

# 1663

The Other Helium Shortage  
Smart Telescopes Go Stargazing  
No-bang, Big-gain Tests  
The Secret Life of Endothelial Cells

Out of **Thin Air**  
Searching the planet  
for much-needed  
climate data





More than a hundred independent laser beams fan out in a hemispherical pattern as a result of passing through the fish-eye lens of a small probe. Together, the probe and lasers form the front end of a powerful new diagnostic demonstrated during the most recent subcritical nuclear weapons test. The test provided an unprecedented amount of high-quality data that will be used to help ensure the safety and reliability of the U. S. nuclear stockpile. Both the diagnostic and the subcritical tests are vividly described in "Critical Subcriticals" on page 20.

### About the Cover:

In broad strokes, greater concentrations of greenhouse gases in the atmosphere bring about greater climate warming. But the complex impacts of clouds and aerosols, too, are significant and remain the single largest source of uncertainty in current efforts to model and forecast the climate. Making finer-detail climate predictions depends on making finer-detail measurements of the various component influences, especially the formation and behavior of clouds in the context of different locations, conditions, and anthropogenic factors. For its part in this endeavor, Los Alamos National Laboratory has deployed atmospheric measurement and sampling stations at key locations around the world to gather the much-needed data.

### 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.

### About the LDRD Logo:

Laboratory Directed Research and Development (LDRD) is a competitive, internal program by which Los Alamos National Laboratory is authorized by Congress to invest in research and development that is both highly innovative and vital to our national interests. Whenever *1663* reports on research that received support from LDRD, this logo appears at the end of the article.

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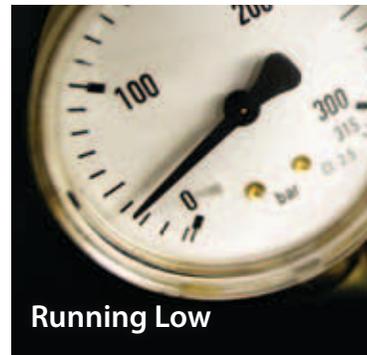
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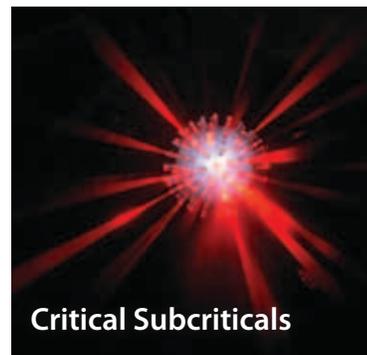
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Microbiome References Required  
Sounds Like Better Weather  
The New Vascular View

14:06:34 NEA



# *tracking transients*



05:24:02 SAT

*how los alamos's thinking telescopes  
monitor and interpret  
millions of points of light*

21:38:16 GRB

OUR UNDERSTANDING OF THE UNIVERSE and our place in it comes from observing the patterns and motion of all the lights that speckle the darkness. Even before the invention of the telescope, stargazers saw familiar shapes among the brightest points—a hunter, a scorpion, a ladle, a lion—and tracked the changing positions of the planets. But the first time a telescope was pointed into space, it heralded a new era of astronomy. With increased depth of vision, new objects were illuminated and new patterns revealed. Indeed, telescopes profoundly transformed our understanding of everything that fell under their gaze—at least, everything that sat still long enough to be seen.

A transient astronomical event is, unsurprisingly, one that lasts for a short time then is gone. Such transients can last anywhere from seconds to days and are caused by changes in the position or intensity of light. They occur when orbiting satellites sail by or distant cosmic explosions blaze into view, when aircraft navigation lights blink and meteors burn up. In a single night, millions of transients take place above our heads; the night sky is alive with momentary twinkles, flashes, and flares. Look up for a moment and you're bound to see one, and if you have a telescope, you'll see it even better.

Astronomy is observational by necessity. Until the not-too-distant past, it was a circadian science—go outside at night, watch the sky, come inside and record what you saw, repeat the process the next night, and see what has changed. But Los Alamos astrophysicist Tom Vestrand says the cadence of astronomy is changing. No longer constrained to a daily rhythm, developments in the night sky can now be observed minute-by-minute.

"We are entering an exciting new era of time-domain astronomy," he says, "where there will be an overwhelming number of transients found in real time." Time-domain astronomy means doing repeated scans of the sky then looking for changes from one scan to the next, and it's Vestrand's goal to get the time domain down to mere seconds. He is the lead on Los Alamos's RAPid Telescopes for Optical Response (RAPTOR), an array of "thinking" telescopes that are being trained to discriminate which transients to observe, independent from their human operators.

Thirty miles outside of Los Alamos, in the Jemez Mountains, lives the RAPTOR family of specialized telescopes. Vestrand likens the array to an ecosystem: multiple discrete

elements serving different purposes and working together for an optimal outcome. They are the fastest-slewing telescopes in the world, able to swivel from point to point in under five seconds. There are wide-field lenses for persistent monitoring (like human peripheral vision) and narrow-field lenses that zoom in to take a better look at interesting events. The most recent additions are a 16-lens telescope that scans the entire sky every five minutes, and a telescope with four colored filters for enhanced observation of the optical emissions from celestial transients.

The RAPTOR robotic observatory is central to Los Alamos's Thinking Telescope Project, which is developing both the hardware necessary to track transients in real time and the software needed to manage the massive amount of data collected. The project already has robotic telescopes that can detect and identify transients automatically. Now Vestrand's team is training them in autonomy—teaching them to determine which transients are interesting and what type of observation to perform on a case-by-case, second-to-second basis.

### Training telescopes

While the idea of thinking telescopes autonomously tracking millions of blinks and twinkles in the sky is thrilling, comparatively slow and clumsy humans can't be eliminated from the picture altogether. Central to robotic observatories like RAPTOR are high-powered computers that first need to be programmed to classify transients and initiate follow-up observation. Each time a transient is detected, it must be correctly classified according to its initially observed characteristics. What kind of event it is will inform what kind of follow-up observation is appropriate, and the follow-up data will feed back and help fine-tune the classification process.

# gamma-ray bursts

## A Los Alamos History of Discovery

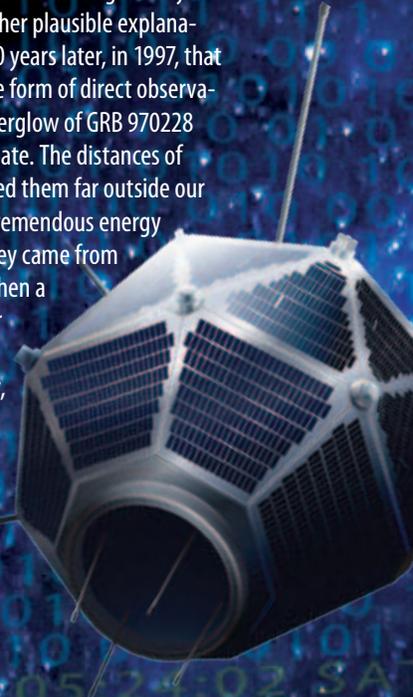
In 1972 a Los Alamos scientist named Ian Strong was asked to dig through nearly 10 years of back-catalogued data collected by the Vela Satellite Program. A tiresome task to be sure, but it would lead to the discovery of one of the most curious modern astronomical phenomena and open the door to decades of fascinating and far-reaching research.

Vela's primary goal was to monitor the earth for illegal nuclear explosions following the Nuclear Test Ban Treaty of 1963. The Vela satellites were built at Los Alamos and configured to monitor x-ray, gamma-ray, and neutron emissions from the entire planet, 24 hours a day, 365 days a year. The gamma-ray detectors aboard the satellites were often triggered by events that were clearly unrelated to earthly nukes. Though interesting, these events were deemed peripheral to the program's main goal and were filed away for later study.

As he worked through the data collected from each trigger of Vela 5's gamma-ray detectors, Strong carefully calculated the source position in the sky for each one. There could be no doubt, he and his Los Alamos supervisor, Ray Klebesadel, finally reported, that the gamma-rays were of cosmic origin—meaning they weren't coming from the earth or its sun. This was the first evidence that major gamma-ray-emitting events were regularly occurring in deep space.

Prior to asking Strong to rummage through Vela's data, Klebesadel and another Los Alamos colleague, Roy Olsen, had noticed something odd. An event recorded by both Vela 3 and Vela 4 appeared to be a burst of cosmic gamma rays, but the instrumentation of the satellites was not yet sophisticated enough to pinpoint the source. After Strong's discovery in 1972, this earlier burst, which occurred on July 2, 1967, was retroactively designated the first-ever recorded gamma-ray burst (GRB).

But that was just the beginning. Many astronomers and astrophysicists weren't sold on the idea of the GRB's cosmic origin. They thought there were other plausible explanations. It wasn't until 30 years later, in 1997, that irrefutable proof in the form of direct observations of the optical afterglow of GRB 970228 finally snuffed the debate. The distances of subsequent GRBs placed them far outside our own galaxy, and the tremendous energy released suggested they came from colossal events, like when a star goes supernova or when two ultra-dense stars collide. Gradually, a clearer picture of what GRBs are, how they occur, and what they do was coming together—and it was breathtaking.



Przemek Wozniak, a scientist on Vestrand's team, is programming the computers to distinguish real transients from bogus ones. It's a balancing act between maximizing event detection and minimizing false positives. Transients are identified by the comparison of light position and intensity between adjacent time-domain scans of the same part of the night sky. The scans, taken roughly 5 minutes apart, are superimposed on one another and the first scan is digitally subtracted from the second. Any remaining light in the image represents a recent change in the position or intensity of a light source, and therefore represents a new potential transient.

A real transient is an astronomical event that occurs somewhere in space and is recorded. A bogus transient gets recorded when there is something that may look to the computer like an astronomical transient but isn't, like a stray cosmic-ray particle hitting the detector dead-on or an aircraft blinking as it passes through the telescope's field of view.

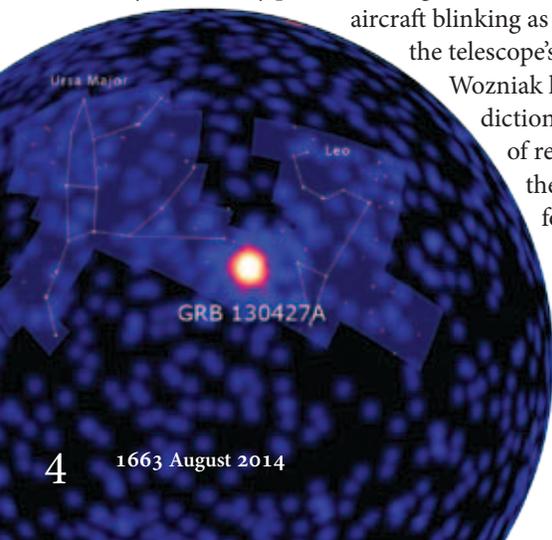
Wozniak has created a dictionary of hundreds of real transients that the computer uses for comparison

against candidate transients. By comparing his millions of candidate transients to the training dictionary, Wozniak identified a sweet spot between false positives and missed events and has been able to achieve a classification accuracy of 90 percent.

Once a transient event is determined to be real, follow-up observation begins, asking new questions and collecting new data. Much like an interview, the answer to each question informs the next question. For example, a car crash is an event. Was the driver speeding? No. Then was the road wet? Yes. Okay, so were the tires worn? No. Was the driver distracted? It is a real-time, iterative process designed to extract maximal, relevant data to fully describe a unique event. And since astronomers can't predict when an important event will occur, having the continuous monitoring system in place, with fast and accurate data acquisition capabilities, is key to capturing and understanding transient events in space.

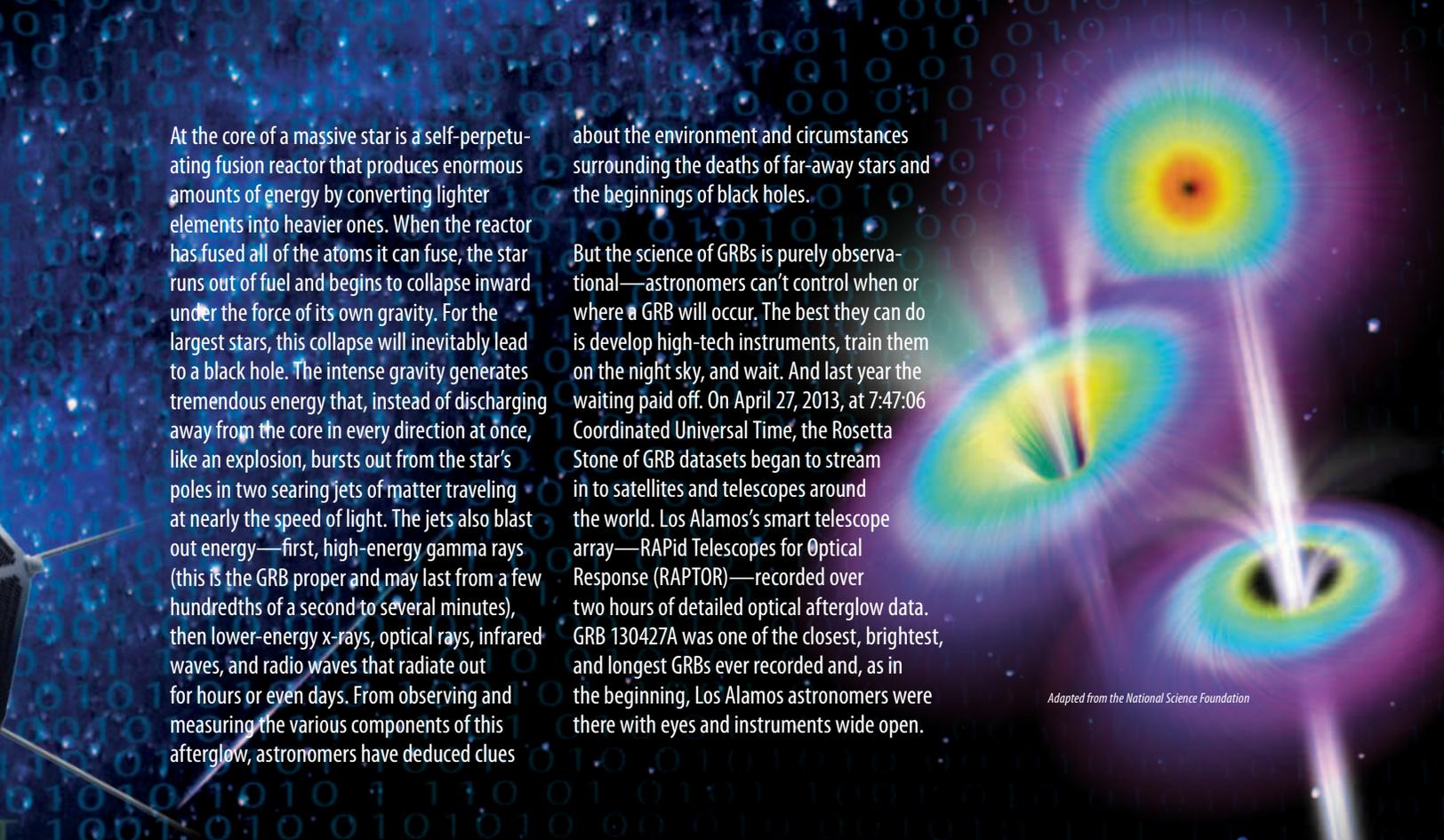
### The burst of the century

Gamma-ray bursts (GRBs) comprise one of the more dramatic cosmic events in RAPTOR's aim (See "Gamma-ray bursts: a Los Alamos History of Discovery" above). GRBs are extraordinary phenomena whose signals arrive on Earth



From in between the constellations Leo and Ursa Major (which includes the Big Dipper), GRB 130427A was one of the brightest, longest, and closest GRBs recorded by modern astronomical instruments, resulting in an unparalleled windfall of data.

Source: NASA



At the core of a massive star is a self-perpetuating fusion reactor that produces enormous amounts of energy by converting lighter elements into heavier ones. When the reactor has fused all of the atoms it can fuse, the star runs out of fuel and begins to collapse inward under the force of its own gravity. For the largest stars, this collapse will inevitably lead to a black hole. The intense gravity generates tremendous energy that, instead of discharging away from the core in every direction at once, like an explosion, bursts out from the star's poles in two searing jets of matter traveling at nearly the speed of light. The jets also blast out energy—first, high-energy gamma rays (this is the GRB proper and may last from a few hundredths of a second to several minutes), then lower-energy x-rays, optical rays, infrared waves, and radio waves that radiate out for hours or even days. From observing and measuring the various components of this afterglow, astronomers have deduced clues

about the environment and circumstances surrounding the deaths of far-away stars and the beginnings of black holes.

But the science of GRBs is purely observational—astronomers can't control when or where a GRB will occur. The best they can do is develop high-tech instruments, train them on the night sky, and wait. And last year the waiting paid off. On April 27, 2013, at 7:47:06 Coordinated Universal Time, the Rosetta Stone of GRB datasets began to stream in to satellites and telescopes around the world. Los Alamos's smart telescope array—RAPID Telescopes for Optical Response (RAPTOR)—recorded over two hours of detailed optical afterglow data. GRB 130427A was one of the closest, brightest, and longest GRBs ever recorded and, as in the beginning, Los Alamos astronomers were there with eyes and instruments wide open.

*Adapted from the National Science Foundation*

daily but originate billions of light years away. To put that into perspective, consider this: our galaxy, the Milky Way, is approximately 100,000 light years across, so GRBs typically occur at a distance from Earth that would accommodate 10,000 Milky Ways strung end-to-end across the universe.

When a massive star in the distant universe has consumed all of the fuel available to it, it collapses in on itself. A black hole begins to form at the stellar core, and jets of matter burst from the stellar poles, producing high-energy gamma rays. If earthbound astronomers are fortunate enough to have one of the jets pointed toward Earth, they may detect it as a GRB. Then, following the gamma rays, which are light that is invisible to the eye, an afterglow of lower energy light, such as x-rays, optical (visible) light, infrared waves, and radio waves, continues to stream away from the moribund star. Most of what we know about GRBs comes from observation of the afterglow.

The GRB closest to Earth (3.8 billion light years) occurred in April of 2013 and had several superlative qualities beyond mere proximity. GRB 130427A, as it is known, was one of the longest ever recorded, with gamma emissions lasting over 20 hours (typical gamma emissions last only minutes or even seconds) and optical emissions lasting nearly two days. It was also one of the most energetic,

which made it extremely bright. In fact, only one other GRB, in 2008, was brighter—so bright that its optical component could be seen from Earth without an instrument, earning it the nickname the “naked-eye burst.” GRB 130427A was only slightly less bright than the naked-eye burst and was clearly visible through a standard pair of binoculars.

What made GRB 130427A a keystone event was not only that it was the closest, longest, and second-brightest GRB ever recorded, but that it was recorded in its entirety by 58 telescopes across four international collaborations. As Wozniak put it, “You need a very well-observed event with data from a wide variety of instruments, as much data as possible, to build a good GRB model. The April GRB was just such an event.”

Another remarkable thing about the data collected by RAPTOR that night is that it begins slightly *before* the GRB itself. Because the system is set up for persistent monitoring, looking everywhere all the time, it doesn't need to be told from an outside trigger that something interesting is happening somewhere. It's like how a witness to the car crash might recall the events leading up to it—she didn't know she was seeing pre-crash activity until the crash began. RAPTOR's wide-field scopes were watching, and when the computer noticed an anomaly (which turned out to be the

early optical emissions), it automatically slewed its deep-field scope to a point in between Leo and the Big Dipper to get a better look—all without waking Vestrand, Wozniak, or any other human for guidance.

With a landmark dataset from an unprecedented GRB event, Vestrand and collaborators now challenge current theoretical understanding of how GRBs work. They found gamma-ray photons (particles of light) with calculated energies at impossible levels, up to 95 billion electron-volts (95 GeV). According to current GRB models, there is no way to produce photons with that much energy. And yet there they were. The data and interpretation were corroborated by independent analyses by NASA's Fermi Gamma-ray Space Telescope, Swift Satellite, and NuSTAR telescope. So, if the models can't account for these photons, and the photons are undeniable, then the models, it would seem, have to change.

There exists a suite of standard proposed models for how GRBs operate, and a lot of data is required to fit any one model. The previously accepted model basically states that a generic GRB involves two distinct shock waves: a forward internal shock followed by a reverse external shock. It was generally thought that the gamma-ray emissions came exclusively from the internal shock and carried million-electron-volt (MeV) energies. However there was a smattering of evidence that a few gamma-ray photons, the highest energy ones, seemed to be delayed relative to the majority. This was a bit of a puzzle. If all of the gamma-ray emissions come from the same source, the forward internal shock, then they ought to have similar timing and energy. GRB 130427A cracked the puzzle apart. The few GeV gamma-ray photons were observed to correspond in time with the peak of optical emissions, which came from the reverse external shock. Therefore, the GeV gamma-ray photons came from the reverse external shock, not the forward internal shock, as stated by the previously favored model.

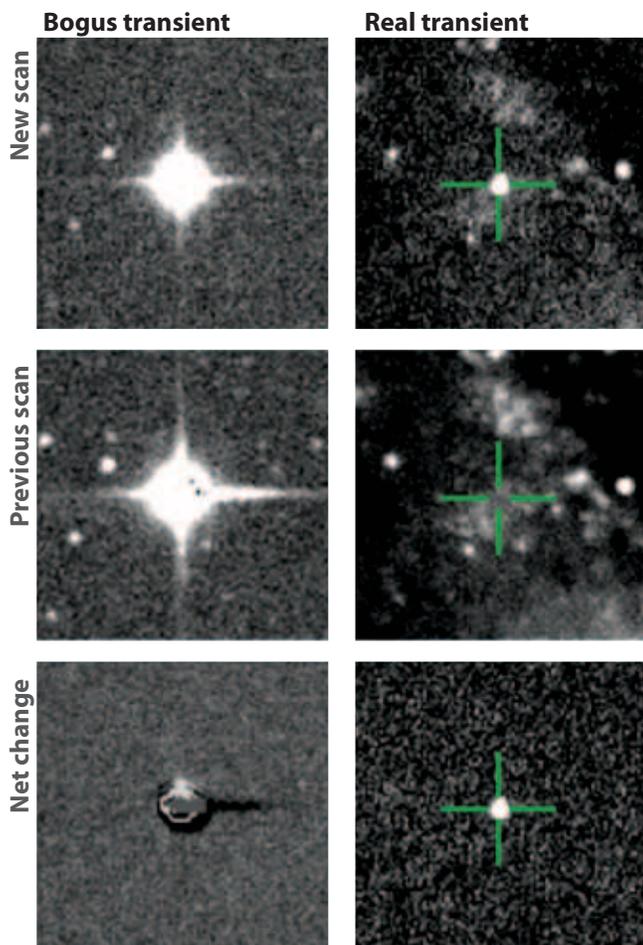
Such strong validation of a model for events that occur in the far universe is exceedingly rare, so GRB130427A is now a superstar among GRBs. But this was not the first chance for RAPTOR to prove its mettle. Since its inception in 2001, RAPTOR has observed countless GRBs and has been a key player in numerous international robotic astronomy collaborations. RAPTOR's observations of the optical counterparts of cosmic events have helped define and test theoretical models of GRBs, supernovae, and other cosmic transients for the past 10 years.

### From generalists to specialists...

The ecosystem analogy that Vestrand uses to describe RAPTOR is apt: heterogeneity in instrument capability and autonomous interaction between the various elements are essential. Now that the instruments are in place, his efforts are focused on the intercommunication aspect. He and Wozniak are working on what they refer to as a dynamic coalition architecture that will reduce redundancy of observation and improve efficiency of data management.

“Right now, transient follow-up takes a second-grade soccer approach,” says Vestrand. “All the players cluster around the ball and kick at it. The trigger comes in and all the telescopes of the world slew over and observe in some way.” The dynamic coalition architecture, in contrast, will allow cooperation between RAPTOR and other robotic observatories and will provide customized task delegation for each transient that comes along.

In addition to training the RAPTOR telescopes, Wozniak is the primary investigator on a Los Alamos multi-institution collaboration called the intermediate Palomar



The computer vision of RAPTOR can automatically distinguish between a real transient and a bogus one with 90 percent accuracy. Shown here are a real transient (right column of images) and a bogus one (left column); in each, the top and center frames were taken at different times and are subtracted to show what has changed (bottom frame). By matching observations of the net change to a database of known real and bogus transients, a probabilistic score is calculated to indicate the likelihood of an event being real or bogus. The real events are then candidates for extended follow-up observation.



The RAPTOR robotic observatory is an ecosystem of telescopes. (Left) RAPTOR-Q (Queue), affectionately known as RQD2, is the wide-field element, providing the peripheral vision for the system with four bottle-cap sized lenses that together can see the entire night sky. It is pictured, left to right, with James Wren and Przemek Wozniak. (Center) RAPTOR-T (Technicolor) is one of the newest additions and consists of four identical lenses, each with its own color filter specially designed for observing the optical counterparts of celestial transients. Left to right are Cade Hermeling, Alin Panaitescu, James Wren, Tom Vestrand, Przemek Wozniak, and Heath Davis. (Right) RAPTOR-Z (Zippy) is the world's fastest telescope and provides the deep-field, up-close vision of the array. Next to RAPTOR-Z is team leader Tom Vestrand.

Transient Factory (iPTF). The iPTF uses a camera to systematically explore the transient sky and has emerged as the leading proof-of-principle experiment to an enormous and much-heralded new undertaking called the Large Synoptic Survey Telescope (LSST). The LSST will provide an exceptionally wide-field survey of the entire sky every few nights and will be the widest, fastest, deepest eye of the new digital age. Among other impressive functions, it will collect data on over two million transients per night. That's about 55 events per *second*. This is where the dynamic coalition architecture comes in. It will have an event broker function, so each time a transient is detected, the broker will consult every instrument in the network, essentially saying, "I've got an event here, and based on what you said you're looking for, I recommend that you take a look at it." In this way, each observatory can specialize in its follow-up and the collective data will be complementary and complete.

But there are some old-fashioned challenges to the new-fangled future of sky watching—international collaboration, for instance. The more observatories that enroll in the coalition, or subscribe to the event broker, the more efficient and useful it will be. Yet astronomers tend to be very protective of their machines, and understandably so. "Most people don't want to give me the rights to take over their telescopes," Vestrand points out. Each institution and researcher has time, resources, reputations, and ambitions invested in their programs. How do they weigh the greater good when their careers are on the line? So the coalition manager needs to know and cater to the priorities of each telescope, which comes from their human owners. It's an iterative process

though, with each round of refinement needing extensive field-testing, which takes time and presents another challenge to the humans involved—patience.

### ...and back to generalists

The persistent-monitoring and data-interview model also has applications to fields other than astronomy. "Once you solve it at an abstract level you can apply it to any set of targets and assets you choose," Wozniak says. The technology is transferable—in any instance where it's important to maintain automated awareness of potentially dangerous patterns or anomalies buried in large amounts of noise, a dynamic coalition architecture can be applied. Biosecurity is an immediate example that Vestrand and Wozniak are not working on but could eventually benefit from the algorithms they are developing. Identifying how an infectious disease outbreak began—whether natural or nefarious—and predicting and mitigating the risks associated with it requires first sifting through incidental chatter to find the pattern and then projecting the pattern into the future. By organizing and interpreting that chatter in a global dynamic coalition architecture, perilous trends might be spotted sooner and dire outcomes avoided.

But the problem is mostly front-end loaded. Once the heavy lifting is done—the programming, training, validating, networking, and streamlining—then the sky is the limit for what sorts of questions might be answered and what sorts of discoveries might be made. Astronomy, it seems, has burst open like a supernova and will never again be the slow and lonely endeavor it once was. **LDRD**

—Eleanor Hutterer

A collection of orange balloons is scattered across a dark, textured stone wall. The balloons are of various sizes and are tied with white strings. The overall mood is somber due to the dark background and the limited number of balloons.

# Running Low

Los Alamos scientists are working to preserve  
the nation's rapidly dwindling supply of a helium isotope critical to  
scientific research, medicine, nuclear safeguards, and border protection.



NUCLEAR WEAPONS OFFER MORE THAN JUST DESTRUCTION. They also produce, from the slow decay of hydrogen-3 (also called tritium), a rare isotope of helium the world needs for a number of peaceful purposes. Helium-3, which amounts to only 0.0001 percent of all helium found on Earth, is used in cryogenics, laser physics, and fusion energy research. It is also used in medical imaging of the lungs and in geological exploration around oil and gas wells. Yet more than three quarters of the demand for this byproduct of nuclear weapons production comes from detection systems that safeguard national borders and the international community against the clandestine diversion of nuclear material for violent purposes.

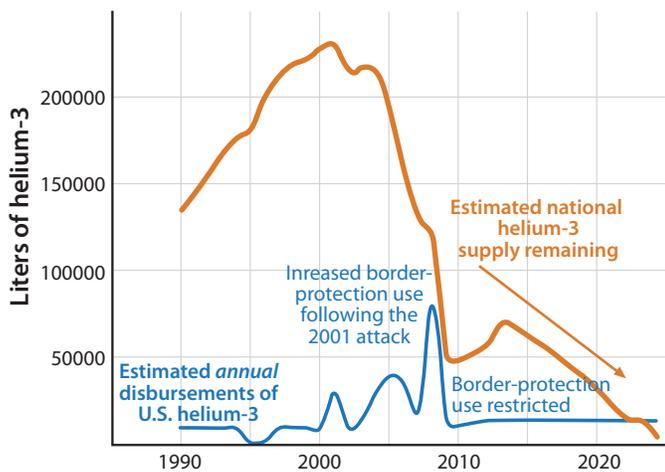
Helium-3 is stable, but its weapons-worthy precursor, tritium, is radioactive and decays into helium-3 with a half-life of 12 years. So when a nuclear bomb's tritium has decayed to the point where it's no longer viable for the operation of the weapon, or when the weapon is retired altogether, the accumulated helium-3 is harvested. Scientists at home and abroad have come to rely on this U.S. supply of helium-3, which today faces an escalating shortage.

In the mid-to-late 1900s, when nuclear weapons production was booming (no pun intended), correspondingly plentiful helium-3 production followed. But then the Cold War began to thaw, and the name of the game slowly shifted from competitive stockpile expansion to cooperative stockpile reduction. For a time, the decline in helium-3 production associated with refurbishing weapons was offset by an increase from dismantling weapons. But with the drawdown in the nation's stockpile leveling off, the U.S. helium-3 supply can no longer keep up with demand. According to the U.S. Department of Energy, about 8000 liters per year are harvested from decaying tritium in weapons, while the annual domestic demand is projected to range between just under 10,000 liters and 14,000 liters, even after significant measures have been taken to mitigate it. Combined international users need even larger amounts. Short of finding an alternative source of helium-3—an uncertain prospect at best—that deficit can only be met at the expense of depleting current reserves. Fortunately, something is being done to stem the demand.

### Supply and demand

The problem isn't only the diminishing supply of nuclear weapons. Part of the shortfall comes from an explosion in demand that followed the September 11, 2001 terrorist attacks, when the United States launched an aggressive program to deploy nuclear detectors to border locations and ports of entry. These detectors rely on helium-3 gas tubes to register the presence of fissionable nuclear materials like plutonium by absorbing the neutrons emitted by the material. In 2008, at the height of the expanded production of neutron detectors for the nation's entry points, helium-3 demand soared to nearly 80,000 liters.

- \* Helium shortages can be a real downer, and the world currently faces two of them. The better known shortage, with its price spikes and shortfalls affecting many industries (including party balloons), primarily concerns helium-4, the most abundant helium isotope in nature. Less well known, however, is a more severe shortage of the much rarer isotope helium-3. Essential for key scientific, medical, and national security applications, no one would dream of filling a balloon with it.



The U.S. supply of helium-3 (orange) has been precipitously declining since the terrorist attacks of 2001. Demand has varied by year, and annual disbursements (blue) have been slashed to extend the life of the national stockpile. But even with these usage restrictions in place, current projections indicate that there will be insufficient helium-3 to meet national needs by the early 2020s and thereafter. (International demand not shown.)

That something had to be done to protect the rapidly diminishing supply of helium-3 did not escape the U.S. government's notice, and in 2010, Congress began to hold hearings on the problem. It soon decided to stop allocating helium-3 to border protection systems, thereby cutting the demand for it and extending the life of current reserves. This brought down the annual projected demand from over 40,000 liters, according to the White House Office of Science and Technology Policy, to where it currently resides at an estimated 10,000–14,000 liters. Even so, meeting the remaining demand for non-border nuclear detectors and other scientific, medical, and industrial applications continues to overspend national helium-3 reserves, albeit at a slower rate than during the previous decade.

"Something has to give," says Howard Menlove of Los Alamos's Nuclear Safeguards Group. "Either a significant new source of helium-3 must materialize in a hurry, or we must develop an alternative to helium-3 in neutron detectors." Such detectors remain, by far, the isotope's largest-use application (even when border monitoring is removed from consideration), as other, non-border nuclear safeguards activities continue unabated. For example, the International Atomic Energy Agency (IAEA), an independent body concerned in part with nuclear safeguards and ensuring nonproliferation

treaty compliance, relies on helium-3-based detectors to conduct nuclear-plant inspections and report its findings to the United Nations. Los Alamos regularly contributes to the training of IAEA inspectors and last year hosted a workshop on helium-3 alternatives that included representatives from the IAEA and others from the international nuclear safeguards community.

"The IAEA has a wide variety of ways to keep track of nuclear materials," says Menlove. "They have tamper-proof cameras and sensor systems installed at nuclear plants around the world. But the main way they account for these high-grade materials is by mass, and that means physically going to the plant with a sensitive detector and comparing weights and neutron emissions from plutonium canisters, one by one.

"Until now," he adds, "that has required helium-3."

### Where there's a will

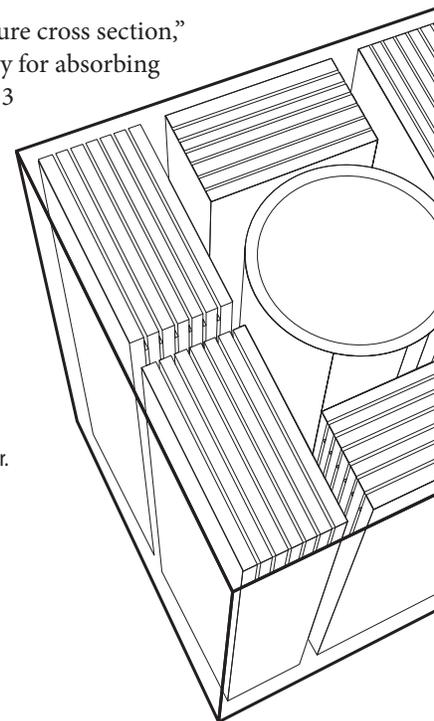
Replacing helium-3 in neutron detectors is harder than it sounds. Scientists at Los Alamos and elsewhere have been searching for decades to find alternative neutron detection technologies. Other neutron absorbers were studied and prototype systems were developed, yet none fully made the grade. Some prototypes weren't efficient enough; too many neutrons went undetected. Others were too sensitive to gamma rays, which can be mistaken for neutrons and bias the measurement results. Still others were unstable, lacking consistent performance over time. Precious few were even deemed worthy of building to full scale for the purpose of further experimentation because detectors based on helium-3 gas tubes were always better. Now, however, the need for a viable alternative is considerably more urgent.

Daniela Henzlova, a colleague of Menlove's, is part of the renewed effort at Los Alamos to develop a practical non-helium neutron detector. She is keenly aware of why helium-3 is so hard to beat.

"It's got a very high neutron-capture cross section," says Henzlova, referring to its proclivity for absorbing neutrons. "Detectors based on helium-3 represent a mature and safe technology, relatively insensitive to



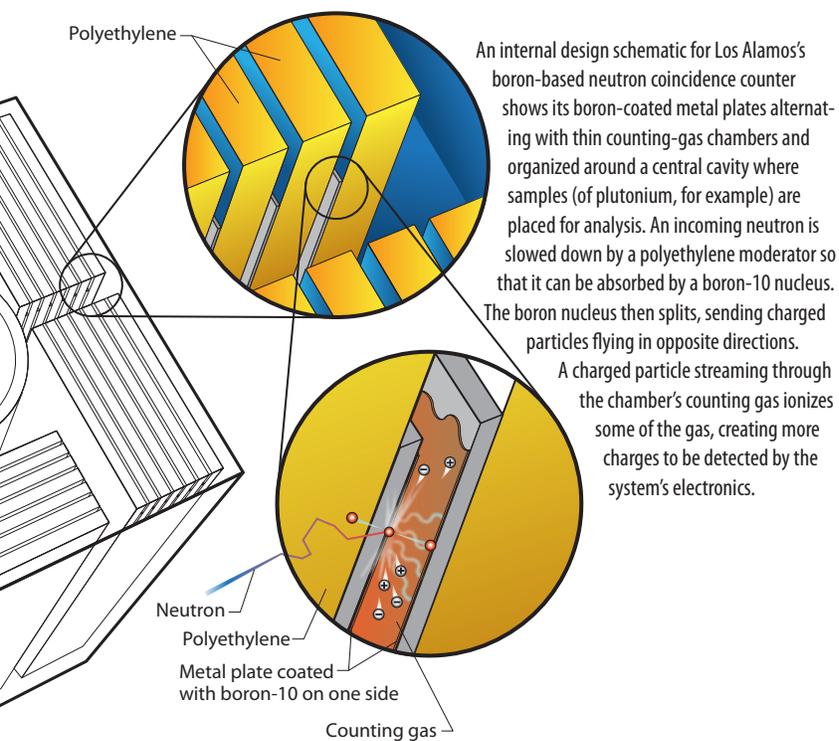
Inside Los Alamos's new boron-based high-level neutron coincidence counter.  
CREDIT: Carlos Rael/LANL



gamma rays, and provide stable and reliable performance. Those currently in use have been in operation for decades with minimal maintenance required.” Ideally, a replacement system should have all these benefits too.

Taking into account the low-energy neutron interaction properties needed, only two helium-3 alternatives that more or less meet these functionality requirements have percolated to the surface for consideration: boron-10 and lithium-6, in a variety of arrangements. They can be made into gases, liquids, or solids. They can be made into gas counters (like the helium-3 tubes) or light-emitting detectors called scintillators, and each of these can be set up in a number of different geometries (tubes, plates, rods, etc.). The question is, which of these isotopes, in which phase, using which detection technology, and packaged in which geometric arrangement would provide the optimal replacement for helium-based gas counters?

Los Alamos has multiple simultaneous research programs underway to answer this question. While their colleagues down the hall pursue scintillators combined with lithium for neutron detection, Henzlova and Menlove pursue a boron-based gas-counter system that made it to a full-scale safeguards counter and is now, thankfully, ready for serious consideration as a bona fide replacement after all these years—no, make that decades—of research. Later this year, their detector will undergo a field trial using a range of realistic nuclear materials to be measured under real-life conditions. It will be evaluated alongside other prototype technologies from teams around the world at a meeting in Italy to see which, if any, proves viable for routine safeguards use—roughly the equivalent of advancing to human trials in a new drug study.



Helium-3 is used in extreme-low-temperature cryogenics, among other scientific contexts. For instance, helium can be used to cool superconducting magnets at the world's most powerful particle accelerator, the Large Hadron Collider (LHC), to 1.9 degrees above absolute zero, and the helium-3 isotope allows components for some experiments to get even colder, reaching a small fraction of a degree. For such ultra-cold applications, there is no substitute for helium-3. Shown here: the cryogenics system for the LHC superconducting magnet test facility.

CREDIT: Laurent Guiraud/CERN

## Everything in moderation

When a neutron is absorbed by the nucleus of a helium-3 atom in a detection tube, the nucleus splits into a proton and a tritium nucleus. (A nucleus of helium-3 contains two protons and one neutron; tritium, being hydrogen-3, is the other way around with one proton and two neutrons.) Both the proton and the tritium are electrically charged at this point, and as they speed through the surrounding gas, they strip electrons from the gas's atoms, creating an ionization streak comprised of free electrons and positively charged ions. An applied voltage set up within the tube drives these charges toward oppositely charged electrical terminals, where their arrival generates a measurable electrical signal in an external circuit.

Boron-10 works similarly. A colliding neutron fractures the boron-10 nucleus into two smaller, charged nuclei, helium-4 and lithium-7, once again creating an ionization trail through a gas to produce an electrical signal. In both helium and boron detectors, a thick layer of polyethylene surrounds the detection tubes to act as a moderator, dramatically slowing down the neutrons to improve the likelihood

they will be absorbed by the helium-3 or boron-10 nuclei. And in both, the moderator also serves as a sort of neutron cage to prevent neutrons from escaping undetected, increasing their chances of scattering back into the detection volume. However, boron-10 doesn't undergo its reaction as readily as helium-3; it absorbs neutrons only about 70 percent as often. And therein lies the greatest challenge: feasible alternative materials are intrinsically inferior to helium-3 for the purpose of neutron detection.

But challenge is not impossibility. Henzlova explains that there are design factors that have the potential to compensate for boron's shortcomings—in particular, the type and number of detection modules (e.g., gas tubes or plates), their geometric positioning, and the manner of coordinating the moderator with the boron.

Henzlova and Menlove focused on three types of boron-based detection modules, each with a different internal organization and each manufactured by a different supplier. They created a test procedure to assess their performance and optimized them with additional moderating material. This took some doing because nuclear safeguards applications impose significant requirements upon the detectors. The detectors must possess extreme gamma-ray insensitivity, demonstrated ease of operation for inspectors in the field, and, in some cases, the ability to perform measurements unattended for months or years at a time.

Ultimately, a winner was identified. Their chosen design turned out to use a detection module containing a flat stack of boron-coated metal plates sandwiching thin chambers filled with "counting gas," wherein neutron-absorption ionization trails trigger electrical measurements. (In existing detectors, helium-3 is both the neutron absorber and the counting gas, but boron-10 is only the former. Its detection module employs a similarly inert counting gas, comprised primarily of argon.)

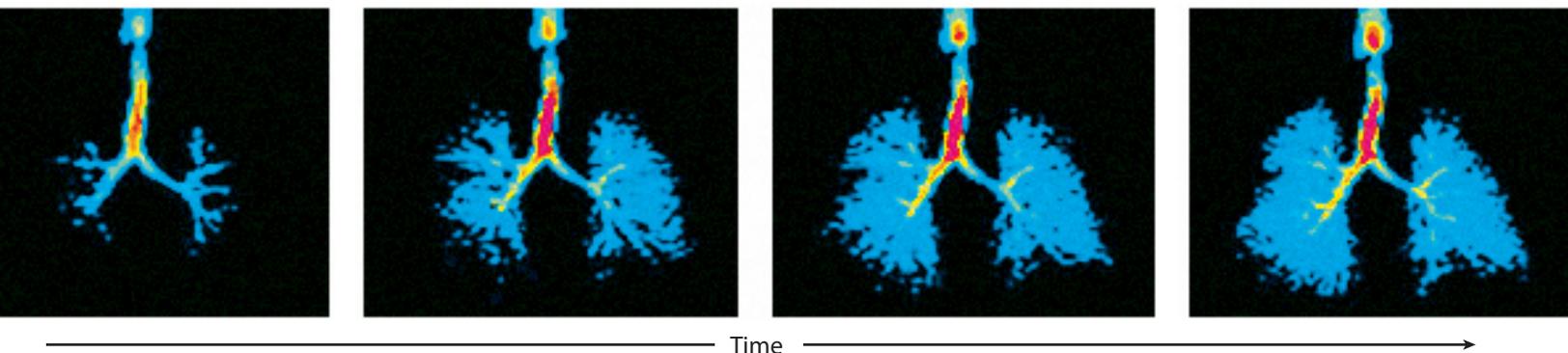
"The large number of plates amounts to a large surface area for the boron," Henzlova says. "Unlike gas tubes, in which helium fills the entire tube volume, boron coatings

occupy only a thin surface. But solids are denser than gases, so with enough surface area—and with optimal coupling between the moderator and the boron—we can compete with gas-tube detectors currently in use."

The next step was to optimize the full-scale design based on the selected detection module. To optimize a single, cylindrical helium-3 gas tube, for example, one might start by deciding how thick the surrounding polyethylene moderator should be to send the most neutrons into the gas tube with the right energy range to be detected (that is, the right speed). A typical neutron from a sample of plutonium, say, would have to down-scatter among the atoms of the moderator to effect more than a million-fold decrease in energy for optimal detection. It's possible to calculate how thick the moderator should be to obtain that million-fold decrease, but that will only take care of the front side—the side facing the sample neutron source. The other sides must be engineered to optimally redirect neutrons that missed the tube (or passed through it undetected) back into it. And that's just for one tube. A more sophisticated design typically involves tens of tubes arranged in a ring pattern around a sample container, all jointly embedded in one or more optimally shaped polyethylene blocks.

To make the optimization process more tractable, Henzlova and Menlove developed a computer-based geometric simulation with which they could rapidly test different designs and calculate the probable neutron detection rate for each. Their ultimate goal was to obtain a detector with physical features and performance characteristics comparable to an existing safeguards standard based on helium-3. When they identified that optimal design, they created engineering schematics and physically built the device to test its actual performance.

All this test, design, and optimization work paid off. Indeed, in their field-test device, which is only marginally larger than the helium-based detector currently used for IAEA inspections, Henzlova and Menlove, for the first time, achieved a 7 percent *greater* neutron detection efficiency than



Helium-3 is used to obtain real-time medical imagery of gas inhalation into the lungs to help diagnose lung diseases at an early stage and thereby preserve quality of life for the patient. (Don't worry: this time sequence of images indicates healthy lungs.) Los Alamos research into replacement technology for helium-3-based nuclear detectors could help to relieve the demand for the isotope, helping to save it for important specialty applications like this one.

CREDIT: Jim Wild/University of Sheffield

that of the helium-3 system. And because their device relies on a particular method of integrating prefabricated detection modules, even greater efficiencies could be obtained by working with the modules' manufacturer to adjust their design for better functionality within the overall device.

### Seeing double

The helium-3 detector that served as a benchmark, the high-level neutron coincidence counter, was originally developed at Los Alamos by Menlove in 1983. And like its potential successor, it is more than a simple neutron detector. In addition to counting incoming neutrons, it also identifies and counts coincident neutrons—two neutrons produced at the same time by the same source. Such neutrons are produced by fission reactions and are a telltale sign that nuclear materials are present. Each fission reaction releases multiple neutrons, and this multiplicity induces a distinctive signal in a neutron coincidence counter. For detailed inspection work in nuclear facilities worldwide (bulk plutonium handling facilities, nuclear material processing facilities, and storage sites), neutron coincidence counters are routinely used.

The trouble is, even though multiple neutrons are emitted by the nuclear material at the same time, they may not reach the helium or boron at the same time after bouncing around inside the polyethylene moderator for randomly different amounts of time. Even if two (or more) neutrons from the same fission are both detected, they won't register a coincidence unless the detections occur at nearly the same time. For that reason, neutron coincidence counters must be specifically designed for both high neutron detection efficiency and accurate assessment of fission-produced coincident neutrons.

To take into account the close timing needed to detect coincident neutrons, scientists in the business have created a composite "figure of merit"—a calculated numerical score that blends the efficiency and timing characteristics of a coincidence counter into an overall measure of its performance. Relative to the benchmark helium-3 detectors in use now, the new Los Alamos boron-10 detector, with its slightly higher neutron-detection efficiency, has somewhat more difficulty with coincident timing. Its overall figure of merit, based on physical hardware tests, is 81 percent that of the helium-3 system, although the simulations suggest that adjustments to the design of the prefabricated boron detector modules within the integrated system could bring the figure of merit up to parity, or even slightly above.

"It remains to be seen if our coincidence counter is good enough for international safeguards use," Henzlova says, referring to the meeting in Italy later this year. "But the



Daniela Henzlova and Howard Menlove celebrate their neutron detectors, new and old, with a helium-4 balloon. The helium-3-based high-level neutron coincidence counter (cylindrical, left), invented by Menlove in 1983, may soon be replaced in nuclear safeguards applications by their new boron-10-based coincidence counter (right).

initial tests at Los Alamos were promising, and the simulations suggest there is room for further improvement."

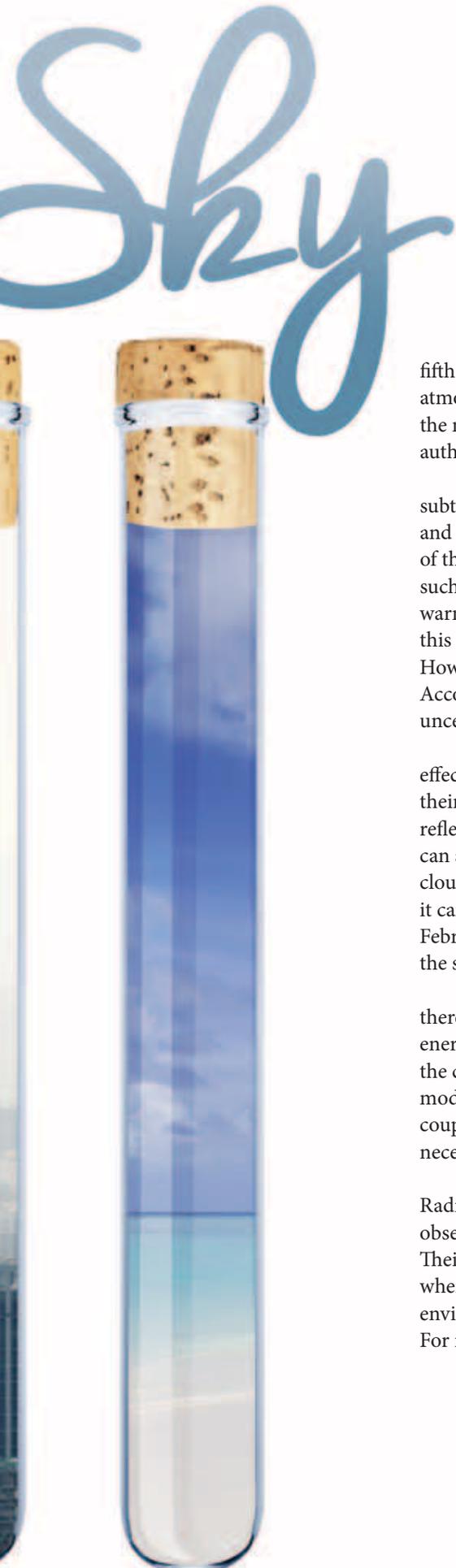
Menlove is optimistic as well. "I've been working on alternative detectors for a long time, and this system is the first one I've seen that performs comparably to the helium-3 counter," he says. Indeed, because the system is so closely patterned after the helium system's design—effectively swapping out helium modules for boron ones, coupling them with the same moderator, and adding compact electronics—there's no reason to expect any problems with performance, manufacturability, safety, or the like. "The only real unknown at this point is cost," he adds. "We've only built prototypes, so we can't know yet what the eventual production and maintenance costs will be. But there's no reason to expect them to be prohibitive."

Possible cost surprises aside, the new system has the potential to contribute to the reduction of global demand for helium-3, and none too soon. With existing reserves shrinking, only a major cut in demand, or an equally major boon in supply, can stop the bleeding. And while several alternative sources of helium-3 are being considered, none is expected to be feasible in the near term. Staving off the immediate shortage, therefore, means reducing the demand with a viable, high-performance, non-helium coincidence counter. So it's probably a good thing Henzlova and Menlove just built one.

—Craig Tyler

# Sampling





# Sky

## Deploying global observatories to improve climate models

In March, the Intergovernmental Panel on Climate Change (IPCC) released its fifth assessment, citing hundreds of studies about increased carbon dioxide in the atmosphere and the planet's ominous fever. Given the complexity of the climate, and the multitude of influences upon it, a vast amount of data was required to inform the authors about what is going on in the global ecosystem.

The Sun warms the earth, but our habitable climate is actually determined by a subtle balance between how much solar radiation is absorbed, rather than reflected, and how much the earth itself radiates back to space at infrared frequencies. Some of this infrared radiation gets trapped by atmospheric greenhouse gases (GHGs), such as carbon dioxide (CO<sub>2</sub>) and water vapor. Although GHGs are a major source of warming, clouds and aerosols—tiny particles in the air and clouds—significantly affect this radiative balance as well because they too can either absorb or reflect the radiation. However, the complexity of this relationship is far from completely understood. According to the IPCC report, “clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the earth's changing energy budget.”

One of the reasons for this uncertainty is that not all clouds are the same. Their effect on the climate varies with altitude, topography, and weather conditions. And their aerosol ingredients don't always have the same effect: some make a cloud more reflective and others make it prone to absorbing heat. Furthermore, some high clouds can act as a blanket, trapping heat and reflecting it back to the earth's surface, while low clouds can reflect the sunlight away, producing a cooling effect. As every skier knows, it can often be warmer under the cloud cover of a snowstorm than on a cloudless February day. Conversely, in the middle of a hot July afternoon, a few clouds blocking the sun might be the only relief from the heat.

So, do all these local variations—a little warming over here, a little cooling over there—really impact the global climate? Yes, because they alter how much radiative energy is kept in the atmosphere, and those changes add up. However, to understand the cumulative effect, scientists need more data. In order to incorporate into a climate model both the worldwide variation in topographical environments and meteorology, coupled with the changing chemistry of the atmosphere at differing altitudes, it is necessary to collect data on various scales from a wide range of locations.

To address these challenges, the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility has been operating climate observatories worldwide, and supporting climate scientists, for over two decades. Their mission is to enable high-quality data collection in new or under-sampled sites where the atmosphere can be studied at multiple scales. By including data from diverse environments, the reliability and predictive power of climate models can be improved. For instance, instead of predicting that the temperature could increase from anywhere

between 1°C and 4°C, the models might indicate a narrower range of only 2–3°C.

At the heart of this major enterprise is a team called FIDO (Field Instrument Deployments and Operations), consisting of 14 Los Alamos project managers and operations specialists. The FIDO team is one of the DOE's go-to groups for coordinating every aspect of the international ARM campaigns. They make the measurements possible by deploying mobile laboratories and state-of-the-art equipment to the far corners of the earth to gather data that improves scientists' understanding of atmospheric phenomena.

"ARM has changed the paradigm. It enables anyone, anywhere to study and model the climate," says Mark Miller, a Rutgers University professor and lead scientist for two ARM measurements sites. "It is widely considered to be one of the best climate programs the government has."

### Global observatories

Established in 1989, today's ARM Facility operates four fixed research sites, three mobile laboratories, and a research aircraft to study a range of climate conditions. The DOE solicits proposals from the international scientific community to determine the locations for the mobile facilities, and the data, once collected, are entered into a large database freely available to anyone in the world.

"The goal is not to measure climate change, but instead to measure the microphysical properties of the atmosphere to improve climate modeling," says Kim Nitschke, the Los Alamos FIDO Facility Operations Manager. Los Alamos has been part of the ARM Facility since it was founded, when the DOE distributed the management of the facilities among its national laboratories. Los Alamos was initially given the responsibility for three locations in the Tropical

Western Pacific: Manus Island in Papua New Guinea, the Republic of Nauru, and Darwin, Australia.

When the program expanded into an official DOE scientific user facility in 2003, ARM created mobile facilities that could be taken to various locations around the world to gather data for periods of 6–24 months. Los Alamos currently operates the first ARM mobile facility (AMF1) and is preparing to take on the second, AMF2. These mobile facilities are rebuilt at each new location using modified shipping containers and a baseline suite of instruments, data communications, and data systems—plus room for additional non-ARM instrumentation. Types of measurements that might be obtained at a mobile facility include measuring the vertical velocity inside thermals (columns of rising air) and clouds; the chemical composition of individual particles in the atmosphere; the life cycle and microphysics of clouds; and a profile of surface radiation, precipitation, or wind speed.

The FIDO team's work begins before a mobile site location is even chosen. During the DOE proposal selection process, FIDO evaluates and determines each potential project's feasibility. This includes budget estimation and risk analysis for safety and security. Once a site is chosen, FIDO conducts pre-deployment visits to identify regulations, the availability of local resources, and possible cultural or language barriers. Multiple shipping containers carry the scientific instrumentation, and the team is then responsible for commissioning the physical facility (which might include building infrastructure) as well as the set up, calibration, and maintenance of the instruments. FIDO coordinates with the collaborating scientists to transport their equipment, but also assists with their travel, health, and safety, as they may visit the sites for intensive operational periods.

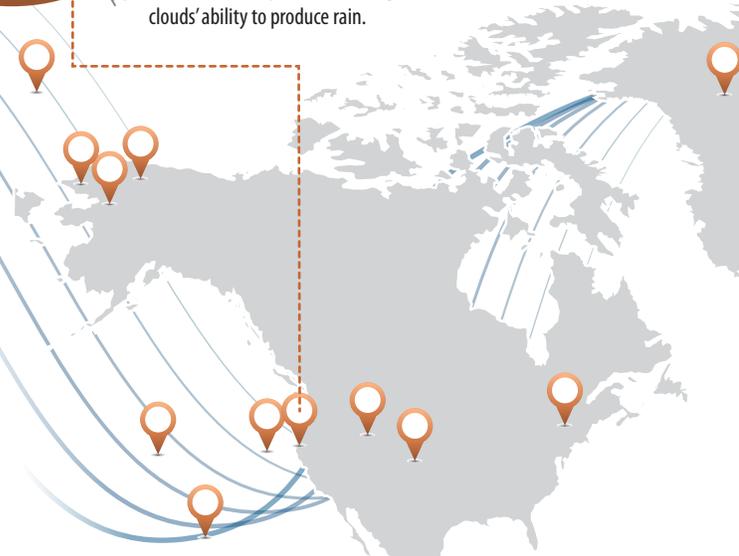
## Sum of the Skies

On any given day, a bank account may experience a handful of transactions—some deducting money and others contributing, some large amounts and others small. But all that really matters at the end of the month or year is the net amount. This is similar to the global energy balance. Cloud cover and aerosols over some areas of the planet may trap heat, adding warmth to the atmosphere; in other areas, the clouds may reflect solar radiation away, cooling the earth below. What really matters is the net effect—whether the overall global atmosphere is warmer or cooler. However, when it comes to modeling the future climate, scientists have discovered they need a better understanding of all the local transactions. Atmospheric additions of greenhouse gases and anthropogenic aerosols add up quickly, but when combined with local weather and topography, they don't always result in a predictably consistent outcome. The more data scientists can gather on the types of changes that occur and why, the more accurately they may be able to predict the future balance.



Point Reyes, California

Point Reyes, California, was the site of the first ARM mobile facility deployment in 2005 for a study of marine stratus clouds, which exert a large-scale cooling effect on the ocean surface, sometimes producing drizzle. These clouds, however, are susceptible to the effects of anthropogenic aerosols that can both trap heat and change the clouds' ability to produce rain.



The continuous collection of high-quality data requires daily on-site effort, for which FIDO hires and trains local personnel at each site, and Los Alamos members travel back and forth frequently to manage each deployment.

A major responsibility of the FIDO team is the diplomatic coordination of international agreements between the United States, participating institutions, and foreign governments to allow both the import of scientific equipment (including aircraft) and the export of data—which are deemed by some to belong to the country of origin. Sometimes these negotiations can be tricky. For example, pollution is a byproduct of development, which is considered essential in some countries, so there are economic and political implications to collecting evidence that may suggest pollution is associated with climate change. FIDO also has to navigate local bureaucracies. For instance, in Niger, the best way to import the ARM equipment was to lease a Boeing 747 jet, but that first required visiting multiple Nigerian agencies to determine who was in charge of the airport where it needed to land.

### All packed, where should we go?

The sites chosen by the DOE and the scientific community for ARM facilities are often in remote, under-sampled areas that may exhibit particularly interesting atmospheric phenomena.

“We don’t really understand enough about the natural state,” says Manvendra Dubey, a climate scientist at Los Alamos who works with the FIDO team. “So ARM sites try to go after interesting, missing pieces.”

The problem is that when it comes to studying the natural state, it can be difficult to find places on Earth that are untouched by humankind. Scientists have evaluated the fossil record, tree rings, ice cores, etc., to understand the history of the climate in search of comparative data to help answer, “What

happens to the climate when people live here?” But the fact remains that, for as long as scientists have been documenting the climate, there have been people living

The sky above the GOAmazon site in Brazil is as pristine as that in the middle of the Pacific Ocean. Normally, the rainforest has a healthy life cycle, including plenty of rainfall, and the trees soak up a significant amount of heat-trapping CO<sub>2</sub> from the global atmosphere. Models predict increases in pollution and drought in this forest, which threatens its ability to reduce CO<sub>2</sub> levels naturally.

Mountainous areas with complex terrain can force moist air to rise quickly, forming thick rain clouds that produce heavy rainfall called orographic precipitation. In 2007, the ARM mobile facility AMF1 deployed to the Black Forest in Germany to study orographic precipitation because it is markedly different from other rain and is difficult to predict, which can result in unexpected storms and flooding.

on Earth. Most of the natural-world data are entangled with multiple variables introduced by humanity—far from the controlled experimental conditions students learn in science classes.

One of those entanglements involves tiny aerosols, which are about a tenth of a micron, or one ten-thousandth of a millimeter, in size. Depending on their type, aerosols can reflect or absorb sunlight. But they can also act as cloud condensation nuclei (CCN), which means that water vapor molecules can gather around an aerosol particle to form a droplet, which then joins with millions of other droplets to create a cloud.

In nature, salt particles in the ocean air and organic molecules from lightning-ignited wildfires are two of many known aerosols that can serve as CCN to aid in cloud development. But pollution from anthropogenic activities, such as soot from smokestacks or burning biomass, also adds aerosols to the atmosphere. The types of aerosols present can determine which kinds of clouds are formed, if the clouds are reflective or absorptive, and whether or not the clouds produce rain.

Some of the ARM mobile facilities have been located at or near major metropolitan areas to study the effects of these anthropogenic aerosols. In 2011, a mobile facility was erected in the Ganges Valley—a densely populated area in Northern India flanked by the Himalayan Mountains, with cement factories, steel mills, and coal-fired power plants all contributing to the aerosol load. The location itself presented quite a challenge for the FIDO team, having to transport the shipping containers up narrow switchbacks with steep cliffs to reach the mountaintop site. In fact, some of their deliveries couldn’t be driven to their final destination, and the contents had to be hand-carried. Then, once the site was set up, the team encountered monkeys that



Black Forest, Germany



Manausapuru, Brazil





Niamey, Niger

Local staff members launch a weather balloon during the ARM mobile facility deployment in Niamey, Niger, in 2006. Here, international scientists studied the effects of Saharan dust—which can block up to 85 percent of solar radiation—on the monsoon system that brings critical rainfall to the region. Although this dust can have a cooling effect, the heat is needed to drive the monsoon.

would chew through equipment cables and steal food. There was also the occasional panther alert. The science, however, was a success; scientists used the facility to study how the pollution in the valley affects the monsoon rains in the area. Some prior studies suggested the pollution could intensify the monsoon, while others suggested the opposite. The truth turns out to be a little bit of both.

Life-sustaining rain happens to require a very particular set of circumstances. When a cloud droplet grows to 20 microns in diameter, it falls through the cloud, gathering more droplets, and increasing in size to a few millimeters. But if no droplet reaches 20 microns, the cloud just keeps growing without producing rain. To increase the likelihood of rain, it is important for clouds to have a heterogeneous population of aerosols, as different aerosols come in different sizes. Pollution, however, tends to create many smaller aerosols—which can result in bright, crisp looking clouds that do not produce rain. On the other hand, a strong current of warm air rising from the ground into the cloud can literally force a cloud to rain.

At another ARM site in the Azores Islands off the coast of Portugal, data are being gathered on drizzly boundary-layer clouds—those found between the earth's surface and an altitude of about 1–2 kilometers—that passively filter sunlight and influence and modulate sea surface temperatures. Studying their detailed vertical structure is valuable as these boundary environments are ubiquitous to global coastlines. Although this lower marine atmosphere tends to be stable, and tends to prevent air masses from mixing vertically, scientists have discovered that when plumes of polluted air from North America and Europe settle above

the boundary-layer clouds, they do mix downward, contributing more anthropogenic CCN to the clouds.

“This is where ARM comes in,” explains Miller. “Satellite data cannot give a detailed understanding of what is happening in these clouds. It is important to look at a diversity of different columns in the atmosphere.”

It's not just about the rain, either. Climate models frequently underestimate the occurrence and persistence of marine boundary-layer clouds, which is a problem because they are so common. Without considering them, the models misrepresent how much sunlight is reflected away by these clouds versus that absorbed by the ocean. This discrepancy is as dramatic as the comparison of light reflected by a snow-covered surface to that absorbed by a dark parking lot. In other words, if the boundary-layer clouds are present and reflective, a lot of sunlight is not hitting the sea. Data from the Azores facility will help quantify how these boundary-layer clouds impact the radiative budget of the planet.

### Navigating the green ocean

Deep in the Amazon rainforest in Brazil is a place called Manacapuru, where the green broadleaf forest stretches beyond the horizon. Often referred to as the green ocean, this area's atmosphere is pristine—as free from human influences as that in the middle of the Pacific Ocean—with daily rainfall to ensure that any contaminants that do arrive in the air are regularly washed away. Earlier this year, the FIDO team deployed AMF1 to Manacapuru to set up what may be the closest they've yet come to a perfectly controlled experiment. By studying the environment in the Amazon, and the cloud and precipitation cycle above the forest, the scientists hope to learn much more about the natural processes in place. But the site has another advantage as well. Only about 45 miles to the east is the city of Manaus, with a population of 2.5 million, which uses

These clouds over the Ganges Valley in India include thousands of small, pollution-derived cloud condensation nuclei per cubic centimeter, some of which reflect sunlight (and therefore produce a cooling effect) but may also, as a whole, suppress rainfall.



Ganges Valley, India

Clouds in clean air, such as these over the islands of the Maldives, tend to have large droplets formed from hundreds of large cloud condensation nuclei per cubic centimeter, making them suitable for creating rain. The AMF2 field-research facility took measurements in the Maldives in 2009.



Gan Island, Maldives

FIDO and the ARM Facility sometimes participate in field campaigns that deploy instrumentation on ships to gather atmospheric data from the middle of the ocean where there are few (if any) anthropogenic aerosols.

high-sulfur oil as its primary source of electricity. So, when the wind changes direction and a plume of sulfuric-acid-polluted air arrives from Manaus, scientists can directly observe the changes.

To set up the Green Ocean Amazon site, GOAmazon for short, FIDO shipped 16 containers to Brazil and coordinated the set up and operation of instruments for more than 100 collaborating scientists from 24 participating institutions. The site will operate for two years, including an intensive operational period in the rainy season and another in the dry, fire season. (Some fires are natural in the life cycle of the forest, but many are deliberately set as part of deforestation for agriculture and development.)

The Amazon environment will be especially valuable for studying the anthropogenic versus natural aerosols and the atmospheric chemistry that changes them. In addition to salt and sulphuric acid acting as CCN, another family of molecules called isoprenes—some of which are produced by trees as an insect repellent but are widely recognized for their pine scent—are also emitted into the atmosphere and contribute to cloud formation. Isoprenes on their own are not CCN but can interact with other molecules in the atmosphere to create them.

One of the problems scientists have when they study various types of aerosols in a cloud is that the numbers don't always add up: the total number of CCN measured in the environment is more than the number of anthropogenic CCN plus natural CCN. Evidently, some other chemistry is happening, which they refer to as gas-to-particle conversion, to enhance the number of cloud droplets. The question is, can they measure and predict how much enhancement takes place when anthropogenic aerosols are present?

In addition to evaluating the unique blend of aerosols in the atmosphere of Manacapuru, the scientists participating in GOAmazon will also be evaluating other factors that influence climate, such as rainfall, temperature, and CO<sub>2</sub> content. For instance, Dubey's



NOAA ship Ron H. Brown

Los Alamos Atmospheric Observations Science team has included, as a guest instrument, a new Solar Fourier Transform Spectrometer to measure concentrations of greenhouse gases such as CO<sub>2</sub> and water vapor over the rainforest at regional scales to understand how the forest responds to climate change, which many climate models suggest will bring more droughts. Since the Amazon rainforests currently soak up large amounts of CO<sub>2</sub> (partially mitigating the increases from human activity), it is important to understand how these forests will respond to changes in water availability. If the droughts kill off parts of the forest, then the atmospheric CO<sub>2</sub> will increase more rapidly, creating a damaging feedback loop.

Dubey's system was previously set up in the Four Corners area in New Mexico, to monitor CO<sub>2</sub> and pollution emissions from two large coal-fired powerplants in the region. Although it was not part of the ARM Facility (instead a Los Alamos internal project), the FIDO team assisted with the deployment.

"I can't do this work without them," says Dubey. He explains that the support infrastructure is vital to enable scientists to take their instruments to remote places for conducting their research.

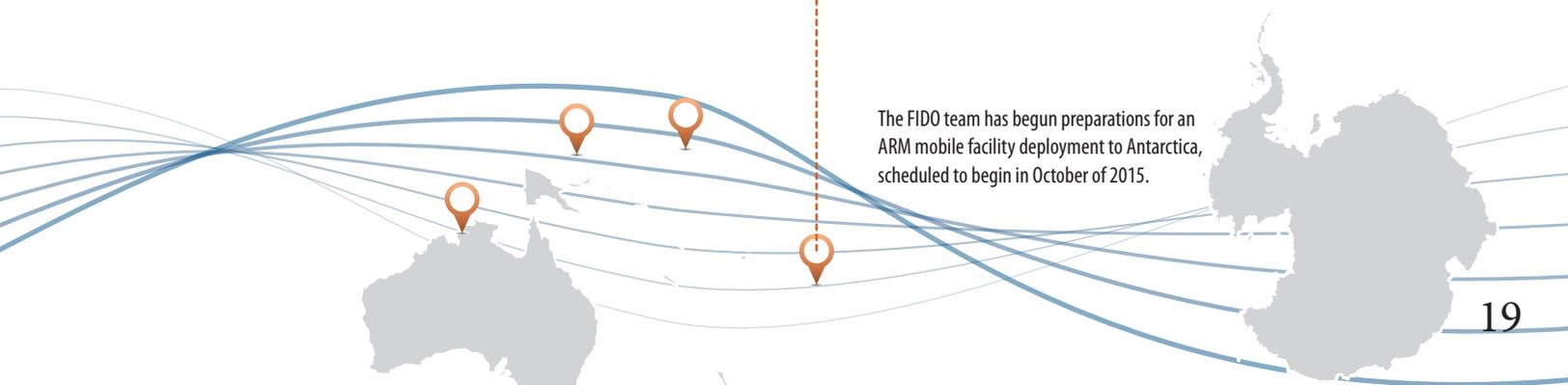
### Predicting the planet's fate

Thousands of scientists worldwide are trying to predict the future of Earth's climate—trying to accurately understand the consequences of the human interaction with the planet. Clouds and aerosols may be only one part of the climate-change puzzle, but they are a significant one. In the IPCC report, discussions on clouds and aerosols cited data from ARM facilities more than 140 times.

Advanced computer models have proven to be valuable for predicting what the future climate may be like, but the answers they put out are only as good as the data that are put in. More real-world examples of the interplay among radiation, clouds, and aerosols hold the key to improving their predictions. And by providing an opportunity for researchers to take their labs to the ideal locations for their science—no matter what obstacles may exist—and then providing the data to any person who might need it, the FIDO team and ARM Facility are playing a vital role in climate research.

-Rebecca McDonald

The FIDO team has begun preparations for an ARM mobile facility deployment to Antarctica, scheduled to begin in October of 2015.



# CRITICAL

# SUBCRITICAL

Real plutonium.

Real experiments.

**No nuclear yield.**

Real important.

It's been nearly 22 years since the United States began its self-imposed moratorium on full-scale nuclear weapons tests, with the last one, Divider, occurring on September 23, 1992. While the moratorium has been strictly adhered to, the nation continues to conduct so-called subcritical tests, intended to help scientists determine the impact that old and aging plutonium will have on the U.S. nuclear stockpile. In the most recent subcritical test, Pollux, a hollow shell of plutonium was forced to implode, raising the plutonium's density until...um, that was it. Nothing else happened. Unlike a nuclear weapons test, a successful subcritical test ends without even a whimper, much less a nuclear bang.

"The device used in Pollux didn't contain enough plutonium to explode," explained Mike Furlanetto, the Diagnostic Coordinator for Pollux. "The test device couldn't reach a critical mass."

A critical mass is the minimum amount of nuclear material needed to realize a self-sustaining chain reaction, the process by which huge amounts of nuclear energy can be released. In a subcritical test, the plutonium mass is subcritical, and the plutonium density remains subcritical before, during, and after the test. A self-sustaining chain reaction isn't possible, and the entire experiment proceeds without generating any nuclear yield. As such, subcritical tests are allowed under the Comprehensive Test Ban Treaty, which bans all nuclear and nuclear test explosions.

Why spend time, effort, and millions of dollars to probe what amounts to a nuclear dud? It's because subcritical tests are currently the best and possibly only way to obtain some of the data needed to validate weapons simulations—the extremely sophisticated supercomputer programs used to assess the weapons in the U.S. nuclear stockpile. In the



absence of nuclear testing, the nonnuclear subcritical tests are crucial for helping the nation maintain a stockpile that is safe and performs as required long into the future.

### **This is a test**

What transpires within a detonated weapon is so complicated and dynamic that as of today, nearly 70 years after the first nuclear device melted the pale desert sand southeast of Socorro, New Mexico, scientists still can't fully describe what happens. Temperatures and pressures inside the weapon soar to extreme values on very short timescales, giving strength to non-linear, turbulent, and non-equilibrium behavior in materials and energy fields. The dynamic behavior of plutonium under such extreme conditions is largely unknown, as is its equation of state—the relationship that, given information about the its volume, pressure, and temperature, would allow one to calculate its density. Consequently, it's not clear what the state of the plutonium is in the crucial last moments when the chain reaction unleashes over 90 percent of the energy. Curiously, it's also not clear how the *initial* state of the plutonium works its way into affecting weapons performance. But it does.

In the pre-moratorium past, such holes in the analytical framework could be ignored because beneath the curve of every question mark lay the capped bore hole from an under-

ground nuclear test. A weapon's performance was determined by how much energy it yielded when detonated during a nuclear test. A weapons designer's intuition about a new weapon design was validated (or not) by a nuclear test. And the reasons why seemingly minor differences in a weapon's components—a change in the texture of the plutonium, for example—could negate a successful weapon design and turn boom to bust was to be explored and answered by one or more nuclear tests. But then all testing stopped.

Scientists today use supercomputers to step through and calculate what happens within a weapon from the moment it is triggered until it explodes. The key question is whether the weapons in our stockpile will perform as required—now, or at any time in the future. The question becomes more relevant the longer a weapon stays in service, given a weapon's sensitivity to changes and the fact that plutonium slowly changes over time due to radioactive decay and the accumulation of decay products. The weapon itself may slowly change over the years as well, as parts get refurbished, remanufactured, or replaced.

Whether a simulation can predict performance depends on how faithfully the simulation reproduces what happens within the weapon. Scientists have a good understanding of the physical processes that take place, but they have only a sketchy feel for how some of those processes feed back,



The Castor subcritical test imploded a tantalum shell as preparation for the Pollux experiment. The test device was placed within the containment vessel shown.

compete with, or complement each other. Whether the simulation sufficiently captures the full dynamic interplay can only be determined by comparing the simulation results with data from an experiment and, in particular, with the data from a subcritical test.

A total of 27 subcritical tests have been performed since 1992. Pollux was notable in that the test device was a scaled-down version of a weapon component. It also fielded a new diagnostic: multiplexed photonic Doppler velocimetry (MPDV). Developed through a partnership between Los Alamos and National Security Technologies, LLC (NSTec), the MPDV system gathered so much high-quality data that scientists are already gaining new insight into plutonium's behavior under extreme conditions.

### Nuclear chain reaction

Almost all modern nuclear weapons are staged explosives consisting of two nuclear devices—a primary and a secondary—sealed together in a case but separated from each other. The primary, detonated first as its name suggests, generates the energy needed to ignite the secondary, the device that produces most of the weapon's explosive power.

Both the primary and secondary derive the bulk of their power from nuclear fission, the process whereby the nucleus

of a heavy atom, such as plutonium or uranium, absorbs a neutron and splits into typically two pieces. Fission releases a relatively huge amount of energy—on the order of 10 million times that gained by breaking a chemical bond—and also lets loose a few neutrons, the latter fleeing the ruptured nucleus like birds from a broken cage.

The extra neutrons are significant because each has the potential to be absorbed and induce fission in another nucleus, spawning a second generation of neutrons, which can then lead to a third generation, and so on in what is called a chain reaction. If every fission event produced two neutrons, and if each of those neutrons induced a fission event that produced two neutrons, then the number of fissions and neutrons increases exponentially with each generation.

The chain reaction is hard to achieve, however, because the uncharged neutrons are rather ephemeral particles, more likely to pass right through even a large piece of plutonium than to be absorbed. For any finite amount of material, one can calculate the rate at which neutrons leak from the surface. It will depend on the density of the piece, its shape, its purity, whether surrounding materials reflect neutrons back into the piece, and other factors. One can also calculate the rate at which neutrons are produced, which also depends on several factors, including the fission rate, and the number of neutrons produced per fission.

Equating the two rates provides a condition of criticality, which can be solved to derive a critical density. Knowing then the shape and volume of the piece, one can obtain the critical mass—the minimum amount of material needed to have one neutron, on average, induce just one other fission. If a critical mass is shrunk in size, thereby increasing its density, the plutonium becomes supercritical—fissions increase exponentially with each generation—whereas making the piece larger makes it subcritical—neutrons are lost faster than fission can replace them, and the nuclear chain reaction can't be sustained.

### A weapon at work

Keeping a weapon safe has led to a primary design in which a thick layer of high explosive surrounds a hollow core made of plutonium. There's enough material that, if the core were smaller, the plutonium would reach critical mass. Because the material is formed into a hollow shell, the core density is subcritical and the weapon can't explode.

When the weapon is triggered, however, detonators on the surface ignite a thin layer of the explosive, launching a shockwave of intense temperature and pressure that races towards the core at several thousand meters per second. Self-powered by burning the material it overruns, the shockwave

Generation 1  
2  
3  
4  
5

10

20

30

50

100

Number of neutrons available

2  
4  
8  
16  
32

slams into the core with enough force to level a small building, causing it to implode, or collapse smoothly in on itself. As the shell diameter shrinks, the plutonium reaches first critical and then supercritical density. Any fission that occurs within the plutonium at this point will initiate a supercritical chain reaction, so a hail of neutrons generated by a component external to the primary are fired at the super-dense nuclear fuel. Multiple fissions occur, jump starting the awesome energy-releasing chain reaction.

In less than a millionth of a second, the released energy is large enough to reverse the implosion and begins to blow the primary apart. The primary is by then so hot that it radiates most of its energy away as x-rays. For a brief amount of time, the weapon's outer case is able to contain the horrifically hot emissions, and radiation flows to the secondary. The radiation exerts enough pressure to compress the secondary, instigating nuclear reactions and a second supercritical chain reaction that produces the bulk of the weapon's nuclear yield.

Of the two devices, the primary is far and away the more finicky. If the primary does its job, the secondary will ignite and do its job. But there are myriad ways for the primary to fail, including mistiming events such that the supercritical state is never achieved, is reached too quickly, or isn't sustained long enough to produce the desired primary yield. The shockwave may not have sufficient energy, or it could converge non-uniformly on the plutonium shell. Its impact with the metal is violent, and the plutonium can crack,

or chunks can spall from its surface. It will heat up, frantically rearrange its atoms, and flow like super-dense water in response to the unyielding pressure.

Do these physical processes affect the amount of energy produced? They do. By how much? That depends on numerous factors, including the response of the metal to the stress—its hydrodynamics—and the density of the shocked metal as determined by plutonium's equation of state.

Los Alamos weapons designer Gary Wall, the lead designer of seven nuclear tests and one of the few people around who has actually participated in a nuclear test, speaking publicly stressed that, "the greatest single technical challenge of primary design and assessment today is understanding and modeling the dynamic behavior of plutonium over a wide range of temperature and pressure."

The subcritical test allows scientists to study the plutonium under conditions similar to what it would experience in a weapon's primary. By measuring, for example, the velocity of the shell as a function of time, one can infer the force imparted to the shell by the shock wave, or alternatively gain insight into plutonium hydrodynamics. As to whether another material could be studied instead, many feel the answer is no.

Says Furlanetto, "You can study surrogate materials and from that deduce how the plutonium will behave, but you won't know until you actually make the measurements on plutonium. Nothing behaves like plutonium except plutonium."

### Going subcritical

The U1a complex lies some 300 meters beneath the dry desert sands of the Nevada National Security Site (NNSS), formerly known as the Nevada Test Site. It is a dense warren of sealable experimental chambers arranged in clusters, which connect to each other by several main tunnels, themselves connected to the surface by three vertical shafts. The tunnels are relatively spacious, with high ceilings and concrete floors; the experiment alcoves would likely feel roomy were they not crammed full of scientific instruments and equipment. The complex is where Los Alamos, Lawrence Livermore, and Sandia national laboratories collaborate with the National Nuclear Security Administration (NNSA), NSTec, and each other to conduct subcritical tests.

Exponential growth proceeds frighteningly fast. If every fission produced two neutrons, and each neutron induced a fission, then the first generation of two neutrons produces a second generation with four neutrons, a third with eight, and so on. The numbers speak for themselves.

1,024

1,048,576

1,073,741,824

1,125,899,906,842,624

1,267,650,600,228,229,401,496,703,205,376

# MultiplexPVD

Multiplexed photonic Doppler velocimetry (multiplexed PDV, or MPDV) can measure the velocity of a moving surface at many points simultaneously. Each of the more than 100 laser beams enters the probe via its own optical fiber, passes through a fish-eye lens, and is directed to a unique spot on a surface moving towards the probe. Some light is reflected straight back to the probe, through the lens and into the fiber. The frequency of this light is Doppler shifted, increased by an amount that depends on the velocity of the surface. It mixes with the outgoing laser light and generates a mixed wave whose amplitude varies (beats) at a frequency equal to the Doppler shift. Measuring the beat frequency yields the velocity.



The two most recent tests, Castor and Pollux, comprised the Gemini experimental series, which was intended to get data on plutonium hydrodynamics as far into the implosion process as possible. Castor, the shakedown experiment, imploded a surrogate material. Pollux, fired on December 5, 2012, was the real deal, imploding a modified plutonium shell. Both experiments fielded test devices that were scaled-down versions of a primary.

The run-up to Pollux was watched with great interest by the weapons and shock-physics communities because the new MPDV diagnostic would be deployed to measure the velocity of the plutonium shell as it imploded. The instrument added a big M (for multiplexed) to photonic Doppler velocimetry (PDV), which was developed nearly ten years ago by Ted Strand and colleagues at Lawrence Livermore National Laboratory.

The frequency of laser light reflected off a moving object is shifted by an amount that depends on the object's velocity. By applying a wave mixing technique used in telecommunications, the velocity can be extracted using proven data analysis techniques. The PDV system, built entirely with fiber optics and standard optical components, proved to be robust, easy to align, and accurate; and given that the necessary optical components had been developed

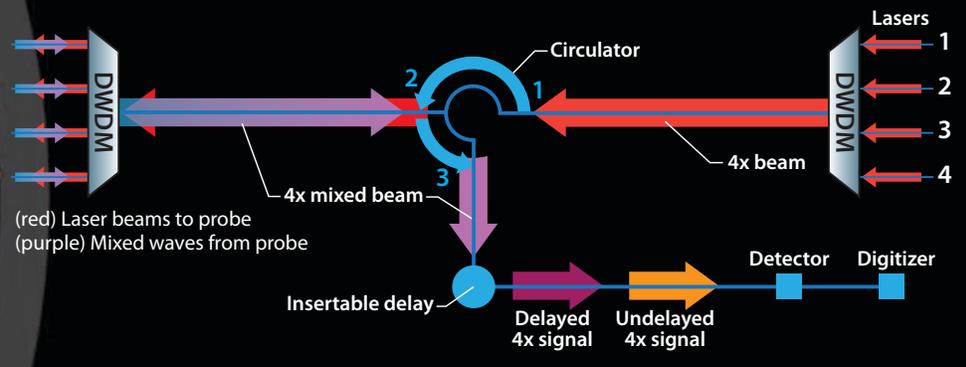
by the telecommunications industry and were commercially available, it could be built and operated on the cheap. The shock-physics community loved it.

The weapons community wanted more than a single probe, however. In particular, they wanted to look at the symmetry of the shell as it imploded, and so desired simultaneous velocity measurements from 100 or more places on the shell. But while one PDV channel was very cost-effective compared to the technology that it replaced, the 25 high-speed digitizers needed to process the minimum of 100 signals (four signals per digitizer) were priced at upwards of a prohibitive \$4 million. In addition, each digitizer needed about a kilowatt worth of power, most of which got dumped into the room as heat. With 25 or more digitizers cranking away, the heat load in the U1a alcove would be difficult to manage.

The solution, developed through a collaborative partnership between Strand, Los Alamos physicist David Holtkamp, and Ed Daykin of NSTec, was to exploit even more what the telecommunications industry had already developed and use both frequency- and time-multiplexing techniques to combine eight PDV channels into a single complex signal that could be recorded by one digitizer channel. The result was a five-fold reduction in the cost per PDV channel and a roughly eight-fold reduction in the total heat load.



For MPDV, a technique known as dense wavelength division multiplexing (DWDM) is used to multiplex, or combine, four mixed beams on four optical fibers (encoding the velocity information of four surface points) into one, multi-frequency beam on one fiber. The velocity information encoded in each mixed beam remains intact, however, and can be extracted from the multiplexed waveform by standard techniques. At the same time, four other points on the surface are similarly probed by a second set of lasers, and a second 4x mixed beam is produced by a second set of fibers and optical components. This signal is delayed by sending it down a length of fiber. The non-delayed and delayed 4x mixed signals go to a detector, which outputs an electric current to a digitizer to be recorded. The detector and digitizer are expensive, so having one setup record data from eight surface points, instead of one, significantly lowers the cost per data point.



The system fielded on Pollux had a total processing capacity of 128 channels, with each channel requiring an independent laser beam. The beams were directed to spots on the inner surface of the plutonium shell by a special probe (above) designed by Brent Frogget and built by Vincent Romero, both of NSTec. During the Pollux test, this probe served double duty. The shell used in Pollux contained a subcritical mass of plutonium, even when imploded to its minimum size. But with the MPDV probe mounted inside, the shell could not implode completely—double insurance that the experiment remained subcritical.

### Supercritical success

Holtkamp and his team fielded the system on the Pollux test. The system provided more than three million data points, vastly exceeding the sum of all such data gathered in previous subcritical experiments. He credits the team with the spectacular success.

“Working with such a talented and dedicated team has been the high point of my career,” Holtkamp said. He remarked that the data “has had a revolutionary impact on the weapons program, reinvigorating Nevada activities and forging close collaborations between the design and experimental physics communities.”

Jeff Hylok celebrates after the success of the Pollux subcritical test.

Gary Wall, commenting on the test results, noted that, “The additional constraints that [the data] put on the simulations are what I would call both exhilarating and frustrating. We typically find out that our simulations are just not up to the task, but that’s what feeds back into improving our simulations.”

And improving the simulations is what it’s all about.

LDRD

—Jay Schecker



# Spotlights

## Heat Flow Stop and Go

This is cool: Los Alamos scientists Markus Hehlen and Alex Mueller have devised a thin-film heat switch—a layer of material that can go from thermally insulating to thermally conducting with the flip of a switch. It takes advantage of fluid motion to achieve its dramatic change in thermal conductivity.

Before a pot of water on a lit stovetop comes to a boil, the upper surface of the water can remain much cooler than the water closer to the burner. But once the water starts boiling, the fluid motion quickly distributes the heat throughout the water. Hehlen and Mueller's heat switch relies on a similar effect, using electrohydrodynamic technology to generate motion in a dielectric fluid, thereby improving heat conduction. But unlike boiling water, the dielectric fluid can be set in a thin layer that doesn't feel wet any more than a liquid-crystal display (LCD) screen does.

To make the heat switch, a dielectric fluid is sandwiched between two electrode plates. When a voltage is applied across the plates, charged particles within the fluid move in response, effectively stirring the fluid. Because of this motion, heat is transported across the thin fluid layer from one electrode to the other. When the voltage is switched off again, the fluid stops moving and greatly inhibits the heat flow. So if a heat switch is inserted between a hot region and a cold one, it can be made to preserve that temperature difference or not, with easy on-off electronic control.

Hehlen and Mueller designed and constructed a specially patterned electrode to make the dielectric fluid circulate smoothly between

the electrodes, carrying heat from one to the other with every revolution. They achieved a factor of greater than 50 in conductivity change, converting a fluid that's normally nonconductive, similar to fiberglass insulation or fleece, into one that approaches the thermal conductivity of a metal.

Initially, these heat-switch films could be used in specialty applications, such as temperature control for satellite electronics—which can face the Sun one minute and the extreme cold of empty space the next. Then they might prove useful in thermal management of computers, other electronics, or even buildings—replacing conventional insulation with something thinner and more adaptable. Hehlen and Mueller also believe they can make their thin-film heat switches flexible enough to be used in temperature-controlled clothing, effectively allowing the wearer to switch between a light cotton tee and a wool sweater without having to change clothes.

In fact, the heat switches may someday enable compact, thin-film refrigeration to compete with today's bulky and noisy vapor-compression-based refrigerators and air conditioners. The trick will be to intersperse suitable electrocaloric material layers—which can be heated and cooled by the application of an electric field—between heat switch layers. By opening and closing the switches in sequence while alternately raising and lowering electrocaloric-layer temperatures to draw heat in and then push it away, it is possible to send heat out of a cold region, against its natural flow direction—analogue to sending a ship through a series of locks, uphill and overland across the Panama Canal.

Hehlen and Mueller put their heat switches to the ultimate test with a rough, first-ever demonstration of thin-film refrigeration and were able to achieve—wait for it—cooling by 0.1°C. That may not sound earth-shattering, and it doesn't prove thin-film refrigeration will be commercially viable any time soon.

"It just proves it works," says Hehlen. "And it proves the versatility of the heat switches."

LDRD

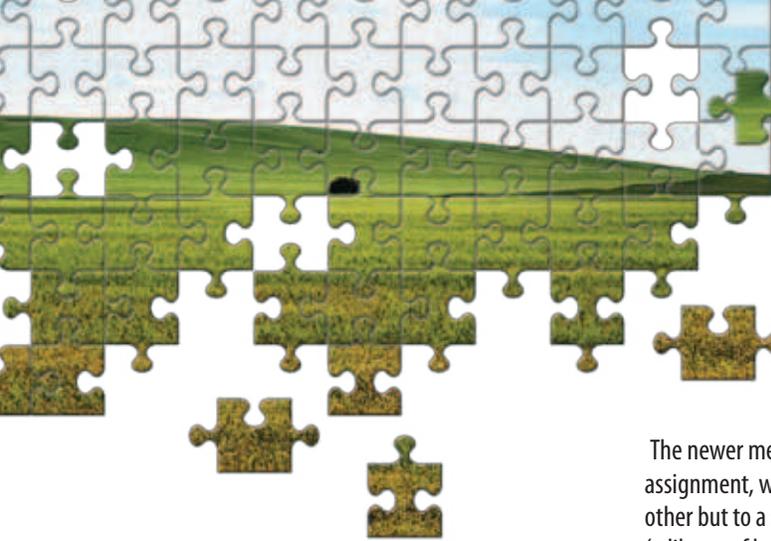
—Craig Tyler

## Microbiome References Required

Imagine a jigsaw puzzle with five billion pieces that shows a picture of a prairie. There are no buildings, no trees, and no people; there's just grassland and sky. Now imagine that you have a dozen such puzzles—one of a prairie in Kansas, another in Iowa, maybe a Canadian prairie for good measure—and all 60 billion puzzle pieces are together in one bag. Without the pictures from the box lids and without knowing how many puzzles there are, you must assemble them all correctly and simultaneously. How are you supposed to tell the difference between *this* piece showing blue sky and *that* piece showing blue sky? Or determine whether a particular patch of grass is from Kansas or Iowa? This, says Los Alamos bioinformatics expert Patrick Chain, is the challenge of metagenomics.

Metagenomics is the field of genetics concerned with the genomic sequencing of microbial communities, the members of which cannot be easily isolated from one another. For example, the human microbiome consists of the hodgepodge of microorganisms (mostly bacteria) that live on and within human bodies. Presently in vogue, this microbiome is increasingly being shown to influence our health,





*Metagenome assembly is like building dozens of similar jigsaw puzzles simultaneously.*

Chain is using new analysis methods that circumvent some of the speed and accuracy challenges.

The newer methods use reference-based assignment, which aligns reads not to each other but to a collection of reference sequences (a library of box-lid pictures) to place them into the correct bin. Reference-based mapping is much faster and can be more accurate than assembly-based methods, but the hitch here is that it requires references. "If you want to use a reference-based approach, you've got to do your due diligence," he says. "You've got to generate reference sequences to optimize your data's utility."

But how many references are required? To answer that question Chain and his Los Alamos collaborator Gary Xie are characterizing the composition and fluctuation of the human microbiome. As it turns out, not only do microbiomes vary from person to person and site to site, but they are dynamic and can change from one sampling to the next. Using a library of 2780 reference genomes to analyze personal metagenomes (collective genomes of all microbial species in a single person's microbiome) from repeated sampling of multiple body sites of study volunteers, they found that, on average, only about 60 percent of the reads mapped to a reference sequence. That means the collection of available references is inadequate for identifying a large proportion of the bacteria living within us—40 percent of the data are orphaned. Further, it suggests scientists know far less than they thought they did, calling into question the general application of many contemporary studies, especially those that draw broad microbiome conclusions from a narrow sampling of subjects.

To increase the utility of microbiome data and the depth of our understanding of the human microbiome, Chain and Xie say more reference sequences are needed, and they ought to be organized by body site. A general estimate

including development, hormonal regulation, and immune system training.

But the human microbiome is exceedingly complex. Our bodies contain roughly ten times more microbial cells than human cells, and we know hardly anything about them. Furthermore, no two sites on the body seem to have the same microbial mix; metagenomic samples from the throat are different than those from, say, the skin or gastrointestinal tract. To better understand what they all do and how they affect us, Chain and other members of the National Institutes of Health's Human Microbiome Project (HMP) are sequencing and studying their genomes.

Metagenomic analyses typically use either assembly-based or reference-based methods. In assembly-based analysis, as with solving a jigsaw puzzle, each 100-character-long snippet of a DNA sequence, called a "read" (puzzle piece), is compared to every other read (every other puzzle piece) to identify where its unique sequence connects to the sequence of an adjacent piece (the big picture). Reads are assembled together and further analyzed to reveal the species and genetic composition of the metagenomic sample. Because comparisons are conducted between every possible pair of reads, assembly-based methods have the benefit that they do not require a reference sequence (box-lid picture). The drawback, however, is a major cost to accuracy and speed—reads from two closely related species can be impossible to assign to one genome bin or the other, and the pairwise comparison of 60 billion reads is computationally intensive and limited by technology.

is that only about one percent of all bacterial species genomes are available as reference sequences. And while producing new references still relies on the cumbersome assembly-based methods, each newly generated sequence goes into a public database where anyone who cares to can access it. In this way, new microbiome data produce maximal bang for the researcher's buck. Generating hundreds of thousands of reference genomes is no small feat, but given the potential medical implications of the one percent we know about so far, it is undoubtedly worth it.

—Eleanor Hutterer

### Sounds Like Better Weather

Like most people, Los Alamos geophysicist Stephen Arrowsmith enjoys listening to the sound of the ocean. The difference is, he does it from thousands of miles away and doesn't use his ears. Instead, he measures the infrasound (sound below the frequency threshold for human hearing) generated by distant, ever-present ocean waves. By comparing the arrival times of distinct wave sounds at different locations, and factoring in some computer modeling, he is able to infer information about the upper-atmospheric conditions through which the sound waves traveled—information that can be used to improve weather forecasts.

Weather models used in forecasting include high-altitude wind data obtained by one of two methods, and both have their problems. Snapshot-style monitoring, in which air conditions are sampled by instruments borne on high-altitude balloons or rockets, gathers information in particular locations at particular moments only. The alternative, continuous monitoring, requires a proliferation of expensive radar and lidar installations. (Lidar is radar with laser light instead of radio waves.) Arrowsmith's acoustic sensors are designed to hit the sweet spot in between: continuous atmospheric monitoring at low cost. And the price of hitting that sweet spot is the challenge of extracting information about atmospheric conditions from acoustical data.



In principle, the source of that data could be anything that generates infrasound; in fact, Arrowsmith and Los Alamos postdoctoral researcher Omar Marcillo were able to verify his system's performance using recorded infrasound from an unseen meteor event in 2010. But when there isn't a nice, sharp meteoric sound source, oceanic standing waves, which hum at a frequency about 100 times lower than the lowest bass note a human being could hear, provide a workable alternative because they are caused by storms and cyclones that are always present over some portion of the ocean. Yet the source of the sound isn't as important as the manner in which that sound is refracted through the atmosphere and down to his sensors on the ground by complex winds and temperature gradients. That's the weather data Arrowsmith wants.

Unfortunately, a variety of conditions could all lead to similar modulations of the sound. So Arrowsmith developed a computer system that works from an initial guess about atmospheric conditions and blends that with the infrasound time delays from a network of ground-based acoustic sensors to arrive at a most-likely estimate for the actual vertical profile of atmospheric conditions. Because upper-atmosphere winds and temperature gradients affect one another, the computer processing is iterative, repeatedly perturbing the presumed initial atmospheric profile and refining it until the system ultimately converges on an optimal solution. Under most test scenarios, the addition of the infrasound data and subsequent processing substantially improves the accuracy of atmospheric profile determinations and, importantly, does so without needing to know anything about the location or timing of the sound source.

So what part of the atmosphere should this new-and-improved method target for maximum forecasting utility? Currently, weather models are built with data from the troposphere, the lowest layer of the atmosphere, which ranges from sea level to over 10 kilometers in altitude. But Arrowsmith initially set his sights on the next, loftier target, the stratosphere—where the ozone layer absorbs solar ultraviolet light, causing temperatures to rise with altitude up to about 50 kilometers. He intended to improve upon weather models by better characterizing stratospheric airflows, which are known to affect the troposphere in a number of ways.

"We chose the stratosphere specifically because it's so complicated and difficult to sample by any other means," says Arrowsmith, "and because we know that mixing between the layers is important. But as I started talking with numerical weather prediction modelers, they told me that similar measurements in the troposphere may be just as useful, if not more useful, because they are currently limited by their periodic, snapshot radio measurements. So now we're looking at both layers."

How soon and how widely his new infrasound technique will be adopted to improve weather forecasts for everyone will depend on establishing a cost-benefit relationship to quantify how much better the forecasts will get with infrasound measurements figured in. It's what he and Marcillo are working on right now.

LDRD

—Craig Tyler

## The New Vascular View

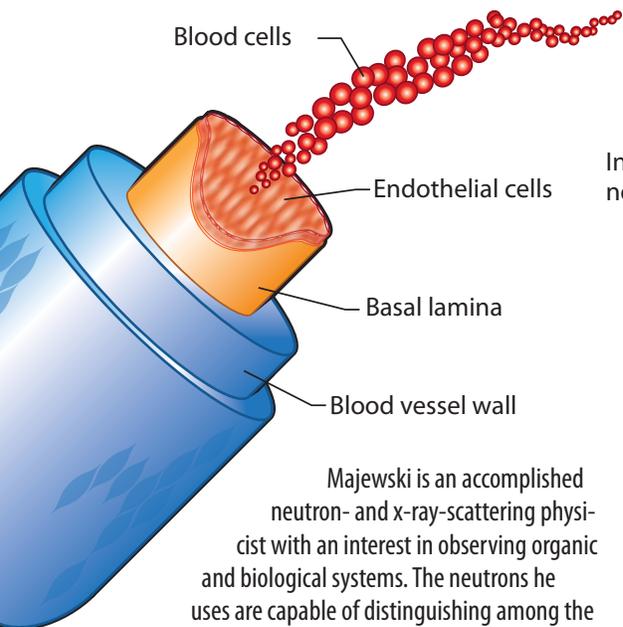
The cells in your body do not live in a Petri dish; they live amidst the frantic bustle of the body's interior. They are stretched and squeezed by nearby muscles, bounced about as you walk, and prodded by the coming and going of blood cells. As a result of all this jostling, most of them must work to stay anchored to the surrounding tissue with an ongoing series of adjustments, involving the secretion of adhesive collagen and other connective-tissue proteins, that goes largely unsung. And it goes largely unstudied, too, mainly because of how difficult it is to make the necessary measurements inside a dynamic, fluid-driven, and biochemically active system.

Recently, however, Jarek Majewski and Ann Junghans of the Los Alamos Neutron Science Center (LANSCE) took a remarkable first step to remedy that, characterizing key adhesive properties of cells and obtaining new insights into the workings of the human body in the process.

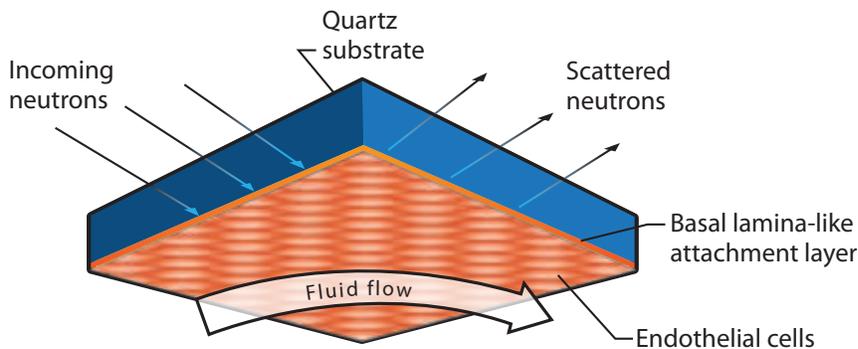
"We use a beam of neutrons to inspect living endothelial cells and their adhesive mechanism," explains Junghans. Endothelial cells line the interior of the entire vascular system—arteries, veins, capillaries, and the heart itself—in a layer that's always one cell thick. These endothelial-cell monolayers provide a smooth, low-friction surface to support the flow of blood while conducting blood-borne oxygen and nutrients out into surrounding tissues. They stand between rushing blood on one side and, on the other, a collagen-rich layer called the basal lamina, which affixes them to the blood vessel wall.

If endothelial cells become stressed or damaged, it's almost always life-threatening; a resultant atherosclerosis, for example, leads to blood clots that can cause heart attacks or strokes. Yet for these cells, mechanical drag from the flowing blood is a constant fact of life, making their ability to adhere to the vascular walls particularly important—and, as Junghans points out, making them particularly promising as a target for cell-adhesion research. Unfortunately, neither traditional x-ray imaging nor fluorescence microscopy provides much practical insight into their adhesive properties.

*Los Alamos infrasound sensors gather data on conditions in the stratosphere (and below) to improve weather prediction.*



*Endothelial cells line the inner walls of blood vessels, where they adhere tightly to resist the shear force from the flowing blood. New neutron-reflectometry research at Los Alamos reveals for the first time how they do it.*



Majewski is an accomplished neutron- and x-ray-scattering physicist with an interest in observing organic and biological systems. The neutrons he uses are capable of distinguishing among the various light atoms found in organic matter without causing any damage to living cells—an improvement over x-rays on both counts. And their reflective properties make them ideal for probing the characteristics of thin-layer interfaces, such as the endothelial-cell monolayer and its basal lamina, at fine resolution. Majewski and Junghans grew the cell monolayer on a quartz substrate, where the cells began to attach themselves by secreting a complex blend of collagen and other proteins, thereby forming the basal lamina-like layer. They then installed a channel through which a bloodlike fluid would flow across the open side of the endothelial cells.

“We couldn’t use real blood because we needed it to be heavy water-based— $H_2O$  using a heavy isotope of hydrogen—for contrast, so the neutrons could distinguish the hydrogen in the cells from the hydrogen in the blood,” Majewski notes. “So we created in heavy water a blend of salts, sugars, and other nutrients to nourish the cells while they are exposed to the neutron beam.”

Once turned on, the neutron beam penetrates the quartz substrate and continues successively into the basal-lamina layer, the endothelial-cell layer, and the “blood.” At each interface, some neutrons reflect toward the detector, which records their time of flight, while others penetrate deeper. A little mathematical manipulation then allows Junghans

and Majewski to combine the detected neutrons’ time of flight with the known neutron-reflecting properties of the atoms in each layer to determine the thickness of the basal lamina and how the endothelial cells respond to shear forces from the blood flow.

When the experiment is carried out at room temperature as a control—well below body temperature and too cold for most human cellular activity—turning on the blood flow induces a fluid-mechanical suction that tends to pull the endothelial cells away from the substrate and stretches the basal lamina layer. The amount of stretch is as expected, based on the elastic properties of collagen. So no surprises yet.

But when the experiment is performed at body temperature, the cells are fully active. Before the simulated blood flow is turned on, the basal lamina layer expands, as the endothelial cells secrete additional collagen and other proteins. (In the body, these cells are always producing such structural proteins to replace those that are naturally swept away as they weaken.) But over several hours of blood flow, the basal lamina contracts until it is 3–4 times thinner, tightening against the suction from the moving blood. At the same time, the endothelial-cell layer itself sharpens, developing flatter surfaces on both the basal-lamina and blood-flow sides. Evidently, endothelial cells are not just inanimate blood-vessel linings; rather, they respond to mechanical stress by adjusting their shape, alignment, and adhesive protein production for optimal vascular function. These responses had never before been directly observed at nanometer length scales and with such accuracy.

“These are exactly the kinds of results you want when you do an experiment no one has ever tried before,” says Junghans. “They are both reassuring and suggestive—replicating expected elastic behaviors to prove we’re on the right track and indicating new mechanisms that could eventually inspire new medical treatments.” Indeed, this experiment reflects the beginning of a new knowledge base not only for treating known endothelial-cell maladies like atherosclerosis, but possibly for treating a broader range of illnesses based on every cell’s structural and adhesive activity.

A significant case in point: At the suggestion of a colleague, Junghans and Majewski repeated the experiment with glioblastoma cells—highly malignant brain-tumor cells. Like endothelial cells, these brain cells secrete proteins to improve their structural adhesion. But the neutron experiment showed that the cancerous cells do so differently than healthy cells, with somewhat weaker and more compressible adhesion characteristics. A full understanding of this difference may take some time to work out, but one early implication is clear: Any difference between cancer cells and healthy ones offers the potential for a targeted treatment. If cancer cells adhere more weakly, then it may be possible to selectively dislodge them.

“That’s why it’s so great to be on the forefront like this,” says Junghans. “You never know what practical knowledge and life-saving treatments might ultimately come from the things you find.”

—Craig Tyler

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