LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

JANUARY 2008

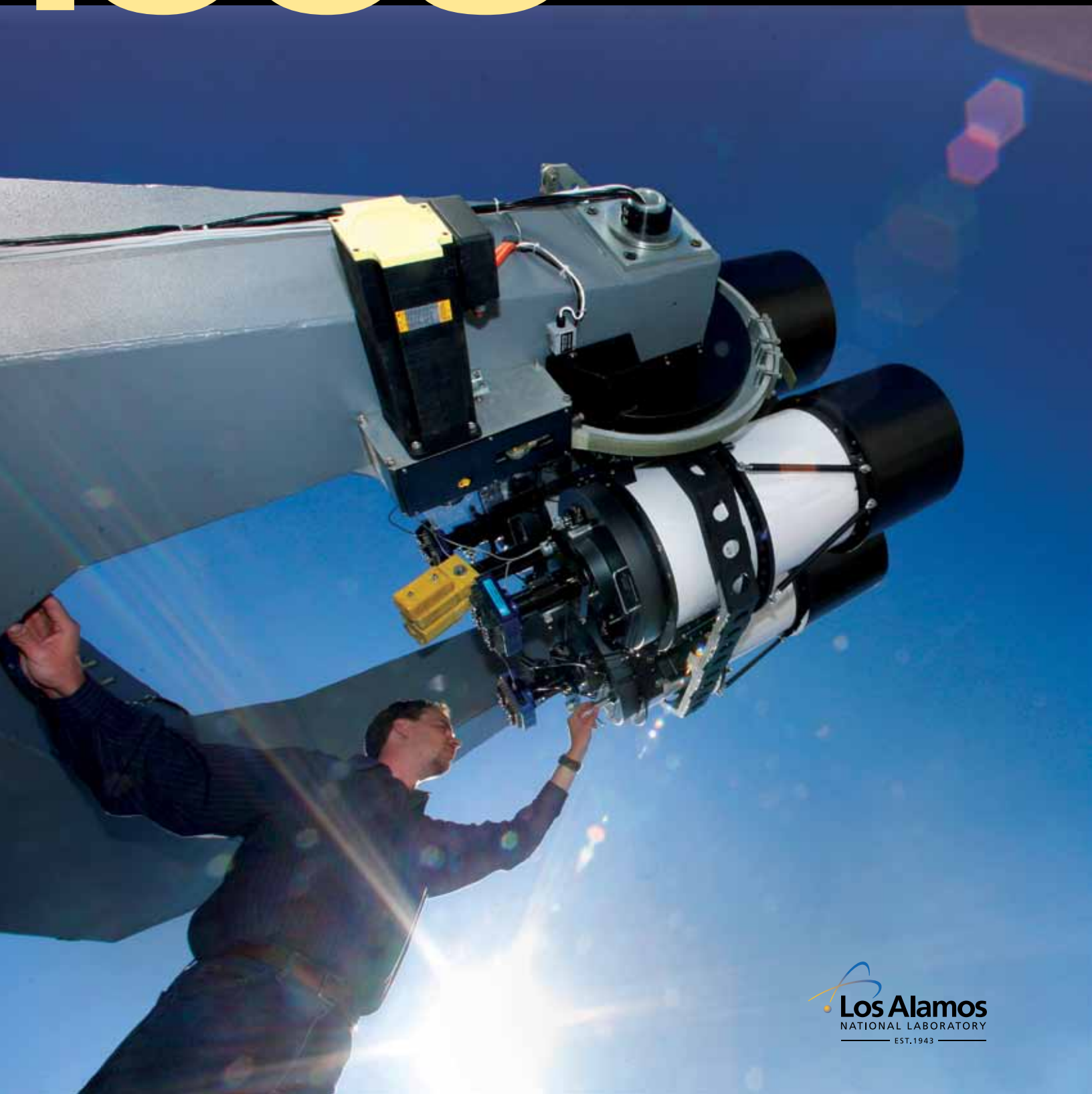
1663

Thinking Telescopes

Containing CO_2

Targeting Anthrax

Hunt for Dark Matter



Los Alamos
NATIONAL LABORATORY
EST. 1943

1663

About Our Name: During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

Located on the high mesas of northern New Mexico, Los Alamos National Laboratory was founded in 1943 to build the first atomic bomb. It remains a premier scientific laboratory dedicated to national security in its broadest sense. The Laboratory is operated by Los Alamos National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

About the Cover: James Wren adjusts RAPTOR-T, a new component of the thinking telescope network. This autonomous robotic network is a pathfinder technology for picking out and analyzing optical transients at unprecedented rates.

Los Alamos archive photo

Hans Bethe and Enrico Fermi share a jeep with Nick King (at the wheel) and Edward Teller's son Paul.

From Duncan McBranch

Discovery to Solution

Discovery is the most gratifying aspect of professional science. At Los Alamos, the scientific discoveries made each year support a surprisingly broad range of national-security programs. The Laboratory's ability to tackle the hardest scientific challenges, make discoveries, and then apply that knowledge to solve entirely new problems—to move from discovery to solution—is one of our greatest strengths.

In this issue, we highlight three areas in which mission-related scientific discoveries opened a new avenue for solving an emerging problem of national importance.

Our responsibility for ensuring the reliability of the nuclear stockpile and planning for a nuclear waste repository led us to acquire expertise in modeling the earth's subsurface and the geochemistry of underground formations. Those models are now being used to combat global climate change. They are at the heart of CO_2-PENS, a new software tool that can help decision makers assess the effectiveness of one proposed response to the global buildup of greenhouse gases: storing carbon dioxide underground.

In another field of research, our biosecurity missions led Los Alamos scientists to study the molecular biology of the anthrax-causing bacterium, Bacillus anthracis, *and those studies have resulted in new ways to counter a dangerous biothreat agent.*

Finally, our work in space-based detection of nuclear explosions led to a dramatic innovation—a "thinking telescope" array that autonomously searches for dynamically changing objects in the night sky. The robotic system, RAPTOR, decides on its own which events warrant further observations and then directs its telescopes to follow up.

As evident from these examples, the creativity fostered by a multidisciplinary science institution can be remarkably powerful. This creativity is the key to the long track record of success that is part of the heritage of Los Alamos National Laboratory.

Deputy Principal Associate Director
for Science, Technology, and Engineering

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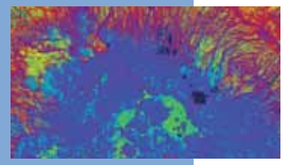

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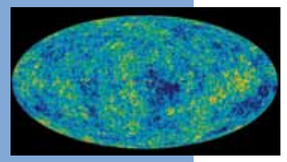

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TO KILL A KILLER
Targeting Anthrax

Los Alamos researchers work to counter a bioterrorism threat

Autumn 2001 was a time of terror, some of it arriving in the mail. A still-unknown someone sent envelopes of anthrax spores (dormant cells, ready to come to life) to several news organizations and to the Washington, D.C., offices of two U.S. senators.

There were only seven envelopes, but the consequences were enormous. Twenty-two office workers and mail handlers contracted anthrax. Five died. Bags of mail were impounded, thousands of people were given precautionary medical treatment, and dozens of contaminated buildings were temporarily closed, one for 4 years.

Those few envelopes caused grief, fear, and a multi-million-dollar bill for response and cleanup. They also put us on alert. Naturally contracted anthrax is extremely rare in humans, but a deliberate biological attack could expose a large population and massively disrupt the economy.

We may never know the enemy behind the 2001 mailings, but the enemy we *can* know is the bacterium that causes anthrax, *Bacillus anthracis* (or simply *B. anthracis*). The better we know it, the better the chance of averting disaster.

Los Alamos Weighs In

Right from the beginning, Los Alamos National Laboratory has been a key participant in the fight against anthrax. It contributed to the DNA forensics used by the Centers for Disease Control and Prevention to identify the 2001 strain of *B. anthracis* (the Ames strain, the so-called "gold standard" for virulence). The Laboratory's longstanding expertise in DNA sequencing has made it a significant player in DNA forensics, wherein patterns in DNA are probed for information about an organism's provenance.

Currently, Los Alamos is expanding its research toward better understanding of the life cycle of this deadly bacterium. It is also developing new medical treatments to supplement current ones, which have serious limitations. The current vaccine induces immunity through the production of antibodies but requires months of vaccinations and an annual booster. It would be of little help in an emergency, like a bioterrorist attack. In addition, bacterial mutations—natural or, in the case of bioterrorism, deliberate—can reduce the vaccine's effectiveness.

Similarly, weaknesses undermine the antibiotics used to treat anthrax victims. The most-prescribed antibiotics cause side effects because they're "broad spectrum," attacking many types of bacteria at once, including the beneficial bacteria in the gastrointestinal tract. And mutated bacteria may be resistant to antibiotics.

To defeat something like *B. anthracis*, you start with how it overwhelms the body's defenses and look for vulnerabilities in what is a seriously tough customer.

PHOTO COURTESY OF U.S. DEPARTMENT OF DEFENSE

Sailors aboard the aircraft carrier USS John C. Stennis receive the first in a series of vaccinations for anthrax. The vaccine, available for military personnel and first responders, requires multiple shots and takes many months to confer immunity.

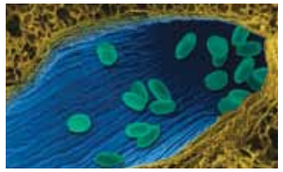
A Formidable Opponent

Outside a living host, *B. anthracis* forms spores that can resist heat, dehydration, and even radiation and can survive for years, long enough to invade a new host. The spores can be ingested with infected meat or enter the body through a break in the skin. They are so tiny (a micrometer—one 25-thousandth of an inch) they can disperse through the air and be inhaled, a potent path to infection attractive to bioterrorists.

Inhalation anthrax has a mortality rate of 50 to 75 percent if not treated quickly, but it's hard to catch quickly because its early symptoms are like those of a cold or the flu. The 2001 victims who died were the ones who inhaled the spores.

Inhalation is especially dangerous because it places the spores deep within the respiratory system, beyond all the body's outer defenses, and on a quick pathway to system-wide infection.

The spores lodge in the lungs' tiniest air sacs, the alveoli. There they encounter mature white blood cells called macrophages (Greek for "big eaters"). Those *should* be the spores' undoing. Macrophages normally envelop and break up (eat) invading pathogens, then travel from the alveoli to the lymph nodes, displaying bits of the pathogens



Inhaled spores, magnified here 1,795 times, are trapped in the smallest of the lungs' air sacs. DENNIS KUNKEL MICROSCOPY, INC

Left: The rod-shaped bacterium, *Bacillus anthracis* (magnified 2,200 times), causes anthrax. Its spores (shown forming at the center of the image)—an inert, protected stage—allow it to survive hostile environments until it invades a new victim. IMAGE COURTESY OF DENNIS KUNKEL MICROSCOPY, INC

on their outer surface. Those displayed bits signal the white blood cells that reside in the lymph nodes to produce antibodies.

Although the anthrax spores are enveloped as usual, they co-opt the macrophages for their own purposes. They resist the "eating" and instead germinate into fully active *B. anthracis* bacteria, which ride along, undamaged, to the lymph nodes. There they burst out to multiply at a staggering rate—and secrete a deadly toxin—in the favorable environment of the bloodstream.

The toxin is a complex of three proteins working cooperatively to kill cells. The first one, called protective antigen (PA), initiates the attack. It binds to a receptor found on almost every cell in the body and lets itself be pulled inside, dragging along the other two proteins—edema factor (EF) and lethal factor (LF). EF and LF can't enter a cell on their own and are harmless outside. Inside, they set off a string of death-dealing events, including the malfunction and swelling of cells and disruption of the intercellular signals that would activate the immune system (see figure below).

Launching a Decoy

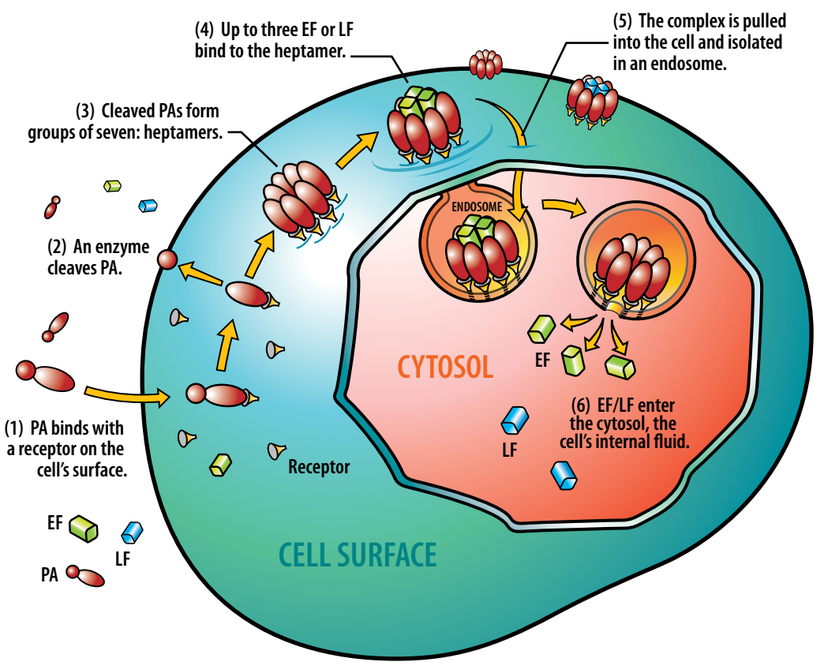
PA is the focus of an antitoxin being developed by a Los Alamos team of Goutam Gupta (heading the team), Momchilo Vuyisich, and "Gnana" Gnanakaran. Team members want to block the toxin by keeping PA from attaching to a cell's receptors.

The antitoxin is a molecular decoy shaped like a human antibody (a Y-shaped protein that helps the body clear invading organisms). The branches of the decoy's Y contain replicas of the cell's PA receptors. PA binds to the replicas instead (see figure, p. 5). The decoy's tail is identical to that of a human antibody, and its presence prompts the immune system to clear the decoy and its captured toxin from the body.

The current anthrax vaccine functions similarly—but not as well. It induces the body to produce its own anthrax antibodies, but over a period of months, not immediately. Those likewise bind to PA, but the Los Alamos decoy binds to significantly *more area* on PA. To escape the decoy, PA would have to accumulate multiple mutations over a wide area. In contrast, a single mutation could allow it to escape the grasp of the vaccine-produced antibody.

In addition, the decoy's antibody tail gives it stability because the immune system sees it essentially as "one of its own." Like a normal human antibody, the decoy is allowed to exist unhindered until needed.

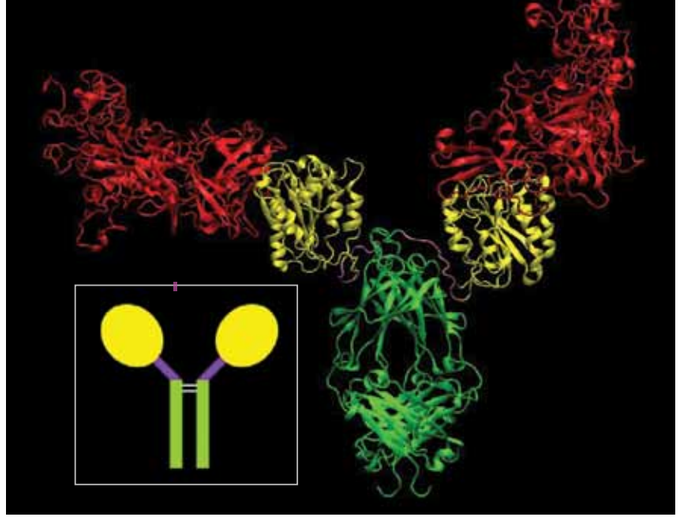
The decoy has passed several major tests sponsored by the National Institute of Allergy and Infectious Diseases and by the National Institutes of Health, Biodefense Program. The tests were carried out on rats and mice at the University of New Mexico's Health Sciences Center. "In about 18 months, if all goes well, we should be ready for trials using infected human blood." Gupta says. "That would bring us more or less to human trials."



Breaking and Entering

Anthrax Toxin Invades a Cell

The anthrax toxin comprises three proteins (PA, EF, and LF) that work together to break through the cell's outer wall and set off a string of reactions that can ultimately kill the host.



The figure shows how the Los Alamos antitoxin, a Y-shaped molecular decoy (yellow, violet, and green), binds two PA molecules (red). PA is the toxin component that binds to human cells. Both the decoy and PA are proteins, long chains of amino acids, depicted here as folded ribbons. The binding configuration shown was calculated by a computer simulation. The inset shows the molecular components of the decoy: the PA receptor (yellow), the human antibody tail (green) and the linker between them (violet).

Metabolism and Mystery Proteins

Other Los Alamos researchers are pursuing the anthrax bacterium down different paths.

A team headed by Christy Ruggiero and Andy Koppisch is trying to develop new antibiotics that specifically target *B. anthracis* through its metabolism. The idea is to block the bacterium's acquisition of iron. Most bacteria require dietary iron to function, and they use a special molecule—a siderophore ("iron carrier")—to bring it in from the environment. The siderophore used by anthrax is called petrobactin. The team's goal is to keep *B. anthracis* from taking up that iron-loaded molecule, effectively starving the bacterium.

"As far as we know," says Ruggerio, "*Bacillus anthracis* is the only pathogen that uses petrobactin."

Currently, the team is identifying and studying the effect of turning off several of the bacterium's genes that control petrobactin uptake. Once the critical genes are identified and the proteins those genes express (produce) are examined, team members will work on antibiotics that block those proteins.

Other Los Alamos teams are pursuing other metabolic vulnerabilities.

Koppish is leading a separate team that is looking into other metabolic functions and investigating how the bacterium develops resistance to antibiotics, in the hope of preventing resistance before it happens.

Because the bacterium's metabolism depends on enzymes, researcher Paul Langan's team is channeling its anti-anthrax work into an attack on one particular enzyme, DHFR, which is needed for the bacterium's synthesis of DNA and therefore essential for its survival.

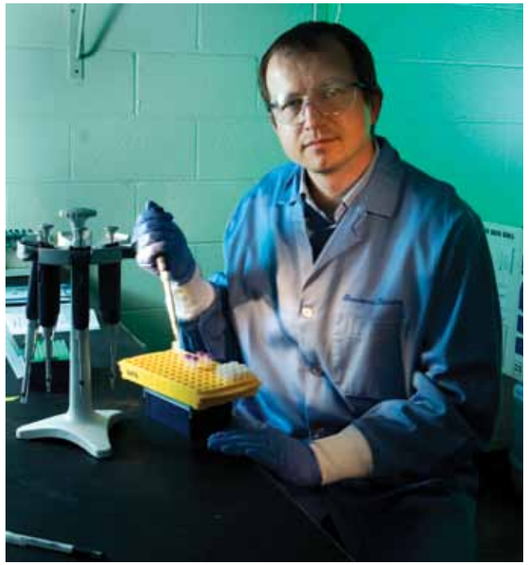
Cliff and Pat Unkefer are working in a new field of study known as "metabolomics," named for the molecules called metabolites that are its focus. Metabolites are the products of metabolism. They offer a window into the biochemical workings of an organism. The Unkefers' recent work with the metabolites in *B. anthracis* has given them leads to new targets for drugs.

Ryszard Michalczyk's anti-anthrax team is studying six extra genes unexpectedly found on a circular piece of *B. anthracis* DNA—a plasmid, the same one that also contains the genes expressing the three toxin proteins. The extra genes also express proteins but of unknown function. Their proximity to the toxin suggests an association, which if it exists, would make them additional drug targets. Michalczyk is hoping so.

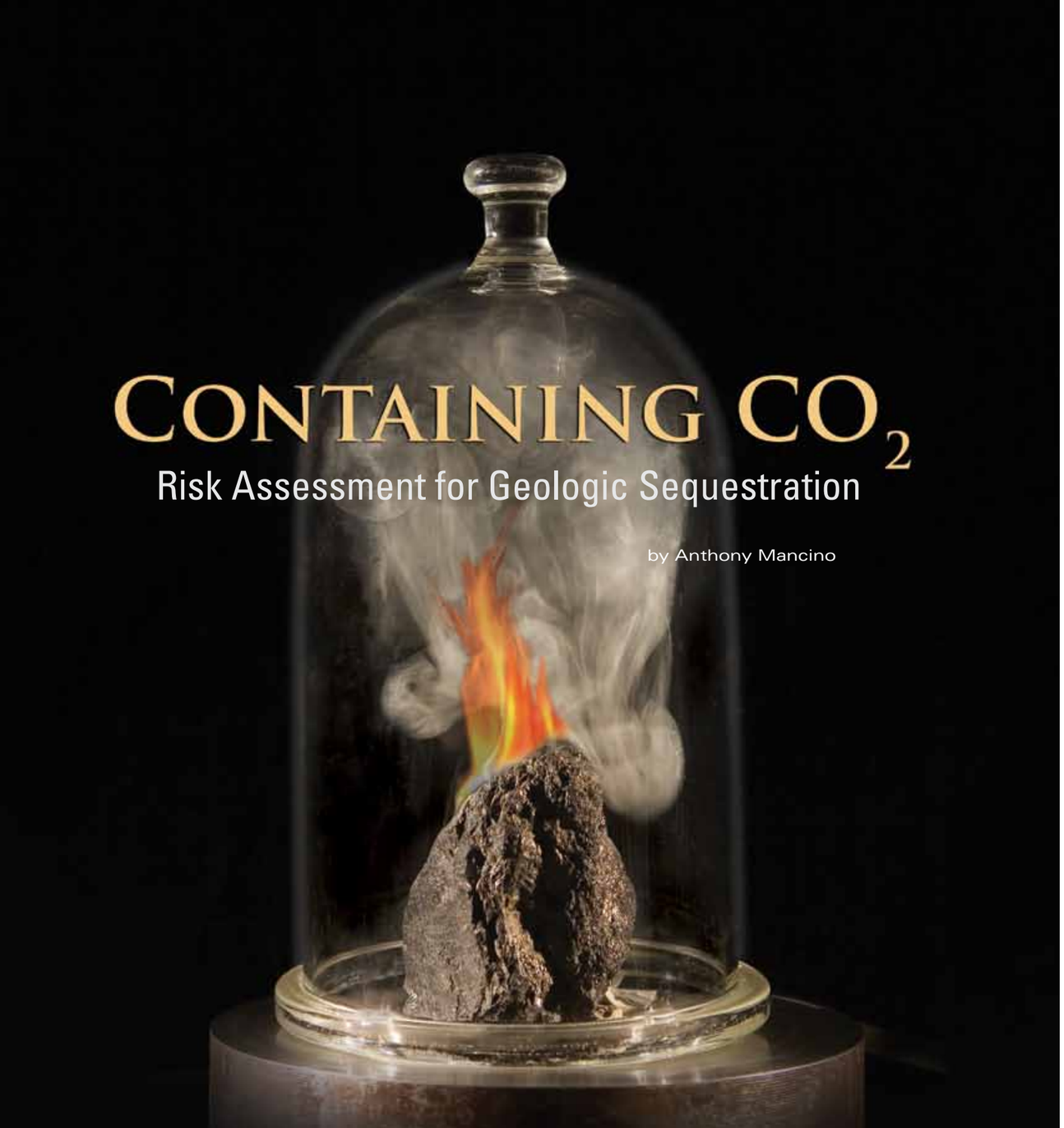
Joining Forces

Sometime in the future, a combination of these Los Alamos strategies may work in tandem. For example, an antibiotic interfering with *B. anthracis*'s metabolism might slow the bacterium's growth and thereby reduce the amount of toxin that the antitoxin decoy needs to block. And all of them may supplement the vaccine, extending its efficacy.

Separately and together, all research avenues may lead to a future that is safer from bioterrorist attack.❖



Momchilo Vuyisich, co-developer of the Los Alamos antitoxin.



Containing CO_2

Risk Assessment for Geologic Sequestration

by Anthony Mancino

During the Cold War, Los Alamos geologists proved their ingenuity by successfully containing nuclear tests underground. The latest global threat, climate change, is challenging them again. Can they successfully contain carbon dioxide, the most troublesome greenhouse gas, deep beneath the earth?

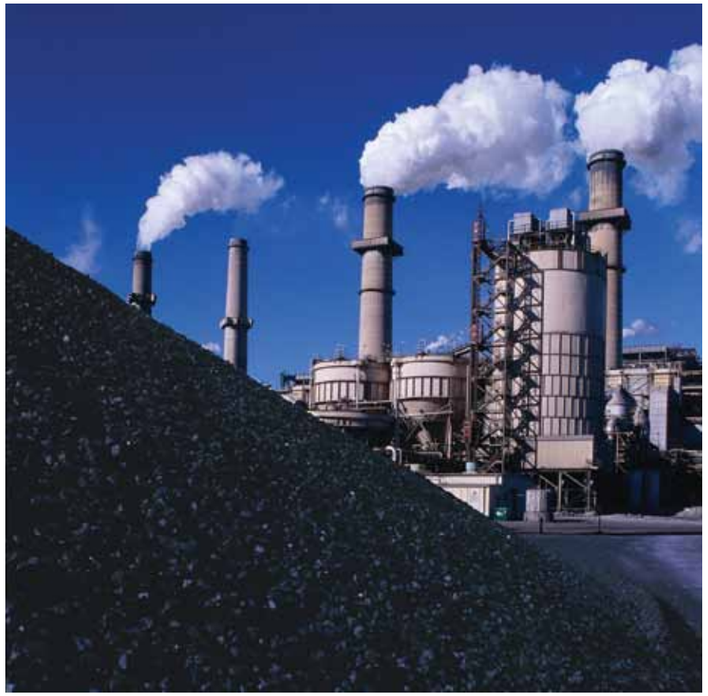
The average American family of four puts about three tons of garbage per year by the curb, but because we burn fossil fuels for electricity, heat, and transportation, that same family is annually responsible for dumping about 80 tons of carbon dioxide (CO_2) into the atmosphere—CO_2 that contributes to global climate change.

Some believe we should just stop using fossil fuels, but that won't happen in the near future unless we're willing to cripple our economy and keep the developing world in poverty. Eighty-six percent of the world's energy comes from fossil fuels, and projections show energy demand and fossil fuel use rising dramatically. China, India, and the United States are planning to add 850 new coal-fired power plants to the 2,100 worldwide that currently chug out one-third of the world's human-generated CO_2 emissions.

We need a way to cut those emissions and slow climate change now without precipitously abandoning the abundant and affordable coal resources that fuel the majority of power plants. The solution may lie in how we handle garbage. We bury it. Burying CO_2 might be the best short-term option for slowing climate change.

It's called geologic sequestration. Instead of releasing CO_2 into the atmosphere, we would capture it at its industrial sources, turn it into a fluid, and inject it into deep geological formations. (See "The Basics of Geologic Storage," p. 9.) There is a neat symmetry to that. Carbon we've released from deep underground in the form of oil, gas, and coal can be returned to subterranean storage.

The global need to slow climate change while still using coal has led Los Alamos scientists to the small town of Snyder, Texas.



Projections show that as coal-fueled electricity generation will increase 74 percent by 2030 and that coal will soon surpass oil to become the largest source of energy-related CO_2 emissions. Geologic sequestration may offer a way to mitigate the climatic impacts of this trend.

A Ready Testing Ground

The drive to Snyder cuts through the expansive flat and treeless plains of west Texas, punctuated here and there by cotton fields and oil wells. Beyond the many wells, on a ridge in the distance, sit several wind turbines, a symbol of our energy situation, in which fossil fuels are still king but alternatives are on the horizon.

Originally a buffalo-hunting settlement, Snyder became an oil boomtown in 1948. The boom was over by late 1951, but in the 1970s, Snyder still managed to extract more oil than any other area in Texas. Producers there had developed a method of injecting CO_2 into the oil-bearing rock to force out hard-to-get reserves. This method, called "enhanced oil recovery," or "EOR," is now used worldwide.

When Los Alamos scientists wanted to understand the effects of large-scale geologic sequestration, they found willing partners in the operators of the SACROC oil field near Snyder, where EOR has been performed with CO_2 since 1972.

SACROC is a large, successful operation, but its numbers reveal the challenge of geologic sequestration. In SACROC's entire 35 years of injecting CO_2, only 70 million metric tons of CO_2 have accumulated in its reservoirs. The world's coal-fired power plants alone emit about 11 *billion* metric tons of CO_2 *per year*.

Anthony Mancino is a communications specialist for the Science Program Office.

"We'll need to sequester amounts of CO_2 that are orders of magnitude larger than anything attempted in EOR," explains Phil Stauffer, a Los Alamos hydrogeologist.

"With EOR," adds chemical engineer Hari Viswanathan, "we have around three decades of history, but we need to consider possibly hundreds of years."

A minute fraction of the thousands of CO_2 injection and oil recovery wells (bright spots connected to dirt access roads) that dot the landscape near Snyder, Texas. The edge of Snyder, where people have lived atop CO_2 injection operations for 35 years, is visible at lower right.

Increased Scale Brings Increased Risk

Increasing the time and volume of sequestration multiplies the potential risks, so Viswanathan and Stauffer are working as part of a team of scientists led by Rajesh Pawar to develop a comprehensive risk assessment framework and computer model to evaluate potential problems associated with geologic sequestration. The model is called CO_2-PENS, with "PENS" standing for "predicting engineered natural systems."

Los Alamos scientists learned to predict the movement of fluids in the subsurface during nuclear testing and while planning for nuclear waste repositories. To contain the effects of underground nuclear tests or store radioactive waste beneath the earth for 10,000 years, they had to understand and predict how materials move and react in complex geological systems. While CO_2 sequestration is far safer than these activities, it still poses potential safety and economic risks.

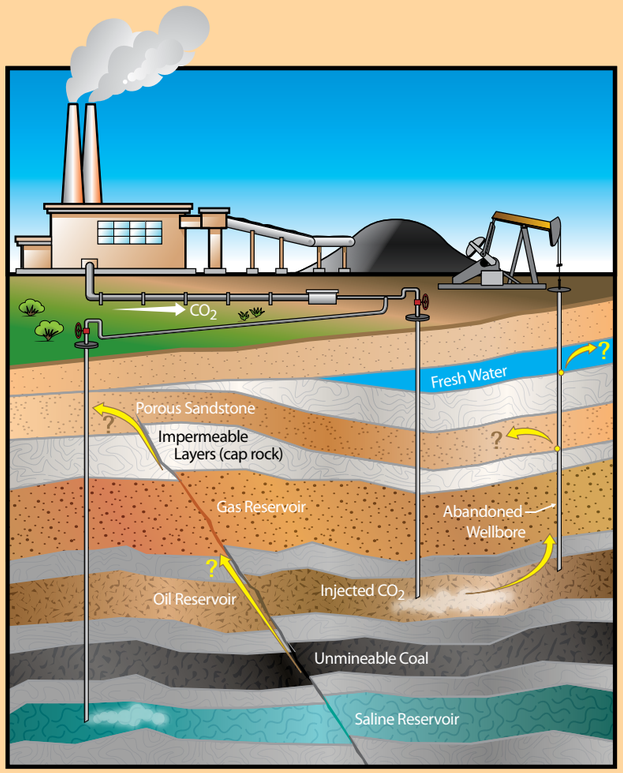
You can't be sure CO_2 will stay where you put it because the subsurface is home to a staggering number of chemical reactions, physical processes, and potential escape pathways. But with the proper scientific understanding, you can predict how the CO_2 will behave, quantify the uncertainties in those predictions, and identify the experiments and field observations needed to reduce that uncertainty.

"There's uncertainty in how fast CO_2 can be injected into a given hole," says Stauffer, "how fast it will move through porous rock, how fast it will mineralize, and how fast it might leak up through different pathways. We're trying to reduce those uncertainties so decision makers can act on a known level of risk."

Scientists can already make fairly good predictions for individual subsurface processes because data and computer models already exist for them. What's been missing is a way to pull them together into an accurate picture of the whole complex system. That's the gap CO_2-PENS fills. It is an overarching program that taps a shared cyber library in which separate process models are dynamically linked. It goes beyond the individual results of each model to reveal how all the many processes affect each other.

For example, if a porous-rock model shows a plume of CO_2 and brine moving toward old cement-plugged oil wells, CO_2-PENS could pass those results to another model that would calculate the likelihood that the plume will remain contained. If a leak seemed likely to occur near a freshwater aquifer, CO_2-PENS would update a groundwater-impact model to determine the possible effects on water chemistry. If an atmospheric leak were possible, CO_2-PENS would

Rajesh Pawar (center), project leader for geologic sequestration, works with Phil Stauffer to develop the computer code for CO_2-PENS, a science-based prediction tool designed to ensure safe and effective geologic sequestration operations.



The Basics of Geologic Storage

The geologic formations that would store CO_2 have many porous and nonporous layers. The sponge-like porous ones would hold the CO_2. Most of these porous layers already have fluid in them, usually saline water and in some cases, oil. These fluids will have to move to make space for the CO_2, which is how residual oil is mobilized in EOR operations.

For sequestration, the CO_2 is first compressed until the combined heat and pressure make it "supercritical," a state in which it displays both gas and fluid properties. When injected, this supercritical fluid diffuses like a gas into the porous rock but takes up less space than a gas because of its fluid-like density. The reservoir layers must be deep enough (under high-enough pressure) to maintain the supercritical state.

Supercritical CO_2 is buoyant and will rise above the other fluids. If it rises high enough (above a depth of 2,600 feet), it will return to a gaseous state, expand, and slip through any available escape route, indicated in the figure by question marks. To keep this from happening, a sequestration site must have an impermeable cap rock, past which the CO_2 cannot rise. For eons, such trapping mechanisms have worked efficiently to contain natural gas, oil, water, and volcanic CO_2, but even impermeable cap rocks are typically cracked, and the CO_2 could seep up faults or fractures in that ceiling.

access data from an atmospheric-circulation model to show how CO_2 would locally concentrate or dissipate.

CO_2-PENS also quantifies the uncertainty in its predictions and indicates if it needs more information—more experiments or more sensors at the site—to decrease that uncertainty. The program will initially be used to select the best sequestration sites, but once a sequestration operation is underway, it will learn from site-generated data and sharpen its predictive accuracy.

It can also help analyze economic risks. For one site, CO_2-PENS unexpectedly predicted that drilling wells 1 kilometer deep would be less economical than drilling them 3 kilometers deep.

"At 1 kilometer, you needed 80 wells to handle the CO_2 volume from a power plant," Stauffer explains. "At 3 kilometers, you needed only 10 wells because the increased temperature lowered the viscosity of the CO_2, and the higher injection pressure allowed it to slide more easily into the reservoir."

A core sample extracted from a plugged wellbore in a geologic formation where CO_2 has been injected for over 30 years. The detail shows a polished section of the core. The orange carbonated zone shows how CO_2 affected the cement next to the formation's shale cap rock.

Geochemist Bill Carey analyzes a cement sample from a CO_2-enhanced oil recovery operation.

Balancing Competing Factors

"Sequestration will be a balancing act between risks and benefits," says Viswanathan. "An existing oil field might seem an economical choice for a site because existing wells would lower drilling costs, but there's some question about the containment properties of old wells. It may be cheaper in the long term to drill new wells into a saline reservoir where old wells are not piercing the cap rock." CO_2-PENS will help manage that balancing act.

Oil companies typically plug abandoned wells with cement, and since a combination of CO_2 and brine is acidic, there is a risk that the CO_2-brine solution would eventually eat its way through the plug. Initially, not enough was known to quantify the risk.

To study the question, Los Alamos researchers recovered cement samples from a SACROC well where cement had been exposed to CO_2 and brine for decades. Laboratory analysis, led by Bill Carey, showed that the cement was still an effective barrier after 30 years. CO_2 did migrate along the well hole's casing and along the nonporous rock above the oil reservoir (the cap rock), but minerals had filled the gaps over time. The results give cause for optimism but also indicate further attention is needed, given the long time scales involved.

The CO_2 can still cause trouble without reaching the surface. It needs only to escape beyond the cap rock to find pathways through porous layers above. If that happens, it could affect freshwater resources by introducing brine or mobilizing inorganic contaminants, such as metals. It could also seep into nearby hydrocarbon resources, such as natural gas deposits, owned by other companies, resulting in legal and financial penalties. So there are risks, but with tools like CO_2-PENS, the risks are manageable and pose far less danger than letting atmospheric CO_2 accumulate unchecked.

Los Alamos researchers are working on other unknowns in the risk assessment framework as well. In one project, scientists are developing complex parallel computer codes to understand exactly how CO_2 and brine mix and what mineral reactions result. Those processes will greatly affect the flow of a CO_2 plume over time.

Researchers are also studying an area in Canada where hundreds of thousands of wells have been exposed to acid gas (CO_2 and hydrogen sulfide). Data from so many wells hold a wealth of information relevant to CO_2 sequestration and should generate statistics invaluable to CO_2-PENS.

Yet another important piece is quantification of CO_2 flux at the surface, where CO_2 constantly cycles in and out of the terrestrial ecosystem through plants, soils, and oceans. You have to characterize the natural variations and inventories of CO_2 before you can tell if new CO_2 from a sequestration operation is seeping into the mix. Julianna Fessenden-Rahn and other Los Alamos researchers are obtaining baseline measurements and using analytical methods to determine if CO_2 is of biological or industrial origin. The data they collect will increase the safety and effectiveness of sequestration operations and increase the predictive certainty of CO_2-PENS.

Hopeful Signs

All the initial signs indicate that geologic sequestration can be safe and effective, but the challenge of implementing it on a scale grand enough to affect climate change is somewhat daunting. The greenhouse gas engine driving global warming is like an onrushing freight train. It would take decades to stop even if we hit the brakes right now. And we're not ready to hit the brakes. Existing coal plants are not equipped to separate CO_2 from their exhaust streams (a nontrivial technical problem that Los Alamos scientists are also working to solve). New coal plants won't include such a capability because there is no regulatory pressure to do so and because it would increase the price of electricity.

So can we implement geologic sequestration in time to make a difference? Stauffer answers with a blunt rhetorical question: "If your car is heading toward a tree and you know you're going to hit it, do you still put on the brakes?"

"We've got to try," adds Viswanathan. "Even if things start getting bad, they won't be *as* bad if we do this."

George Guthrie, program director for the Laboratory's Fossil Energy and Environment Program Office, is a bit more optimistic. "Geologic sequestration is being implemented today, and it will take off. The momentum in the last 2 or 3 years is just amazing, and there's a lot of optimism that it will be able to make a dent. Internationally, you see large-scale field efforts proposed and deployed. So far these operations involve natural gas production instead of coal plants because the ability to separate CO_2 already exists as part of the gas-purification process. There is still a lot of economic uncertainty for the electric power industry's coal-fired plants, but that's why we're doing all these pilot studies and experiments."

In the end, the right economics and regulatory policies will drive industry's willingness to implement geologic sequestration. When that time comes, Los Alamos researchers plan to be equipped with the scientific and engineering knowledge needed to do it right.❖

Julianna Fessenden-Rahn works on an eddy covariance tower used to measure CO_2 flux at the land-atmosphere interface.

THINKING TELESCOPES

A Discovery Engine for Astronomy

A small but agile robotic-telescope system named RAPTOR surprised the world with its unexpected detection of the early optical light from gamma-ray bursts, the super-energetic cosmic explosions believed to announce the birth of stellar-size black holes. Now RAPTOR is being transformed into a next-generation global network of survey and fast-response telescopes, a pathfinder technology for exploring the dynamic universe in real time and making significant discoveries without human intervention.

RAPTOR-T, four co-aligned telescopes with insertable color filters, will be the first to observe gamma-ray bursts in four different color bands while the gamma rays are being emitted.

On the night of February 6, 2006, Los Alamos astrophysicist Przemek Wozniak was awakened by a cell-phone call from RAPTOR—the small robotic optical telescope array on Fenton Hill, about 30 miles from Los Alamos in northern New Mexico's Jemez Mountains. RAPTOR had found something strange—a rapidly rising light signal coming from the position of a very short (7 seconds) gamma-ray burst detected and located 50 minutes earlier by the National Aeronautics and Space Administration's (NASA's) Swift satellite. The burst position had just come above the horizon, so it was RAPTOR's first chance to look for an optical signal.

Gamma-ray bursts are violent explosions releasing invisible high-energy photons (gamma rays) and lasting only seconds to minutes at most. They are followed by a steadily fading afterglow emission of lower-energy photons, ranging from x-rays down through visible light to infrared and radio waves (see box, "Gamma-Ray Bursts"). The afterglow typically lasts for hours to days.

Following its own logic, RAPTOR recorded the light signal every 30 seconds and noted a doubling in brightness over 4 minutes—an afterglow that was *rising* rather than fading. Running real-time analysis software, RAPTOR decided to report the anomaly to a human.

After receiving RAPTOR's call, Wozniak checked online and saw what looked like an explosive event. He quickly alerted Tom Vestrand, RAPTOR's team leader. Vestrand recalls his excitement, "This was a first, an autonomous optical telescope finding an anomaly on its own with no human intervention. If humans had been in the loop they would have said, as we did, 'Gamma-ray bursts don't act like that. Forget it.' And RAPTOR wouldn't have found anything."

RAPTOR's observation of that spectacular "rebrightening" hints that a gamma-ray burst can sometimes "turn itself on" a second time, emitting intense visible light but no gamma rays—an intriguing possibility.

For the RAPTOR team, the discovery had a broader significance. It was proof that RAPTOR has a mind of its own—truly a *thinking* telescope system. This network of relatively small but rapidly aimed telescopes, coupled to a central computer, is able to define its own observing strategy and make discoveries in real time with no help. R2-D2, step aside!

The Los Alamos team is now trying to build a global network of upgraded fast-response telescopes that are

ARTIST'S CONCEPTION COURTESY OF NASA

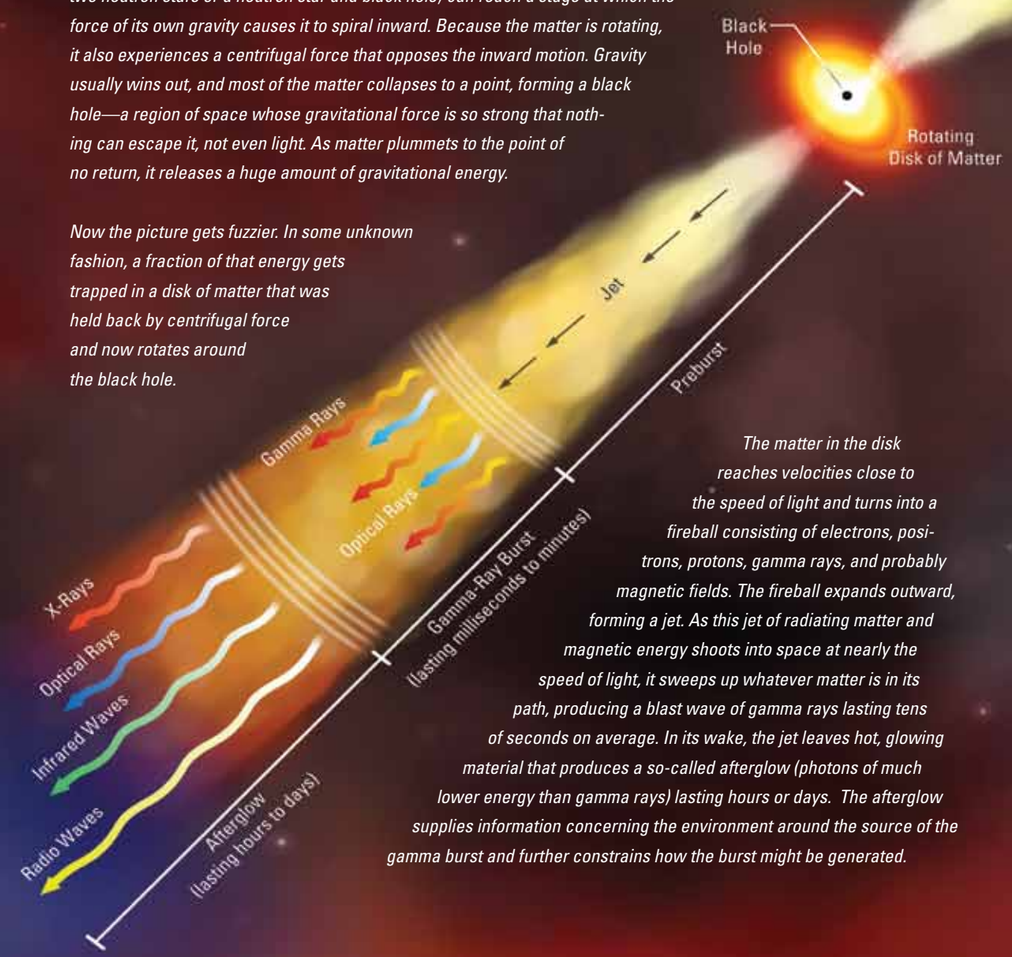
Top: NASA's Swift satellite, launched into a low-Earth orbit in November 2004, is shown here, as a cartoon, detecting a gamma-ray burst. Swift sends an alert to ground-based telescopes as soon as it determines a rough location for a gamma-ray burst.
Bottom: Tom Vestrand (left) and Przemek Wozniak, with the RAPTOR telescope that recorded the rebrightening event of February 6, 2006.

Gamma-Ray Bursts

Cosmic gamma-ray bursts, pulses of gamma rays, were detected in 1967 by the Vela satellites (sent into orbit to monitor the 1963 U.S.-Soviet Union treaty banning nuclear weapon tests in the atmosphere). The bursts' extreme energy output has continued to puzzle astrophysicists, but a general picture has emerged.

Rotating matter, in the form of a massive star or a pair of compact objects (such as two neutron stars or a neutron star and black hole) can reach a stage at which the force of its own gravity causes it to spiral inward. Because the matter is rotating, it also experiences a centrifugal force that opposes the inward motion. Gravity usually wins out, and most of the matter collapses to a point, forming a black hole—a region of space whose gravitational force is so strong that nothing can escape it, not even light. As matter plummets to the point of no return, it releases a huge amount of gravitational energy.

Now the picture gets fuzzier. In some unknown fashion, a fraction of that energy gets trapped in a disk of matter that was held back by centrifugal force and now rotates around the black hole.



The matter in the disk reaches velocities close to the speed of light and turns into a fireball consisting of electrons, positrons, protons, gamma rays, and probably magnetic fields. The fireball expands outward, forming a jet. As this jet of radiating matter and magnetic energy shoots into space at nearly the speed of light, it sweeps up whatever matter is in its path, producing a blast wave of gamma rays lasting tens of seconds on average. In its wake, the jet leaves hot, glowing material that produces a so-called afterglow (photons of much lower energy than gamma rays) lasting hours or days. The afterglow supplies information concerning the environment around the source of the gamma burst and further constrains how the burst might be generated.

hot-wired to a next-generation information system. Just as Google has revolutionized how we learn, the new thinking telescope network should serve as a "discovery engine" for astronomy, scanning the entire night sky every 5 minutes, screening a hundred million visible objects for ones with time-varying signals—optical transients—and picking out, on its own, the ones that have something new to tell us. It will then implement an effective observational strategy. Very ambitious, but what will we learn?

Patrolling the Mutable Heavens

There are many kinds of optical transients, not just those from gamma-ray bursts, and they tell us about the dynamic evolution of the universe. For example, the light pulses from distant supernova explosions suggest that a radically new force—dubbed dark energy—is causing the universe's overall expansion to speed up, not slow down. The optical signals and afterglows of gamma-ray bursts are giving us hints about the various progenitors of stellar-size black holes. Because these bursts are found in the very-early universe, their bright afterglows may also teach us about the environments in which the first stars were born.

There's a thirst to learn more about dark energy and dark matter and about the unknown "life-cycles" of *bright* energy and *bright* matter—all the visible entities in the night sky, which are made of the same chemical elements we see on Earth. In 2012 the National Science Foundation, NASA, and the Department of Energy plan to initiate a very deep all-sky optical survey using the Large Synoptic Survey Telescope (LSST), an 8.4-meter telescope with a billion-pixel digital camera that will see halfway across the universe and pick up tens of thousands of optical transients every night.

Top: The first RAPTOR system, with four small lenses for performing an all-sky survey and a huge telephoto lens for observing interesting optical transients.
Bottom: James Wren adjusts the new 16-lens RAPTOR-K telescope, which is capable of viewing most of the useful local sky (about 20 percent of the full sphere) every 5 minutes.

But the LSST by itself won't be able to differentiate the important transients from the less-important ones. "The LSST could drown us in a flood of data," says Wozniak, "unless we have autonomous systems in place that are able to recognize the interesting events and follow up with real-time observations. Those systems will have to learn and evolve over time if we are to make sense of the dynamic database that is the night sky."

RAPTOR, with its impressive record observing the optical transients from gamma-ray bursts, the largest and most violent of stellar explosions, provides a solid platform for building a prototype system that can cope with LSST's torrent of data.

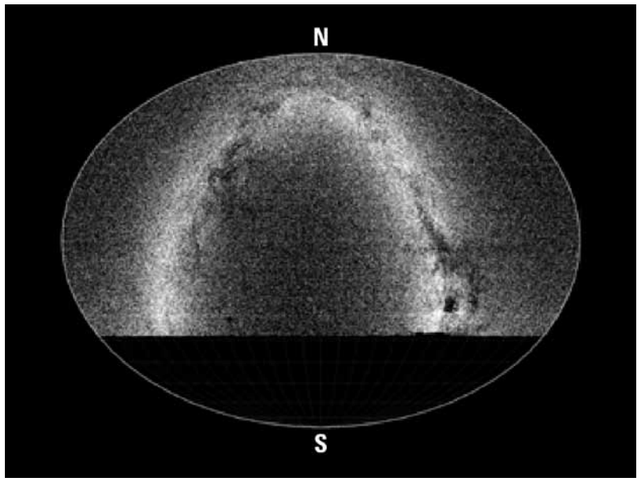
The Most-Violent Explosions in the Universe

When Los Alamos scientists began building robotic telescopes 10 years ago, gamma-ray bursts were making headlines because their location in the universe was finally becoming known.

These explosions, known since 1967, are so bright that the laws of physics seemed to demand that they originate in our galaxy. However, telescopes can't focus gamma rays, so it was impossible to trace them back to their source.

Then in 1997, a NASA satellite finally detected both a burst and the x-ray portion of its afterglow, which could be traced to a tiny patch of the sky. The world's largest optical telescopes—the Hubble in space and the ground-based Kecks in Hawaii—collected light from that patch for 4 to 6 hours and finally detected an ancient galaxy at the edge of the universe. Evidently the burst had come *not* from our Milky Way but from a galaxy billions of light-years away. One of the great scientific debates of our time was settled.

To be detected from so great a distance meant that the source of the gamma rays was astonishingly bright, releasing in tens of seconds as much energy as the sun would radiate in light in 10 billion years. Only the birth of a black hole could release that much power.



Above: RAPTOR images of the time-varying sky are the latest in "cosmic cinematography." This single frame from a several-hundred-frame movie in SkyDOT (Sky Database for Objects in the Time-Domain) shows the positions of a half-million objects, 7,000 of which are newly discovered variable stars. The next-generation RAPTOR will add to the movie at the rate of 100 frames per night.

The race was on to see more of these bursts and to follow up each NASA satellite gamma-ray alert with studies of lower-energy signals (x-ray, optical, infrared, radio) that might hint at the source, or "central engine," of the gigantic energy release (see "Gamma-Ray Bursts").

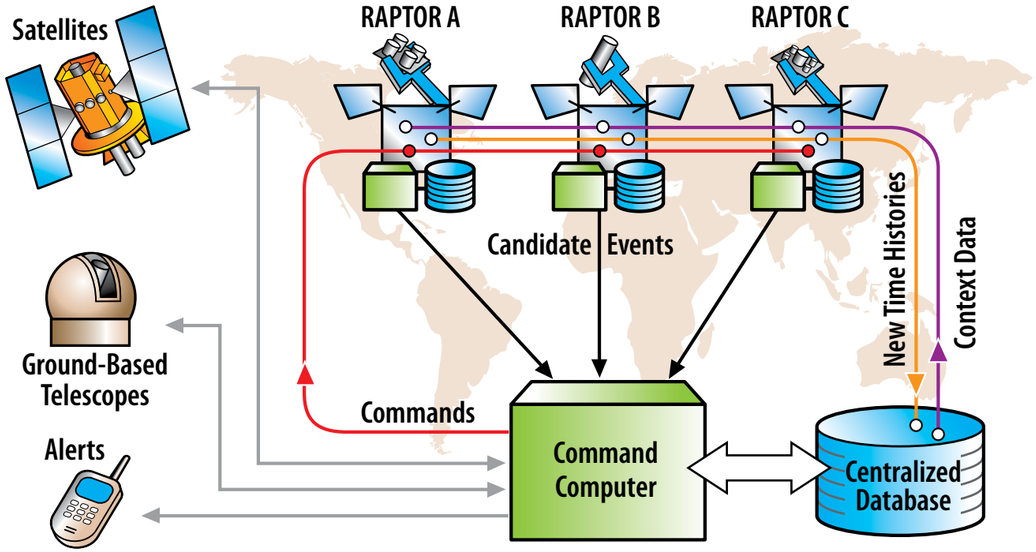
Because these short-lived explosions occur only three or four times a day at random places in the universe, it seemed that optical telescopes, which must wait for satellites to spot the bursts, would never be able to follow up quickly enough to discover if an optical signal accompanied the burst itself. They would see only the afterglow that followed. Then, in a series of tour-de-force measurements, Los Alamos robotic telescopes did the impossible.

A Burst Caught in the Act

On January 23, 1999, RAPTOR's predecessor, ROTSE-I (Robotic Optical Transient Search Experiment-I), responded to a NASA gamma-ray burst alert and within 10 seconds recorded the very-early afterglow, the most-luminous optical source detected up to that time but not part of the burst itself.

Determined to catch a burst in the act, Vestrand and team improved and transformed ROTSE-I into the first generation of RAPTOR. Modeled on human vision, it had four small lenses that acted like the eye's peripheral vision and a central telephoto lens that captured the fine details.

Two of these systems placed 38 miles apart saw a patch of sky from two slightly different viewing angles (stereovision). A central command computer



The Next Generation RAPTOR—A Closed-Loop System for Astronomical Discovery

The next-generation RAPTOR will have smart, rapid-response telescope arrays at several locations around the globe. The on-site computers will identify interesting transients and send information about them to a central command computer that compares and interprets the data from the various sites. The command computer will also dispatch requests for information about local conditions affecting image quality, direct a coordinated observing strategy among all assets, and share information with satellites and ground-based telescopes outside the RAPTOR system, as well as with human overseers. The entire system will be continuously kept abreast of past and current developments through a centralized database of context data (images, observational conditions, and long-term time histories. The hierarchical structure will ensure coordinated real-time processing and rapid response to both internal and external alerts.

(RAPTOR's brain) continuously compared the two views to distinguish distant from nearby (mostly man-made) astrophysical objects and automatically remove thousands of small data glitches such as equipment noise and cosmic-ray hits.

Vestrand comments, "This distributed and yet integrated operation of robotic telescopes and data systems was the heart of RAPTOR and the 'thinking telescopes' concept from the very beginning."

By December 19, 2004, a second-generation RAPTOR, with a larger 0.4-meter telescope and larger high-speed mount, was able to respond in only 8 seconds to a gamma-ray burst alert from Swift. The NASA satellite had seen a small gamma-ray pulse that turned out to precede the main burst by several minutes. RAPTOR was in position to record the optical emission throughout the burst and beyond. The recording revealed a complete surprise. Optical pulses were occurring *during* the burst, synchronized with the gamma-ray pulses. They must have been generated by the same "engine" that produced the burst itself. It was the first-ever recording of what is now called "prompt" optical emission.

On August 20, 2005, RAPTOR recorded another long burst that confirmed the previous findings. It also allowed scientists to say with a great degree of confidence that gamma-ray bursts have two distinct types of optical emissions *contemporaneous* with the gamma rays: the newly discovered prompt optical emission and the very-early afterglow, which starts up almost simultaneously. It's like a sudden energy release from an explosive charge, accompanied by embers glowing in the path of the blast wave.

Significance of the Optical Signals

RAPTOR's discoveries have set the stage for us to learn more about the central engine driving gamma-ray bursts and the medium immediately surrounding them.

The brightness of the optical signals suggests that RAPTOR could search independently for gamma-ray bursts without waiting for a satellite's gamma-ray alert. The afterglow's dramatic rebrightening that RAPTOR reported to Wozniak suggests that even more "optically rich," high-energy phenomena may exist and that they can be discovered *only* by surveying the sky for visible light. Each transient astrophysical phenomenon represents an area of intense interest that scientists want to study in depth.

But is it really possible to detect these short cosmic explosions from their optical signals alone, considering the complexity of the night sky? The gamma-ray sky is almost empty but for the few lone gamma-ray bursts and several hundred very faint persistent sources. By comparison, the visible sky is a maelstrom of flickering objects—satellites, airplanes, space debris, cosmic rays, meteors, asteroids, comets, flaring stars, active galactic nuclei, exploding novae, supernovae, and the rare optical transients from gamma-ray bursts—observed against a static backdrop of billions of ordinary stars and galaxies.

"The next version of RAPTOR will be a powerful new tool for searching out previously unknown phenomena within the maelstrom," comments Vestrand.

"Thinking" Goes Worldwide

RAPTOR's next incarnation will collect and analyze the plethora of optical transients at unprecedented rates (see "The Next-Generation RAPTOR"). A wide-field system such as the 16-lens RAPTOR-K will "harvest" time histories of all objects up to 10,000 times fainter than those detectable with an unaided eye. Tens of thousands of images collected every night, roughly 1 terabyte (a trillion units of data) per week, will be processed within seconds of collection and then compared with an enormous body of stored data on the time history of the night sky.

Emerging transient objects will be reported automatically while they are still occurring, giving response instruments enough time to make otherwise-impossible observations. In addition, the next-generation system will use arrays like RAPTOR-T (T for technicolor), carrying four co-aligned 0.4-meter telescopes with four different color filters, to pinpoint changes in the intensity of each color emitted during the first critical minutes of a gamma-ray burst. Information about the distance to the burst and about the burst's environment and dynamics may be gleaned from the color changes.

The speed of the system will continue to set records, but the truly revolutionary aspect is the introduction of "thinking" software agents in the system's command computer. These agents use modern statistical decision theory and algorithms that allow machines to learn in order to perform increasingly complex classification and anomaly-detection tasks, to carry on two-way conversations between the central decision-making computer and deployed assets about the state of the telescopes and the quality of the observed data, and to direct increasingly flexible allocation of telescope resources—all with no human intervention.

The RAPTOR team, riding on a wave of success, is now leading the development of an autonomous global network—a "discovery engine"—that can find totally new phenomena in the many uncharted regions of our time-varying universe. The team is hoping to be awakened many times in the coming years by phone calls from RAPTOR.❖

Right: New-generation telescopes RAPTOR-K and RAPTOR-T, stationed on Fenton Hill. Like their predecessors, they perform their own routine housekeeping functions, including closing up during bad weather and alerting the central computer to equipment malfunctions.

The Hunt for Dark Matter

Andrew Hime, a neutrino physicist who helped discover neutrino masses at Canada's Sudbury Neutrino Observatory (SNO), and Salman Habib, an elementary particle theorist who studies the effects of dark matter and dark energy on cosmology, discuss why a novel new experiment conceived at Los Alamos might well detect dark matter and thereby unify the physics at the smallest and largest scales of our universe.

Andrew Hime

1663: What is dark matter and why is it interesting?

Habib: When we look up at the night sky, we see bright matter—stars and galaxies, comets and asteroids, all made of the same chemical elements we have on Earth. They radiate and absorb light over a range of wavelengths, and that's how we know they're there.

Hime: Dark matter is very different. It neither absorbs nor emits light, so there's no direct way of knowing it's there. But in the 1930s a fellow named Zwicky was studying the motions of galaxies in the Coma cluster, a giant galaxy cluster close to our galaxy, and he noticed that the bright matter in the cluster didn't have enough mass to keep the fastest-moving galaxies from flying off into space.

Habib: Some missing mass, invisible to us, had to be holding the galaxies together through its gravitational pull.

Hime: Zwicky dubbed this mysterious matter "dark" matter. Evidence for it has accumulated over decades, but in the last 5 to 10 years, precision measurements of the cosmic microwave background (CMB), the primordial radiation left over from the Big Bang, clinched both the existence of dark matter and its great abundance.

DIALOGUE

1663: The Big Bang is the explosion that started the expansion of the universe?

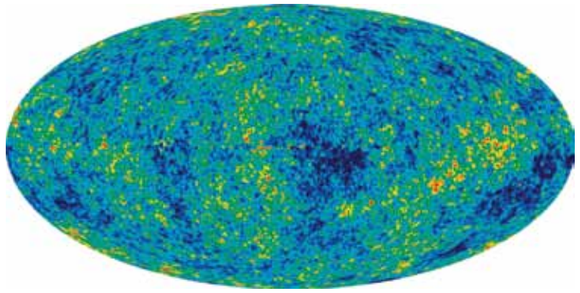
Habib: That's right. The CMB is important. It fills all space and contains an imprint of the hot gaseous matter that existed about 100,000 years after the Big Bang. Although that matter appears to be nearly homogenous, very small temperature fluctuations in the CMB reflect its tendency to condense into separate clumps under the attractive force of gravity. Cosmologists have calculated that ordinary matter alone could not have driven the gravitational instability needed to condense the nearly smooth matter distribution imprinted in the CMB into what we see some 13 billion years later—huge walls of galaxies and galaxy clusters surrounding giant regions devoid of bright galaxies. Instead, the total amount of matter in the universe must be much larger, with ordinary visible matter composing only 15 percent and dark matter, which we cannot see, composing the other 85 percent.

1663: What might dark matter be made of?

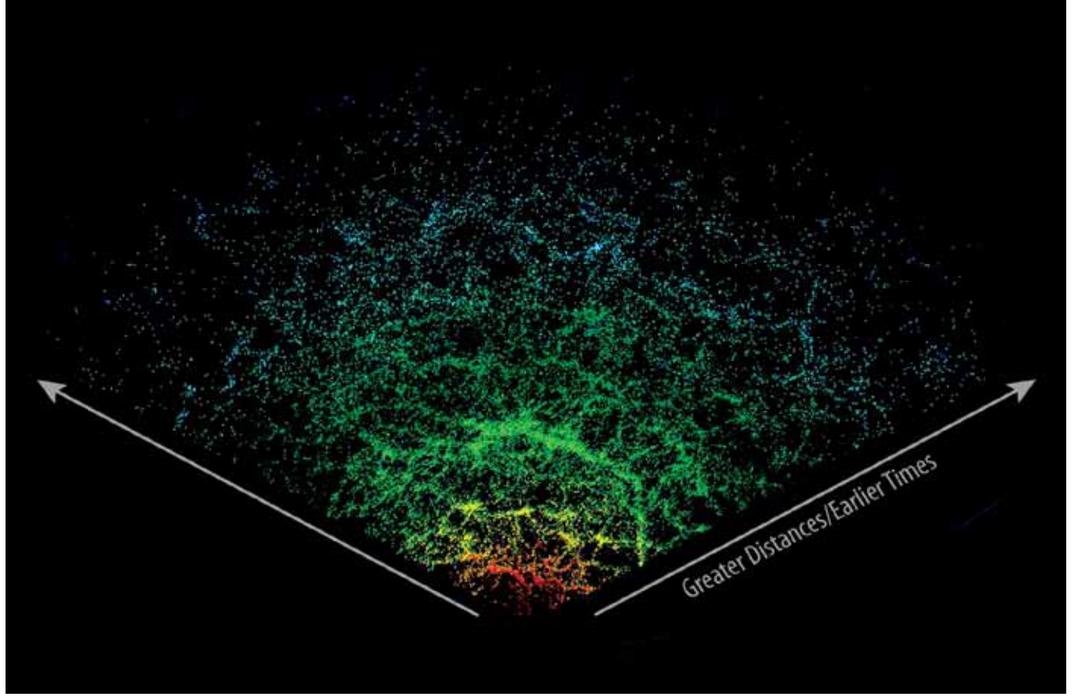
Hime: We don't really know, but there are compelling reasons to think it's made of subatomic particles yet to be discovered—particles that interact very weakly with ordinary matter.

1663: Could they be neutrinos?

Hime: We do live in a sea of primordial neutrinos, also leftovers from the Big Bang, and we discovered at SNO that neutrinos are particles with mass. However, they are too light and too energetic—they move on average at nearly the speed of light. We need a massive, slow-moving particle to form the cosmological dark matter.



Map of the cosmic microwave background (CMB) radiation, showing temperature fluctuations (yellow and blue) that vary by only a thousandth of a percent. These fluctuations represent an imprint of the variations in matter density in the early universe. IMAGE COURTESY OF NASA/WMAP SCIENCE TEAM.

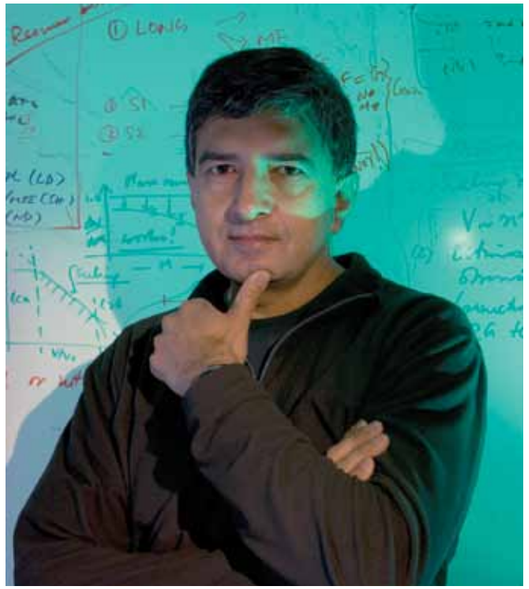


This map shows the positions of over a million galaxies (dots) relative to us (the origin—center, bottom). As time progressed, galaxies coalesced into walls and clusters surrounding large voids—the lumpy large-scale structure of the universe in our cosmic neighborhood. IMAGE COURTESY OF: SLOAN DIGITAL SKY SURVEY (SDSS.ORG)

Habib: If the dark matter particles move too quickly, they would counteract the tendency for gas clouds to condense into galaxies. With slow dark matter particles, structure in the universe would form naturally in a hierarchical fashion, small structures forming first and then merging to create larger ones. And that is what we see in the universe. First, galaxies formed, then galaxy clusters, and finally a network of galactic superclusters encircling our cosmic neighborhood.

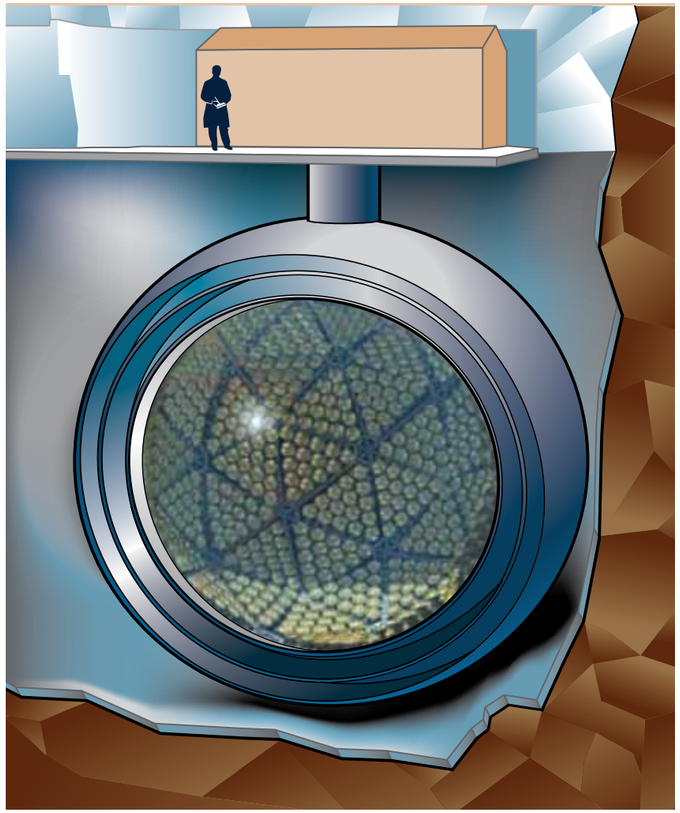
Hime: Remarkably, a new theory of elementary particle physics, called supersymmetry, predicts the existence of elementary particles with just the right properties to explain what dark matter is and where it came from. These new particles have no electric charge, but they do interact with ordinary matter through what's called the weak nuclear force, the force that causes nuclei to undergo radioactive decay. They are called Weakly Interacting Massive Particles, or WIMPs, and the strict symmetries in this new supersymmetric theory ensure that they remain stable and do not decay. They also have the right masses and the right level of interaction with ordinary matter to be yet another relic of the Big Bang.

Habib: Andrew means that as the universe expanded after the Big Bang, it cooled to a temperature at which the WIMPs froze out of the cosmic soup, forming a background of matter with the right mass density (and hence gravitational influence) to explain the buildup of the structures we observe in the universe.



Salman Habib

The proposed 100-ton CLEAN detector (for Cryogenic Low-Energy Astrophysics with Nobel gases) is designed to detect dark matter particles (WIMPs). Buried deep underground, it will consist of a giant bottle filled with liquid argon (or liquid neon) and lined with photomultiplier tubes that convert scintillation light to electrical signals. CLEAN is expected to detect upwards of 100 WIMPS per year.



Hime: Just a back-of-the-envelope estimate based on the strength of the weak nuclear force and the expansion rate of the universe gives you the right mass density for a primordial background of WIMPs. Now we want to make a direct search for those particles to see if they're really out there.

1663: How can you detect a WIMP if it hardly interacts with ordinary matter?

Hime: Imagine our galaxy permeated by a cloud of dark matter WIMPs, and imagine the solar system, and thus Earth, moving through the cloud as it circles around the center of the galaxy. The WIMPs would be moving at several hundred kilometers per second relative to us. We want to record the small wake of energy left behind as a WIMP collides with and recoils from an atomic nucleus in our experimental apparatus.

In the experiments we now have planned, a big spherical container filled with an ultra-pure, liquefied noble [inert] gas—either argon or neon—will be surrounded by light detectors. When a WIMP hits an argon or neon nucleus, that nucleus will recoil, causing the energy of its motion to be translated into a flash of light (scintillation light) as it slows to a stop. The WIMP has the same mass as 100 protons, and if you work out the math, you find that the nucleus it collides with will recoil with a very tiny energy, some thousand times smaller than the energies we detect when a neutrino from the sun collides with a heavy water molecule (D_2O) in the huge detector at SNO.

1663: Can you detect such a low-energy collision?

Hime: Yes, we can, and we have successfully demonstrated that in the laboratory. Even though a WIMP collision will produce only a few photons [light particles], all of them will reach the light detectors because these noble liquids are transparent to their own scintillation light. The wavelength emitted by the ionized diatomic molecules created by the WIMP collision is longer than single neutral atoms can absorb (see "WIMP Detection"). From the pattern of light hitting the detectors, we can reconstruct the position of all these events, and we consider only those that are distant from the container walls to eliminate events caused by radioactive impurities or other nuclear reactions in the walls.

Habib: The real question is, how will we know the photons we detect are from a WIMP and not some other particle going through the tank?

Hime: That's the difficult challenge of this experiment, to reduce the background signals, and that's where the properties of argon and neon become so important. First, because these noble gases liquefy at very low temperatures, all the radioactive contaminants that would produce spurious signals condense out of the starting gas well before it liquefies. Second, because these liquids are transparent to their own scintillation light, we can make a very big spherical container and still detect the very few photons produced in a WIMP-nucleus collision.

Third, these liquid noble gases scintillate very brightly in the extreme ultraviolet—enough to allow detection of even the faint signal induced by the recoiling WIMP of interest.

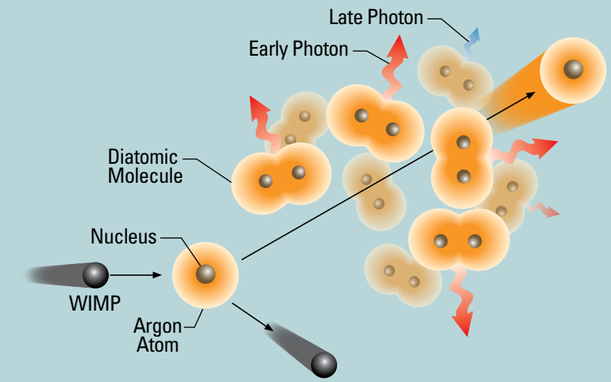
Now, the pièce de résistance for both neon and argon is that the scintillation light has two different components: a fast component, "early light," emitted in nanoseconds and a slower "late light" component emitted over several microseconds. This allows us to distinguish a nuclear recoil, which produces hardly any of this late light, from an electron or a gamma ray from radioactive decay, which produces a lot of late light. So if you don't see this late light, you know it's a WIMP, provided the detector is deep underground where there are no other neutral particles—no cosmic-ray neutrons, for example—to fake the nuclear recoil signal of a WIMP. This power to discriminate between background events and the nuclear recoil from a WIMP collision is so large that it increases our sensitivity a thousand times over present experiments.

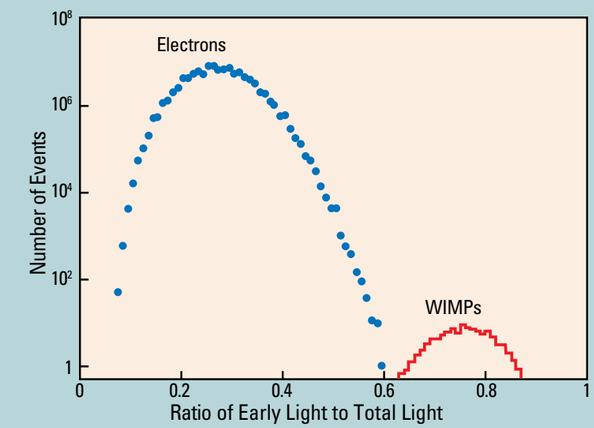
1663: How many WIMP events do you expect to see?

Hime: It could be as little as one per year per ton of noble liquid. We're working with argon first because its nucleus is twice the size of neon's and has four times the chance of colliding with a WIMP. The downside is that argon contains a radioactive isotope, but since the decays will produce late light, they will be distinguished as background.

We've already tested and demonstrated the concepts in small prototype experiments of 1 to 10 kilograms. Obviously, we don't have a source of WIMPs, so we used neutrons. They produce nuclear recoils in the liquid just as WIMPs would do. Now we're building a 100-kilogram detector, which should be about 50 times more sensitive to WIMPs than the current state of the art. If it works, it's easy to take it up to the metric ton scale, which adds an additional factor of 10 in greater sensitivity. If we detect a WIMP, it will be very exciting. If we don't, it will be equally important because it will rule out WIMPs as dark matter candidates. In any case, these novel detector concepts will be paramount to resolving the dark matter problem.

Supersymmetry may not be exactly the right theory of elementary particles. But there's got to be a simple principle like it that solves fundamental issues on the microscopic scale and, for a completely unpredicted reason, solves this dark matter mystery for you. The possible existence of dark matter particles like WIMPS is so compelling that it just invites you to go out and directly look for them.❖





WIMP Detection

Top: A WIMP (black) can pass through the earth and into the liquid argon-filled CLEAN detector, where it collides with an argon nucleus.

In the liquid, the recoiling nucleus collides with and ionizes atoms, which pair up and form excited diatomic molecules. These decay and emit light either quickly ("early light") or slowly ("late light"). In the WIMP event shown here, there's hardly any late light. But in background events (electrons stemming from radioactive decay), most of the light is late light.

Bottom: A simulation of signals shows a clear separation between a WIMP signal and an electron signal. Each data point is the ratio of early light to total light detected for each event.

GRAPH REPRINTED FROM M.G. BOULAY AND A. HIME, *ASTROPARTICLE PHYSICS*, VOL. 25, P. 179, 2006.

SPOTLIGHT

Present at the Solar System's Birth

Vesta and Ceres—two of the largest bodies in the main asteroid belt between the orbits of Mars and Jupiter—have remained largely intact since forming 4.5 billion years ago. These two asteroids essentially are records of the solar system's physical and chemical condition in its early planet-forming phase, which is why NASA's Dawn spacecraft is on its way to study them.

Launched in September, Dawn will reach Vesta and Ceres in August 2011 and May 2015, respectively. An onboard gamma-ray and neutron detector, GRaND, developed by Los Alamos, will then map the near-surface abundances of major rock-forming elements (oxygen, magnesium, aluminum, silicon, calcium, titanium, and iron). Combined with data from optical spectroscopy, the information will enable scientists to determine how the asteroids formed and evolved. The spectrometer will also map the abundance of hydrogen, which indicates the presence of ice or hydrated minerals. Lastly, GRaND will measure the abundances of the radioactive elements potassium, thorium, and uranium. The heat generated by the decay of these elements may have driven volcanic activity on Vesta or caused the formation of a sub-surface ocean on Ceres.

"GRaND will help us understand how the surfaces of Vesta and Ceres were shaped by such things as volcanism and the presence of water, giving us new insights into how the asteroids evolved," says Tom Prettyman, lead scientist for the Los Alamos instrument and co-investigator for Dawn.

GRaND can identify the major rock-forming elements because each emits a characteristic spectrum of gamma rays or neutrons when bombarded by galactic cosmic rays. It will similarly detect the gamma rays from the radioactive elements. Elemental abundances are determined by analyzing the gamma rays, with the neutrons providing additional but necessary information.

Tom Prettyman, in a clean suit, prepares GRaND (inset) for launch.

A superluminal transmitter.

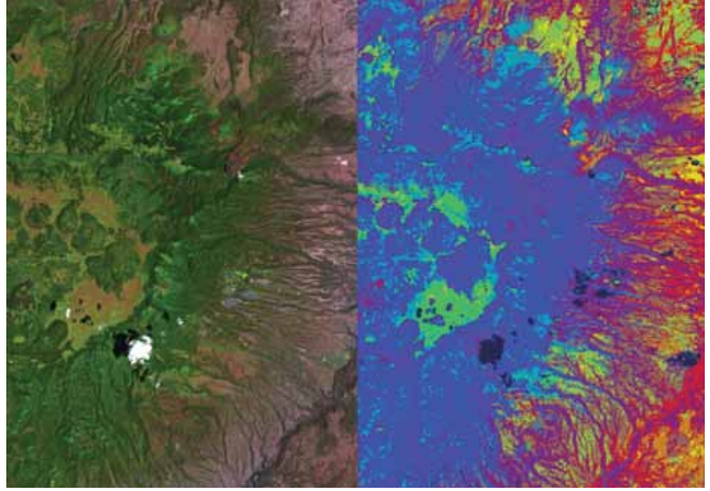
Unusual Waves

Forget Superman and "faster than a speeding bullet." How about superluminal and faster than the speed of light!

John Singleton of Los Alamos and his collaborators have built a radio transmitter that incorporates a radio wave source that moves superluminally (faster than light). The emitted waves have several unusual properties. For example, they lose much less power over a distance than do ordinary radio waves; thus, they show promise for long-distance, low-power broadcasting applications.

Ordinary objects can't move faster than light. But consider a line of people where the first person snaps their fingers, then after a delay, the second person snaps theirs, and so on. The "snap" moves down the line with a speed determined by the delay, which can be arbitrarily short. Hence the snap can move arbitrarily fast.

The radio wave source moves similarly through the transmitter, a long, curved piece of dielectric (a material that can be polarized) with electric amplifiers attached every few inches. When triggered, the first amplifier "snaps its fingers" and produces a strong electric field in a region of the dielectric adjacent to the amplifier. Positive and negative ions move in opposite directions, and the region becomes polarized. Turning the second amplifier on and the first one off causes the polarized region to move down the transmitter, creating a "polarization current" that is a source of radio waves. The amplifiers can be triggered in such a way that this source moves the length of the transmitter faster than the speed of light.



A NASA satellite image (left) was analyzed using Genie Pro (right). It identified land areas of interest: forests in blue, grasslands in green, scrub and bare ground in yellow/red.

Genie Pro

Satellite imagery data are being captured at higher quality and in greater amounts than ever before. Unfortunately, few organizations are capable of analyzing so much complex data.

A Los Alamos team has developed a remarkable image-analysis software system called Genie Pro that will make the job easier by reducing the time and skill required for analysis.

Genie Pro is a machine-learning software system that analyzes color and texture in image data to find features of interest. Genie Pro uses an evolutionary algorithm that evolves new software each time it's used.

An analyst uses a simple point-and-click graphical interface to identify a small set of example data in a satellite image, say a region of conifer forest or a particular agricultural crop. Genie Pro then learns a new software program that can detect and map out that feature using the selected satellite data. This new software program can then be applied to similar images, for example, to map a type of forest across a large region or entire country.

Developed and funded by the Department of Energy and Department of Defense, Genie Pro has been used to analyze damage caused by natural disasters such as wildfires, hurricanes, and earthquakes; to evaluate terrorist attacks; and to monitor environmental changes and crop health. Genie Pro can also be applied to a wide range of non-satellite imagery, such as microscope images of tissue samples.

Future developments will expand its analytical capabilities to video and 3-D data and extend its application to more fields of science and industry.

Los Alamos recently signed exclusive field-of-use license agreements for Genie Pro with the Virginia company Observera, Inc., which does remote sensing and image science, and with Aperio Technologies, Inc., a digital pathology company based in Vista, California.

An MRI for Your Luggage

If you've flown recently, you've encountered the "3-1-1 rule" for fluids (liquids, gels, and aerosols) in carry-on luggage. Containers of such things as toothpaste and cosmetics must not exceed 3 ounces each and must be packed together in a single quart-size plastic bag—one per traveler. The plastic bag is screened separately at the airport security checkpoint.

The rule dates from September 2006, after London authorities uncovered a plot to blow up airliners with liquid explosives.

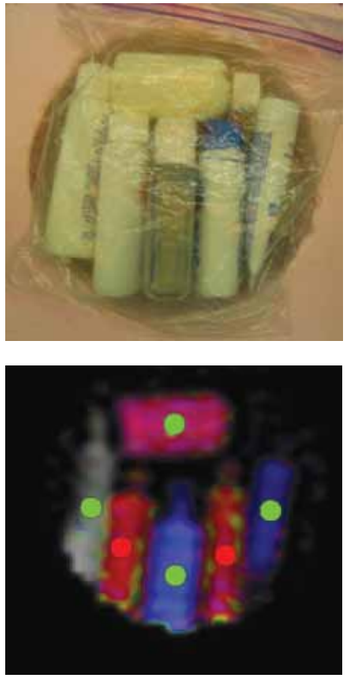
A Los Alamos research team is hoping to make 3-1-1 unnecessary by developing a new kind of magnetic resonance imaging (MRI) machine—MRI Screen—adapted to the needs of airport security.

At hospitals, MRI scans provide images of internal organs. They do so by using radio waves and a strong magnetic field to coax hydrogen atoms into revealing their positions within the body. The Los Alamos machine uses the same principle to capture images of fluid products and will ultimately be applied to products packed deep inside a carry-on bag.

Because different chemicals produce different magnetic "signatures," MRI Screen even distinguishes between fluids—hand lotion versus liquid explosives, for example—by feeding data to a computer for determination of which fluids are safe and which are possible threats. It then marks the items in the image with a colored dot: red for unsafe, green for safe, and yellow for unknown. Security personnel can then remove the red-labeled items and double-check the yellow-marked ones.

The magnetic fields used in MRI Screen are at least 1,000 times weaker than the ones used for medical MRIs, resulting in a smaller, lighter, and less-expensive machine, perfect for security purposes. A prototype will be tested in August 2008 at an operational airport, possibly the Albuquerque Sunport.

Work on MRI Screen is sponsored by the Department of Homeland Security.



The fluid containers packed in compliance with the 3-1-1 rule (top) are marked with colored dots in an MRI Screen scan to indicate level of potential threat.

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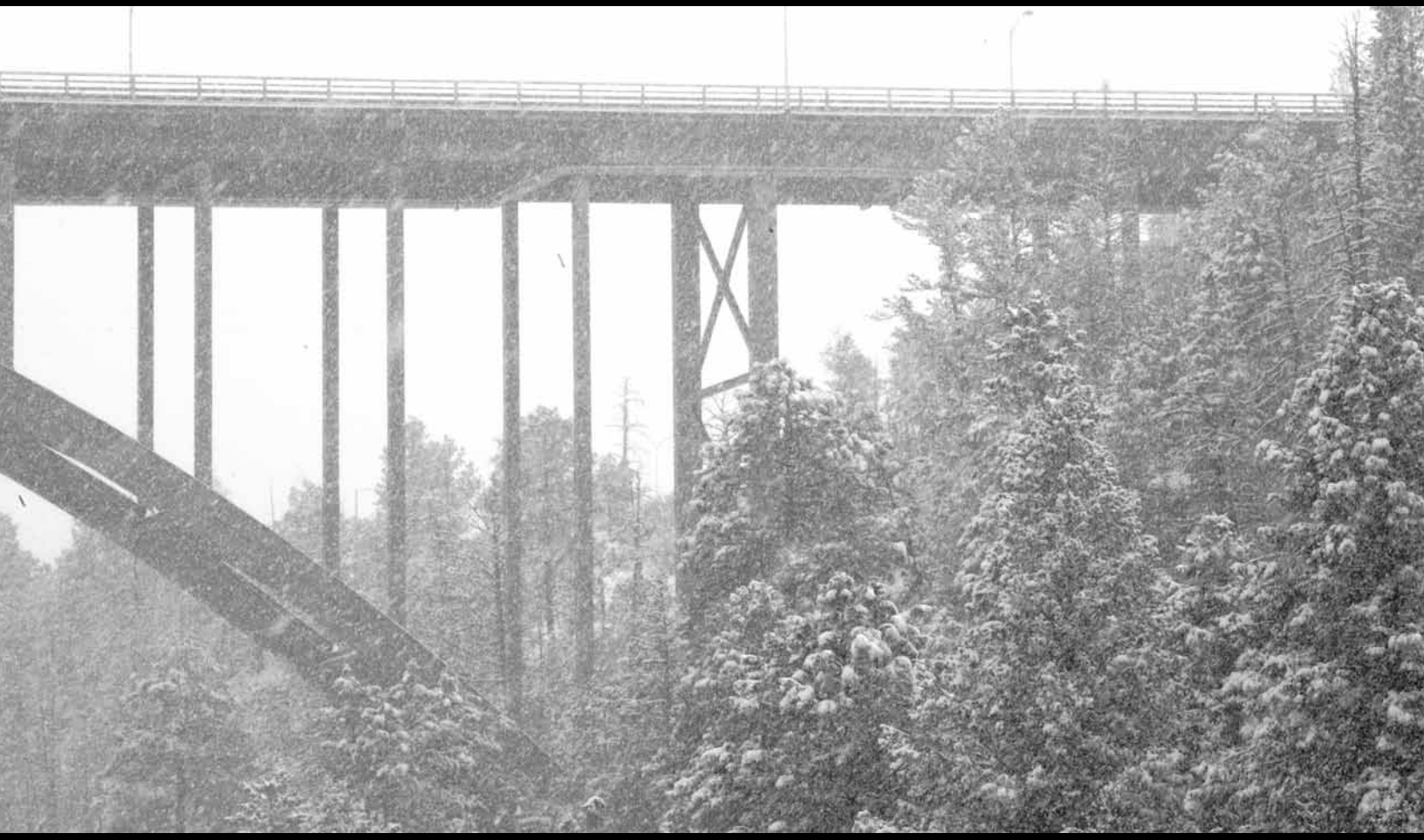

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