred-thousandth the distance.

And theoretically, there's no limit on how energetic the accelerators can get. Right now Leemans' team is shooting for 10 billion electron volts — more than a thousandth the maximum energy of a proton beam at the LHC — in less than a meter. The researchers are also looking at chaining several plasma wave accelerators together to combine their energies. Instead of spanning two countries, a future collider could fit in a backyard.

A wrinkle in spacetime

Just as laser-driven plasma waves can carry particle physics to new territories, lasers can propel astrophysics out of

FROM TOP: NICOLLE RAGER FULLER; EUROPEAN SPACE AGENCY the electromagnetic spectrum to catch a new kind of wave.

Telescopes, like lasers, are best known for their close relationship with light. By observing all kinds of electromagnetic waves, detectors can discover the structure of galaxies and the birthplaces of stars. But scientists are building a new kind of telescope. LISA, launching in 2020 at the earliest, will listen for a different vibration. And its "L" stands for laser.

Short for Laser Interferometer Space Antenna, LISA will look for gravitational waves, ripples in spacetime that Einstein predicted but haven't yet been found. These waves would be shaken up when a massive body accelerates, and they would have a major advantage over light: "They don't scatter and are not absorbed as they traverse spacetime," says Stanford physicist Robert Byer. "They give you a really close look at objects that radiate them," objects like waltzing pairs of superdense stars and merging black holes.

LISA will consist of three spacecraft arranged in a triangle, 5 million kilometers on each side, that will cartwheel around the sun just behind Earth. Inside each spacecraft will be a 2-kilogram cube of gold-platinum alloy. The spacecraft are carefully designed to shield the cubes from all external influences except ripples in spacetime.

Here's where the lasers come in. To tell if the cubes have been nudged, each spacecraft aims an infrared laser at each other spacecraft. The laser beams reflect off the test cubes and a signature returns to the original spacecraft, which counts wavelengths to see if the cubes have stayed put. Any movement, however slight, could be a sign of gravitational waves.

And the movement would be slight indeed. "If you think of space as like a fabric, or a rubber sheet, what happens when a gravitational wave goes by is it stretches it in one direction," says physicist Jeffrey Livas of NASA's Goddard Space Flight Center in Greenbelt, Md., pulling a rubber sheet to demonstrate. "This doesn't stretch very much."

"Neither does space," adds his Goddard colleague James Ira Thorpe. For the cosmic bodies LISA is tuned to, the lasers will have to detect movements of about a picometer — one trillionth of a meter — from their 5-million-kilometer journeys between spacecraft. That's like trying to measure the radius of a helium atom that's as far away as the sun.

In its first months after launch, LISA will observe a few known systems that are expected to make gravitational waves. This detection alone would be cause for celebration, proving that gravitational waves are real and allowing physicists to study them in detail.

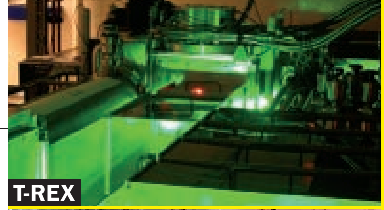
But the unexpected sources will be the exciting part — just as the unimagined applications of the laser, once famously called "a solution looking for a problem," are the ones that revolutionized society.

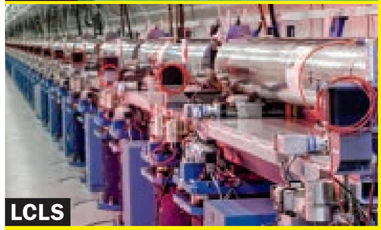
"It's the stuff you don't know that's out there that makes it an interesting experiment," Thorpe says.

The same goes for X-ray lasers, phonon lasers and plasma acceleration. Scientists have their wish list of applications, but even more transformative, unpredicted uses may emerge, Vahala says. "The applications will be stimulated — no pun intended — by the device itself." ■

Explore more

- LISA website: lisa.nasa.gov
- LCLS website: lcls.slac.stanford.edu





Who's who of laser facilities

FLASH A free-electron laser in Hamburg, Germany, FLASH made its first laserlike pulses of X-rays in 2005. FLASH produces laser light in the extreme ultraviolet and soft X-ray ranges, useful for exploring the atomic structure of large biomolecules and taking images of nanoscale objects — though once the camera flashes, the objects explode.

Linac Coherent Light Source (LCLS) This light source at SLAC National Accelerator Laboratory in Menlo Park, Calif., claimed the record for the world's shortest-wavelength X-ray laser in 2009. It is the first free-electron laser (undulating magnets are shown) to produce pulses of hard X-rays, light whose wavelength is close to the width of an atom. Physicists are already using the laser to probe the inner workings of atoms and molecules.

Godzilla, T-REX and Chihuahua Lawrence Berkeley National Laboratory in California has an army of powerful lasers. Named Godzilla, T-REX and Chihuahua, these lasers could help accelerate charged particles to unprecedented speeds using a phenomenon called laser-plasma acceleration. In 2006, T-REX (amplifier shown) set the record for the highest energy in the shortest space, accelerating electrons from zero to a billion electron volts in 3.3 centimeters. The next laser sibling to be built, BELLA, could reach 10 billion electron volts in 80 centimeters.

AS-1 The AS-1 beam line at the Max Planck Institute for Quantum Optics in Garching, Germany, holds the record for the shortest-ever laser pulse: 80 attoseconds, or 8x10^{-17} seconds. The ultrashort flashes start with pulses from a laser called FP-1. The AS-1 setup then focuses those bursts into a hollow fiber between special mirrors that compress the pulse into even shorter extreme-ultraviolet beats. With such brief pulses, physicists could take snapshots of electrons zipping around atoms (*SN: 3/27/10, p. 16*).

National Ignition Facility (NIF) This facility at Lawrence Livermore National Laboratory in California aims to reproduce — in a 10-story building — the reactions that make the stars shine. The facility, which began operating in March 2009, will focus 192 ultraviolet lasers into a space the size of a pencil eraser to fuse hydrogen nuclei and generate huge amounts of energy (device that aligns the beams is shown).

Texas Petawatt Laser Located at the University of Texas at Austin, this laser boasts an instantaneous power of 1.1 petawatts, or 1.1x10^{15} watts. It's creeping up on the all-time world record, 1.25 petawatts, which a now-decommissioned laser at Lawrence Livermore reached in 1996. The Texan near-infrared laser will produce high-energy pulses lasting 150 femtoseconds (1.5x10^{-13} seconds) to simulate the formation of stars and supernovas.

CLOCKWISE FROM TOP LEFT: COURTESY OF W. LEEMANS; LAWRENCE LIVERMORE NATIONAL LAB; BRAD PLUMMER, COURTESY OF SLAC NATIONAL ACCELERATOR LAB

A statistical education

Odds are it's wrong, but the chances that statistics is to blame are slim and fat. Tom Siegfried ("Odds are, it's wrong," *SN: 3/27/10, p. 26*) accurately portrays the importance of statistics in the conduct of science. However, his failure to clearly distinguish between the misuses of statistics and its methodological limitations leads to misleading conclusions about the role of statistics in the proliferation of erroneous scientific results.

Statisticians have long recognized the challenges presented by multiple testing, the interpretation of observational data, and more recently, the analysis of high-dimensional data. Siegfried rightfully acknowledges the many statisticians and biostatisticians who have persistently and repeatedly written eloquently on these issues. He also notes that appropriate methods, such as those for false discovery control, are available to ameliorate the problems. Yet he curiously persists with the theme that statistics is defective, when it is the misuse of statistical methods that is the main culprit in the situations he describes.

Siegfried has fired a shot across the bow of science that although not perfectly on target, serves as a call for further discussion among statistical scientists and researchers. There is a need to educate statistical practitioners at all levels, as gross misuse of statistical methods borders on scientific misconduct. However, it is also important to realize that while statistics usually plays the role of the fall guy in these matters, there are other more fundamental factors involved.

Sastry G. Pantula, President, American Statistical Association
Jef Teugels, President, International Statistical Institute
Len Stefanski, Editor, Theory and Methods, *Journal of the American Statistical Association*

"Odds are, it's wrong": Long, confusing, hard to read. Also possibly the most important article you've ever published.
Seth Hill, Topanga, Calif.

Tom Siegfried is to be commended for his essay. For someone who taught graduate classes in statistics for the behavioral sciences for almost 40 years, I was gratified to see that someone was still trying to correct the many statistical myths and misconceptions referred to as M and Ms in my first statistics text, *Everything You Always Wanted to Know About Statistics but Didn't Know How to Ask*.

After having studied statistics with Wilcoxon, Savage, Bradley, Olkin, Soloman, Parzens and Atkinson, I now understand their frustration with getting us to "say it correctly." However, even if we say it correctly, statistical inference does not allow us to say very much of value for researchers today. Maybe an overhaul of the entire logical system is in order and I hope your essay is another "beginning."
James K. Brewer, Professor Emeritus of Behavioral Statistics, Florida State University

Your piece on statistics was very welcome. I think *SN* should do a lot more of this sort of analysis of the methodology, politics and philosophy of science.

One piece I'd like to see is on "innumeracy." It fascinates and startles me how little understanding most people have of numbers and their relationships.
James Monaco, Sag Harbor, N.Y.

I just read your editorial and article on flawed statistical analysis of scientific experiments. Perhaps a partial solution would be for a group of good statisticians and analysts to produce a pamphlet illustrating common flaws in analysis, together with illustrations of flawed analysis and of correct analysis.

This could be used together with a checklist or analysis sheet to use during the analysis phase to let the researcher catch any major errors. The pamphlet and checklist could be made universally available at a major scientific organization's website, such as the National Academy of Sciences, and at major publications. As a further solution, the checklist would have to be submitted along with any potential articles to peer-reviewed publications. This would have the effect of preventing a lot of poorly analyzed articles from being submitted in the first place, and of raising the bar for article submission and publication. There is nothing like having an expert looking over your shoulder to make one do better work.
Bruce MacKay, Portland, Ore.

I laud Mr. Siegfried for bringing to the front the problem with statistical conclusions. However, I was surprised that the concept of causality was not mentioned. For example: "There is a 100 percent correlation between people who die of stomach cancer and having drunk milk as babies." All kinds of measures can be put to that correlation, but without the test of causality, it's also wrong.
Fred Marton, Export, Pa.

Kudos to Tom Siegfried for his excellent article. I think we've all seen too many of these errors. In trying to find a pithy, Twitterable summary, I hit on the phrase: Statistical significance isn't. But that's too absolute, too certain given the probabilistic nature of the topic. So, better yet: Statistical significance isn't — usually.
Ken Green, Chino Hills, Calif.

Correction

In the article "Happy 20th, Hubble" (SN: 4/10/10, p. 16)*, the caption entitled "Crash of '94" on Page 21 contains an error. The picture is a composite of images showing fragments of Comet Shoemaker-Levy 9 heading toward Jupiter. The image does not show the result of the comet's collision with the gas giant planet. Instead, the black dot visible in the upper left portion of the planet is the shadow of Jupiter's largest moon, Io. The mark left by the comet crash isn't visible in the image, but would have been in the planet's southern hemisphere.*

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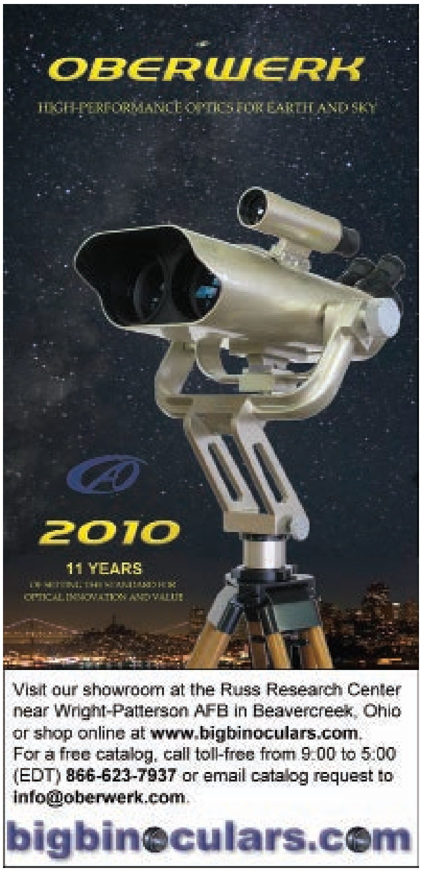
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Charles Townes

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Laser pioneer reflects on making Einstein's idea real

The laser celebrates its 50th birthday this month. Charles Townes shared the 1964 Nobel Prize in physics for his role in the laser's invention and at age 94 remains active in research at the University of California, Berkeley. Townes spoke about his life in science and the events leading up to the development of the maser — the laser's microwave cousin — and of the laser itself with Science News *reporter Ron Cowen.*

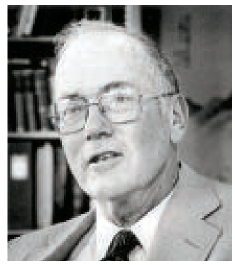
In what way did your experience growing up foster your interest in science?
It had a very big influence. We lived on a small farm in Greenville, S.C., and we had to do our own chores and make things work and that was a hands-on experience that [later] was quite important for experimental physics. I was interested in anything and everything, especially natural history and the outside world, and that's thanks to my father. He would bring home clocks and other gadgets for us to take apart and see how they worked.

Einstein described in 1917 the concept of stimulated emission, which is the basic principle behind the laser and its predecessor, the maser. So why did they take more than 30 years to develop?
The laser and maser could have been developed much earlier. It took time and the right mix of people and events.

After World War II, the military was very good at allowing scientists to explore and expand new fields.... In my case, I was working with microwaves during the war, doing the work on radar, and I recognized that one can do very interesting spectroscopy with microwave radiation, studying the structure of atoms and molecules, if you had an intense source of the radiation.

To develop the maser, we somehow had to get more atoms in an upper energy state than the lower state. At Columbia [University], people were using atomic and molecular beams to separate various energy states. I knew about the work and recognized it was one way to separate and trap atoms in a higher energy state and make a maser.

Several people at Columbia in the early 1950s, including physics Nobel laureate I.I. Rabi, told you that trying to build a maser was a waste of time. What made you disregard that advice?
I'm accustomed to being myself, being independent, and that's a very important part of creativity. My parents taught me that, too. Don't do what other people are doing; you do what you think is really right. I had to think about what these people were saying, yes, but it wasn't troublesome or upsetting when someone disagreed with me. Luckily, I had tenure at Columbia. If I didn't have tenure, that would have been a bigger problem certainly, whether I would have taken a chance or not [to build the maser], I'm not sure. After we built the maser, Rabi didn't exactly apologize, but he did congratulate me on my work.



The laser and maser could have been developed much earlier. It took time and the right mix of people and events.

Once you and your colleagues developed the maser, what made you decide to refocus your efforts and try to develop the optical analog — the laser?
I first tried [making an amplified beam] in microwaves because I had microwave equipment and that was the easiest way to do it. And that was so exciting that everyone got interested in it. We were doing very successful spectroscopy and finding out a lot of things about molecules and atoms and nuclei and so on using the maser. But my primary purpose was to try to get down to shorter wavelengths than microwaves, into the infrared and light waves. And I wanted to do that because I saw there were new kinds of spectroscopy to be done there. Everyone was familiar with light waves. After some analysis, we [Townes and his collaborator, brother-in-law Arthur Schawlow] wrote a paper that covered all of that.

In the early 1980s the Reagan administration embraced the idea of a system of lasers powerful enough to destroy nuclear ballistic missiles, a program nicknamed Star Wars. What did you think of that program?
Initially, the laser wasn't thought of as a weapon but pretty soon after it began to be developed, it was examined by many people as a possibility. I think some unnecessary money was spent [on Star Wars], even though we did need to explore the idea. But some people were overly enthusiastic and were convinced it would work. It never worked, and I didn't expect it to work. And I said that I didn't think it would work. It's more feasible now, but we also recognize more clearly how difficult it is to get enough directed energy [into the atmosphere] for such a system. We can get somewhat close but we can't quite do it.

At age 94, when most people have long since retired, you're still doing research, using laser technology to measure the sizes and shapes of stars. What keeps you going?
It's such fun. I have a great time with it, so why stop? ■

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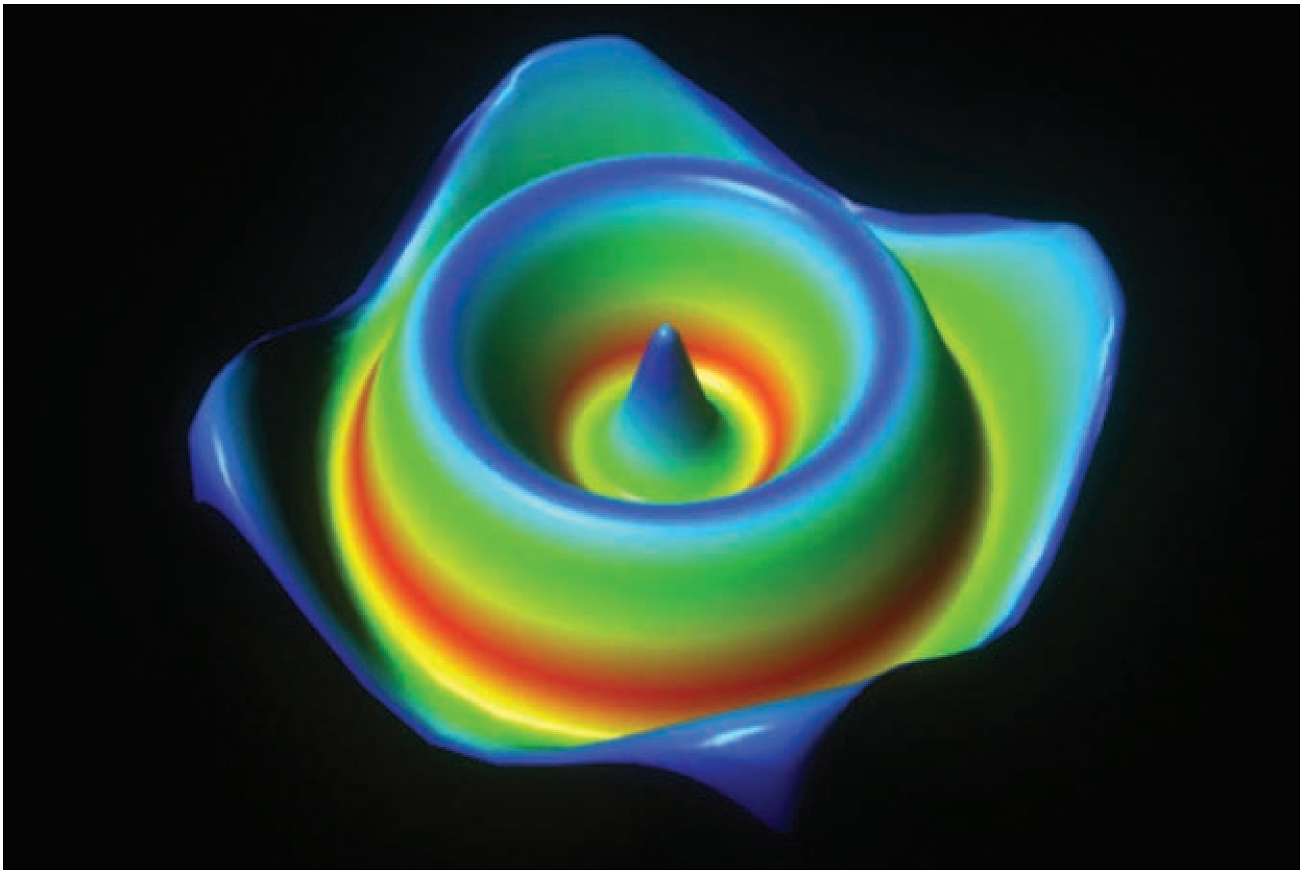

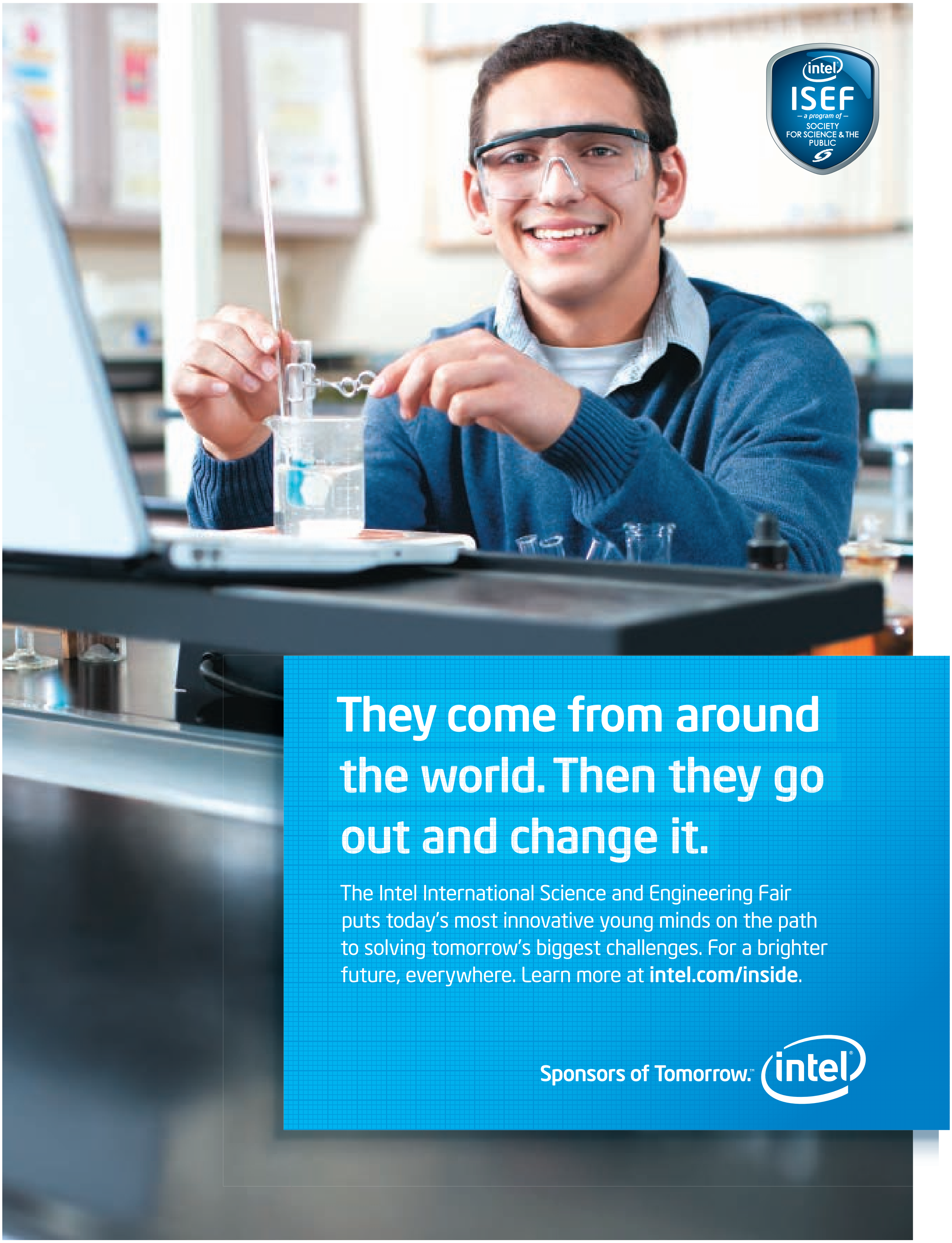
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