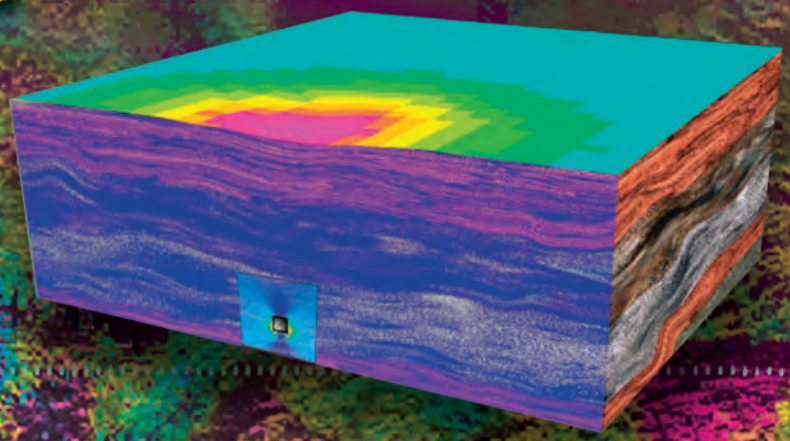
April 2005

Science & Technology Review

National Nuclear Security Administration's
Lawrence Livermore National Laboratory

Detecting Underground Changes from Space



Also in this issue:

- Livermore Attracts Top Sabbatical Scholars
- Frogs Help Identify Human Gene Functionality
- World's Most Powerful Supercomputer Arrives

About the Cover

Interferometric synthetic aperture radar (InSAR) has become a standard tool for mapping changes to Earth's surface from such sources as earthquake faults; glaciers; and oil, gas, and geothermal reservoirs. As the article beginning on p. 4 describes, Livermore researchers are using subtle surface deformation signals captured by InSAR to detect and characterize underground explosions as well as underground tunnels or facilities that might be associated with nuclear test preparations. On the cover, the background image is an interferogram of surface displacement from a large earthquake. One cycle through all the representative colors represents 28 millimeters of near-vertical surface displacement. The foreground image shows the predicted InSAR signal of surface subsidence from a finite-element-simulation of gravitational loading in an underground cavity.

Cover design: Daniel Moore

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (925) 423-3432. Our e-mail address is str-mail@llnl.gov. *S&TR* is available on the World Wide Web at www.llnl.gov/str.

National Nuclear Security Administration

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Lawrence Livermore National Laboratory

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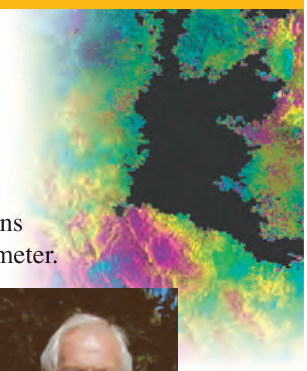

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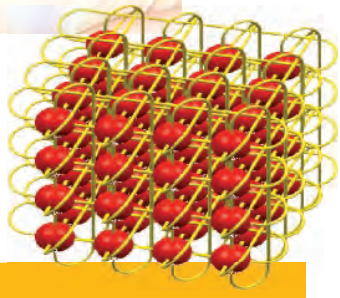

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Van Emden Henson

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Writers
Arnie Heller, Ann Parker, Gabriele Rennie, and Maurina S. Sherman

Art Director and Designer
Daniel Moore

Compositor
Louisa Cardoza

Proofreader
Carolin Middleton

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Analysis of interplanetary dust yields clues

Using a transmission electron microscope, Laboratory researchers have detected a 2,175-angstrom extinction feature (or bump) in interstellar grains embedded within interplanetary dust particles (IDPs). They identified organic carbon and amorphous silica-rich material as the carriers of the 2,175-angstrom bump. This discovery may help explain how some IDPs formed from interstellar materials. The team's research is presented in the January 14, 2005, edition of *Science*.

The carbon and silicate grains may have been produced by irradiation of dust in the interstellar medium. The measurements may help explain how interstellar organic matter was incorporated into the solar system. "Our finding potentially breaks a log-jam in the search for the carrier of the astronomical 2,175-angstrom bump," says John Bradley, director of Livermore's Institute for Geophysics and Planetary Physics (IGPP) and lead author of the paper. "Over the past 40 years, a variety of exotic materials have been proposed. Our findings suggest that organic carbonaceous matter and silicates, the 'common stuff' of interstellar space, may be responsible for the 2,175-angstrom bump."

The Livermore work was funded by the Laboratory Directed Research and Development (LDRD) Program. Other collaborators on the project include researchers from the University of California at Davis, Lawrence Berkeley National Laboratory, Washington University, and the National Aeronautics and Space Administration's Ames Research Center.

Contact: John Bradley (925) 423-0666 (bradley33@llnl.gov).

Tibetan tectonic fault linked to recent tsunami

Laboratory researchers along with colleagues in France and China have determined that the Karakorum Fault in Tibet, a feature formed by the same tectonic "collision" that caused the tsunami on December 26, 2004, in Asia, has slipped 10 millimeters per year during the last 140,000 years.

Scientists Rick Ryerson of IGPP, Bob Finkel of the Energy and Environment Directorate, and Marie-Luce Chevalier (a visiting student from the Institut de Physique du Globe de Paris) studied Karakorum movement along a single strand of the fault system over a millennial time scale and found the slip to be 10 times larger than previous data have shown.

The researchers measured the mid- to late-Pleistocene (from 2 million to 11,000 years ago) slip rate on the southern stretch of the fault by dating two moraine crests displaced by the fault at the end of the Manikala glacial valley. (A moraine is an accumulation of boulders, stones, or other debris carried and deposited by a glacier.) The dating method is based on the accumulation of isotopes produced when cosmic rays hit Earth's surface. The researchers found that the moraines become younger from east to west, which is consistent with the right-lateral motion on the fault.

"Determining the past and present movement along the Karakorum Fault is crucial in understanding the movement of the entire Asian continent," Ryerson says. "It's the collision of the India continental material and the Asian continental material that has caused the uplift of the Himalayas and Tibet." The research, conducted under LDRD funding, appears in the January 21, 2005, edition of *Science*.

Contact: Rick Ryerson (925) 422-6170 (ryerson1@llnl.gov).

Banner year for the JASPER gas gun

Fifteen successful shots were fired with the JASPER two-stage gas gun at the Nevada Test Site (NTS) in 2004. An experiment on December 14 was the eighth plutonium shot for the year, the eleventh plutonium experiment in the series, and the thirty-eighth shot since the gas gun became operational in March 2001. For the December 14 shot, the JASPER team used a bullet to create the first isentropic compression on a plutonium sample. The method used a new Livermore-developed impactor technology, allowing the JASPER team to investigate plutonium at pressures and densities previously inaccessible to experimentalists.

Mark Martinez, test director, characterizes the gas gun's capabilities as unique. "Shots cost significantly less than a subcritical experiment while providing the very best equation-of-state data over a wide range of relevant conditions," he says.

Chief scientist Neil Holmes heads JASPER's shock-physics experiments that study how materials—especially plutonium—behave as a shock wave passes through them. Holmes explains, "Specifically, JASPER's main goal is to measure plutonium's EOS [equation of state]." EOS is the relationship between the pressure, density, and temperature of plutonium at extreme conditions that encompass millions of atmospheres of pressure and temperatures up to thousands of kelvins. JASPER uses shock waves generated by high-velocity impacts to achieve these extreme conditions.

According to Holmes, acquiring plutonium EOS data is a crucial requirement in stockpile stewardship. The JASPER EOS results complement shock-physics data produced by the ongoing subcritical experiments at NTS and experiments at the National Ignition Facility at Livermore.

Contact: Mark Martinez (925) 423-7572 (martinez17@llnl.gov).

Continued on p. 26

Addressing National Security Needs Benefits Energy and Environment

LAWRENCE Livermore's Energy and Environment Directorate conducts a wide range of research projects in the geologic, atmospheric, and environmental sciences to address challenges in national security, environmental remediation, and energy supply. Because different challenges can require surprisingly similar technical advances, a Livermore technology developed for one national need often benefits others.

The article beginning on p. 4 describes one technology that is helping to address a national security need and is also useful in managing Earth's resources and furthering our understanding of natural hazards. Called interferometric synthetic aperture radar (InSAR), the technology uses data from radar satellites to monitor Earth's surface from space and detect surface deformations as small as 1 centimeter. InSAR is assisting the Department of Energy in its ongoing effort to monitor for clandestine underground nuclear testing. Experiments have shown that InSAR can potentially locate clandestine events to within 100 meters, even long after the event has occurred. It is also useful for a variety of Earth systems and engineering applications.

Because InSAR monitors Earth from space, it can detect deformation patterns over a large region. This capability can provide researchers in other basic geoscience and applied research areas with useful data. For example, geologists use the information to help them determine Earth's tectonic plate boundaries. Seismologists are furthering their understanding of natural phenomena such as volcanoes, earthquakes, and tsunamis. The technology could be used as an early warning system for these events.

InSAR complements Livermore-developed seismic methods that have been used to calibrate seismic stations around the world to monitor compliance with nuclear test bans and improve characterization of earthquakes. In both nuclear testing and earthquakes, seismic waves travel under Earth's surface. Livermore seismologists have studied the differences between signatures produced by the waves from both types of events. Strengthening Livermore's ability to distinguish and characterize earthquakes, nuclear explosions, and other events also advances Laboratory efforts in resource management.

As stewards of our Earth, it is important that we find ways to address worldwide environmental concerns and also help the U.S. develop sustainable energy reserves to reduce dependence on petroleum from the Middle East. The Laboratory has many efforts addressing these important needs. Remote systems such as InSAR are a powerful way to obtain integrated information to advance research for resource management. Remote sensing can be combined with other technologies such as geographic information systems (GIS) to layer data tailored for a specific application. For example, we can combine InSAR data with geologic information to help determine the most likely locations for geothermal reservoirs or provide information for managing reservoirs.

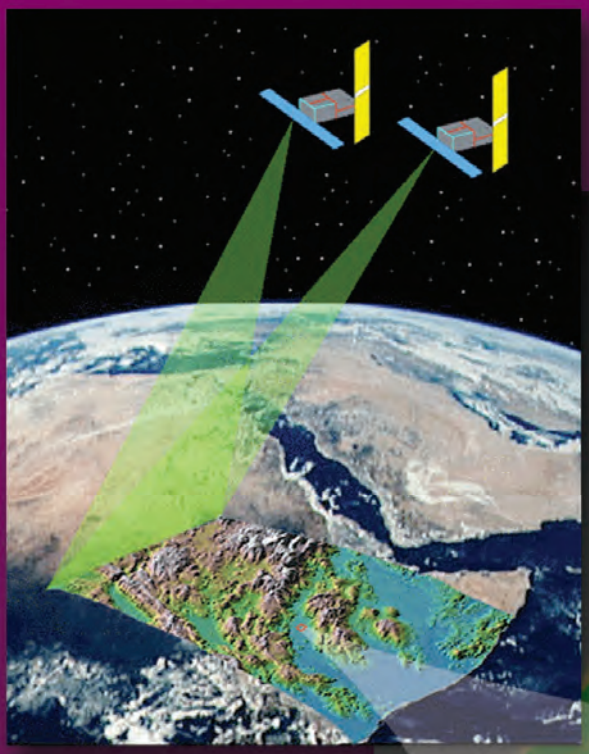
Many Laboratory technologies also take advantage of Livermore's vast experience modeling Earth systems, which provide an understanding of subsurface processes on multiple space and time scales. For example, the InSAR team models data to determine the propagation of surface deformation or changes to underground structures over time.

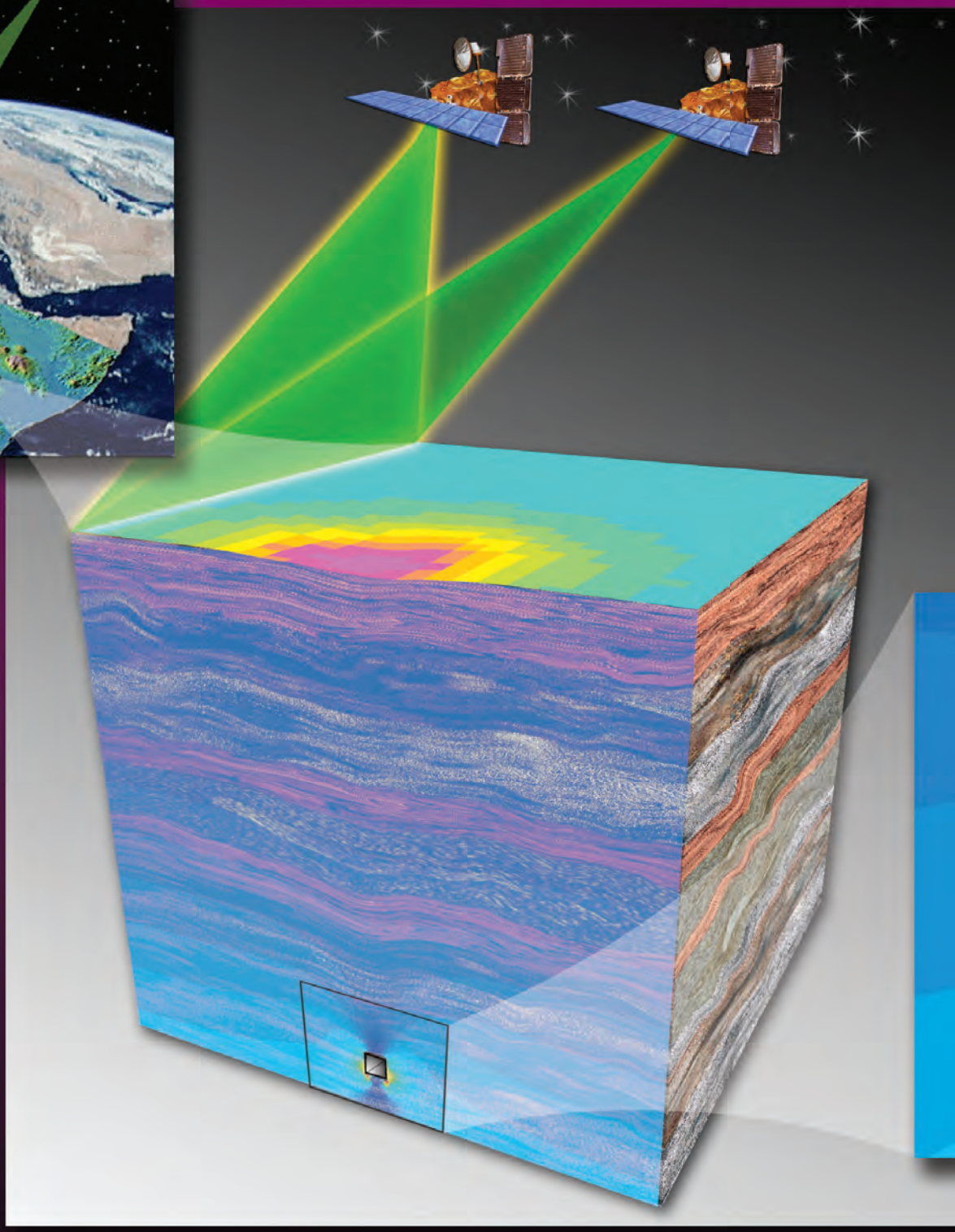
Combining methods such as InSAR with GIS and simulations involves multidisciplinary teams. Livermore's multidisciplinary efforts maximize the Laboratory's capabilities and enable it to develop technologies that contribute to both national security and environmental science. Many technologies such as InSAR have also benefited from Livermore's Laboratory Directed Research and Development Program, which provides initial funding for many Laboratory efforts.

It is an enormous undertaking to address the challenges in national security and to effect change in environmental management and energy supply. However, the Laboratory excels at addressing these national needs.

■ Jane C. S. Long is associate director of Energy and Environment.

Monitoring





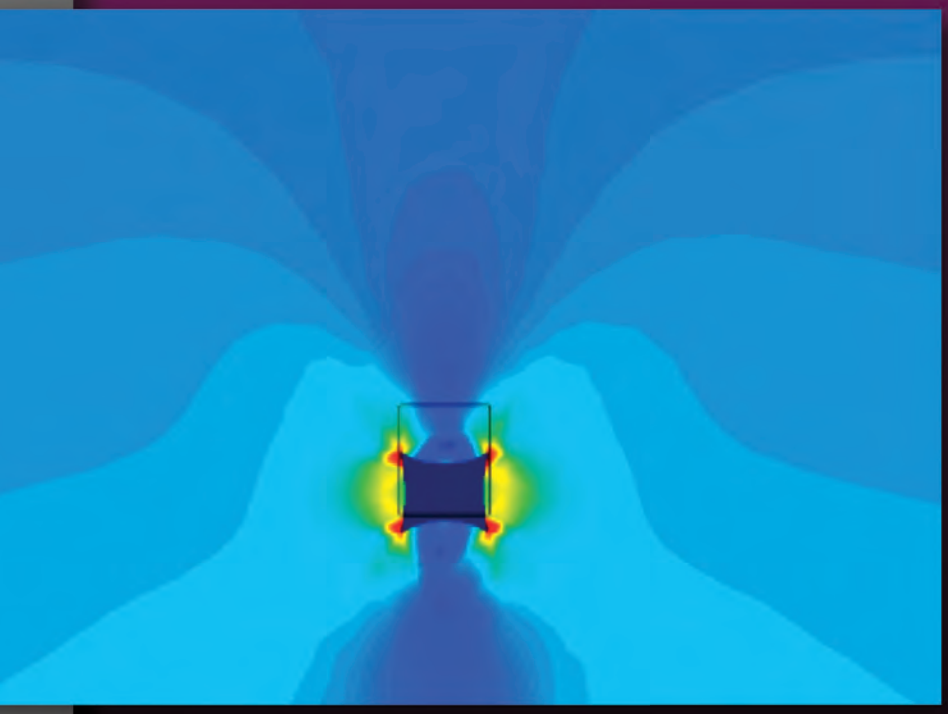
(top) Radar images are taken from a satellite making a repeat pass over an area of Earth's surface. (*Image courtesy of Howard Zebker, Stanford University.*) (center) By analyzing these images, researchers can detect surface changes caused by an underground cavity (shown), a clandestine nuclear explosion, or an environmental hazard. (right) Researchers can also run simulations to characterize deformation.

Earth's Subsurface from Space

A new application of radar technology is helping scientists detect very small subsurface changes.

SINCE 1945, when U.S. scientists conducted the first nuclear test, Trinity, nations have been signatories to a series of treaties designed to reduce the scope of tests and eliminate nuclear testing. For example, the Limited Test Ban Treaty in 1963 banned tests in the atmosphere, under water, and in space, and the Threshold Test Ban Treaty in 1976 established a yield limit of 150 kilotons (150,000 tons of TNT) for underground testing. The Comprehensive Test Ban Treaty (CTBT), signed in 1996, banned all nuclear tests.

Although the U.S. has not ratified the CTBT, it has a significant effort aimed at monitoring worldwide for nuclear explosions. Detection and identification of seismic events is one of the primary monitoring methods. Concern about the possibility of concealing a nuclear test by deliberately minimizing its seismic signals has led to an interest in developing tools that can complement standard seismic monitoring techniques and increase the precision of detecting, identifying, and characterizing underground explosions.



One such method is the use of radar images from satellites. Laboratory geophysicist Paul Vincent is leading a team that is applying a radar imaging technology to detect near-vertical surface deformations measuring less than 1 centimeter caused by underground disturbances.

Called interferometric synthetic aperture radar (InSAR), the technique can be used to monitor Earth's surface from space and possibly detect clandestine underground nuclear tests. InSAR has become a standard tool for mapping changes to Earth's surface caused by earthquake faults; glaciers; and oil, gas, and geothermal reservoirs. Livermore's Laboratory Directed Research and Development Program provided the initial funding for applying InSAR to deformation problems, and the Department of Energy (DOE) is sponsoring ongoing InSAR research.

For decades, DOE has funded Livermore research to monitor underground nuclear testing. Vincent says, "The challenge with monitoring is not only in detecting signals from small nuclear explosions down to a very low

magnitude but also in discriminating them from nonnuclear events, such as earthquakes and mining explosions." More than 100,000 earthquakes similar in seismic magnitude to a small nuclear explosion occur in the world every year. Many of these are disregarded because of their depth or similarity to other events known to be nonnuclear, such as mine blasting. However, many others are not so easily identified. By combining seismic techniques developed over the past 40 years with InSAR images, Livermore researchers hope to increase international confidence in monitoring for underground nuclear testing.

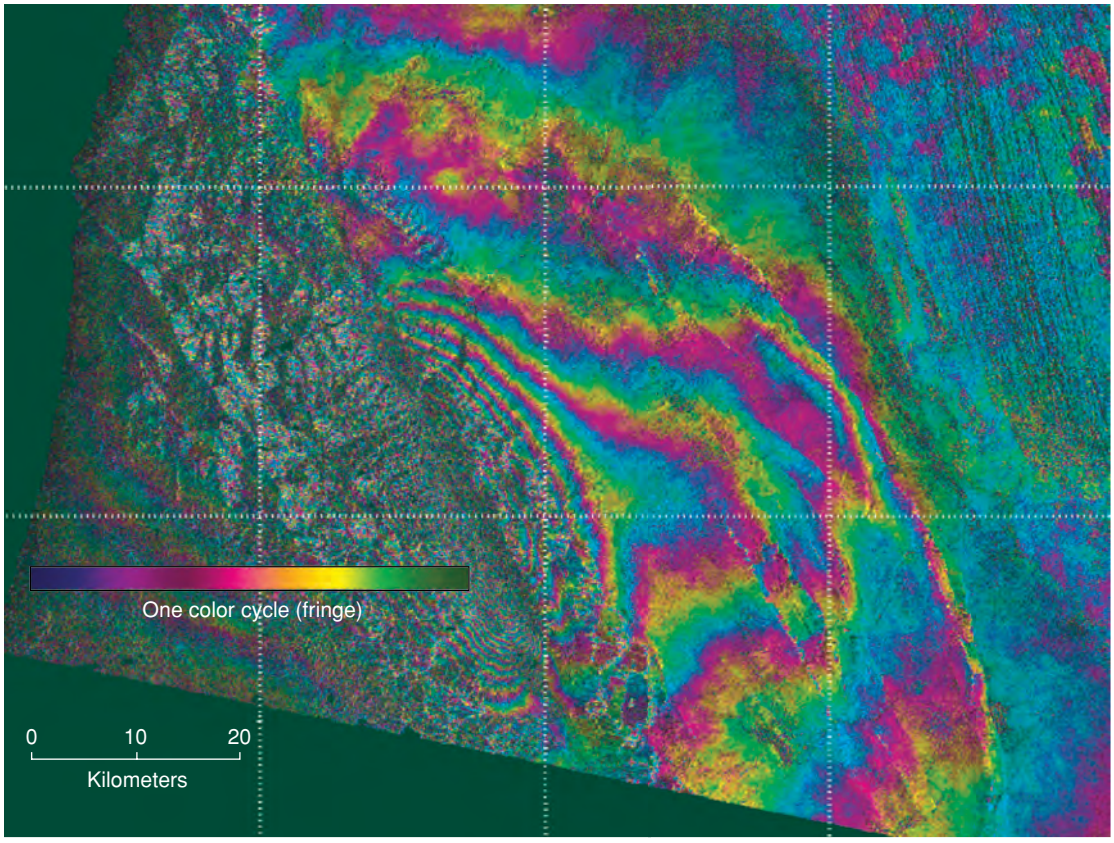
Advances in Radar Technology

In 1978, the National Aeronautics and Space Administration (NASA) launched its Earth-orbiting remote-sensing satellite, Seasat, which was designed to gather information about Earth's oceans. Seasat was the first satellite to use a new type of radar technology, called synthetic aperture radar (SAR). A SAR system "synthesizes" a large antenna by collecting a series of radar pulse returns as the satellite moves along its flight track, which results in increased image resolution. Because a moving SAR antenna can collect radar returns in two directions (range and azimuth), two-dimensional (2D) images can be constructed.

SAR has advantages over other remote-sensing techniques. For example, SAR provides its own illumination in the form of microwaves, so it can image any time of day or night without the need for sunlight. The wavelengths of the microwaves range from 1 to 30 centimeters, which are much longer than those of visible or infrared light. Thus, SAR's longer wavelengths can penetrate cloudy conditions that are opaque to visible and infrared instruments. Also, SAR satellites provide a map view of entire swaths of Earth's surfaces.

SAR's microwave signals or pulses—transmitted at 1,700 times per second—are Doppler-shifted as they are reflected back to the antenna. That is, waves in front of the satellite register a higher frequency, or positive Doppler shift, and waves behind the satellite register a lower frequency, or negative Doppler shift. The Doppler shift registers as zero for ground regions (pixels) directly broadside of the antenna at acquisition time. The zero Doppler allows for the correct placement of each radar return echo along the flight path (azimuth) direction. Researchers use the zero Doppler associated with each azimuth return to construct a 2D SAR image.

Each pixel in a SAR image is represented by a complex number from which the magnitude and the phase can be



This interferogram is based on two radar images taken from the same viewing angle at different times. The fringe pattern shows surface displacement from an earthquake that ruptured up to the surface. Each fringe (a cycle through all of the colors) represents 28 millimeters of near-vertical surface displacement. By counting the number of fringes from the outer edge of the interferogram toward the center of the fringe pattern, scientists can determine the total deformation.

calculated. The magnitude represents how much power from the original transmitted pulse is reflected back to the antenna from a given ground pixel. The phase, or fractional wavelength of the echo, can be used to extract range information similar to what can be obtained from conventional radars, but SAR data are much more precise.

Detecting Subtle Surface Changes

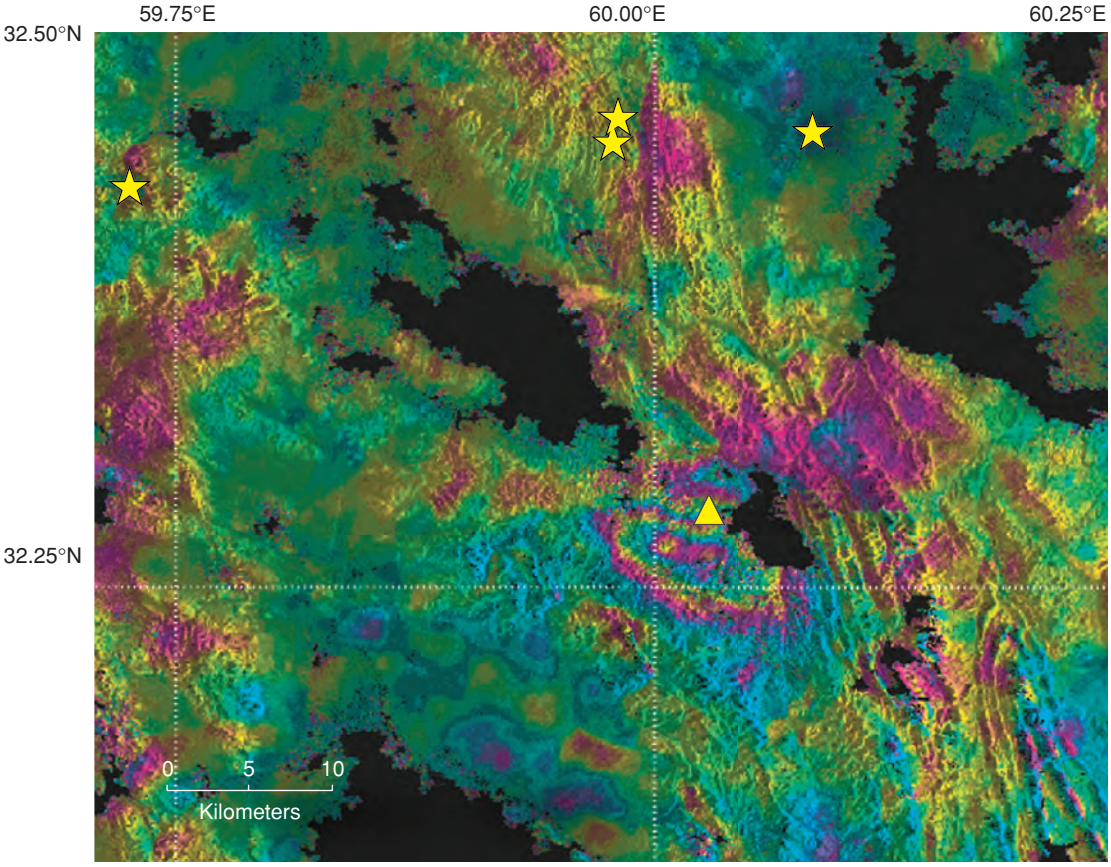
To convert the raw SAR data into maps showing surface deformation (interferograms), Vincent's team uses a combination of open-source and commercial software. Researchers look for common points between two SAR images and line up each of the pixels in a frame. Then they apply algorithms to obtain the phase difference. When two SAR images of the same ground region are acquired from similar viewing angles, the phases of the two images can be interfered (subtracted) pixel by pixel. This process creates interferometric fringes, producing an image called an interferogram. A fringe appears on an interferogram as a cycle of arbitrary colors, with each cycle representing 28 millimeters of near-vertical surface displacement.

Two methods were devised to remove topographic fringes, which can mask surface deformation. In 1993, a French team developed a technique that uses a digital elevation model (DEM) to remove the topographic fringes from an interferogram, leaving only those fringes that are proportional to surface deformation. (A DEM image represents heights above sea level for a particular location.) Also in 1993, the Jet Propulsion Laboratory, California Institute of Technology, developed a method to combine two interferograms of the same region and subtract out the topographical fringes. One (topographic) interferogram is acquired over a short time period to ensure there is no surface deformation. Once the topographic fringes are subtracted, the remaining fringes are proportional to surface displacement plus some atmospheric phase noise.

Today, researchers use both of these methods to create a continuous 2D map of surface displacements over a 10,000-square-kilometer area. By counting (integrating) the fringes on the deformation-only interferogram using a technique called phase unwrapping, they can determine how much the ground has moved, pixel by pixel, to finally form a deformation map. The more the surface has been displaced, the tighter (closer together) are the fringes.

Profiling Seismic Signatures

In their work to monitor globally for nuclear explosions, Livermore researchers have extensively studied

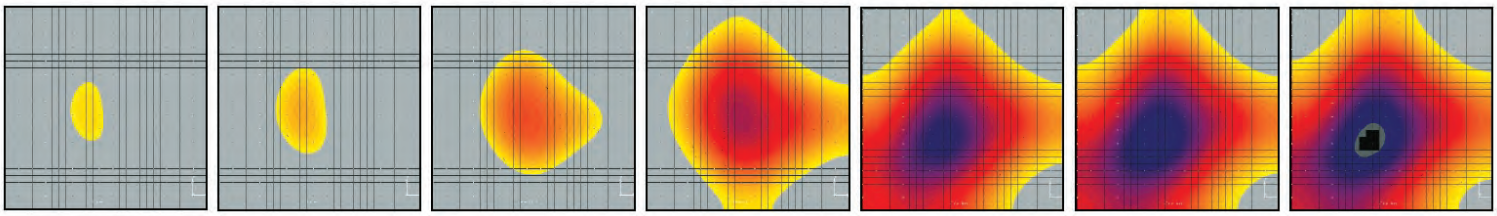


Interferometric synthetic aperture radar (InSAR) can be used to increase the precision of pinpointing the origin of earthquakes. For example, after the April 10, 1998, earthquake in Iran, InSAR (triangle) provided a 20-kilometer correction to the seismic locations (stars) registered by regional seismic stations.

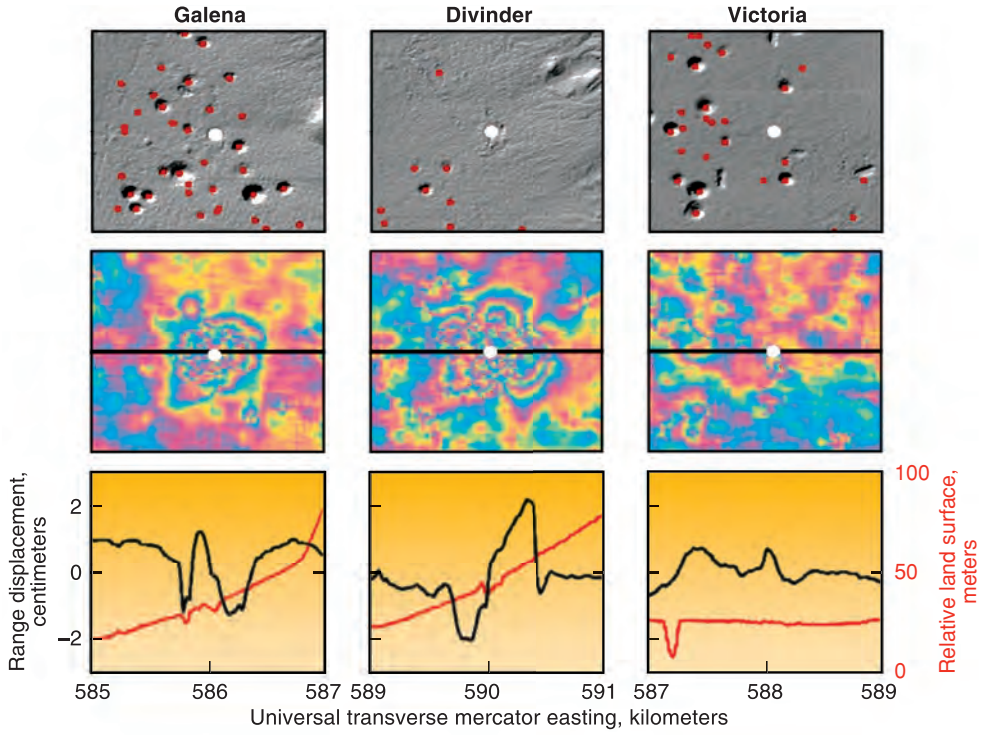
the differences in signatures produced by seismic events. Earthquakes and explosions differ in four important ways. Explosions tend to occur within a few kilometers of Earth's surface and produce spherically symmetric pressure pulses, whereas earthquakes can be many kilometers deep and produce shear slips along faults. The postevent elastic properties of the rocks at the sites of earthquakes and explosions also tend to differ. Finally, explosions have a shorter duration than earthquakes. Laboratory researchers have used these differences to develop a variety of seismic measurements that allow them to identify and discriminate most explosions from the ongoing background of earthquakes.

Seismic instruments can detect seismic waves with amplitudes as small as a nanometer, allowing researchers to pick up medium-size seismic events around the world and very small events at closer distances. Broadband seismic instruments contain a mass kept in place using a force-feedback system. As seismic movement occurs, the instrument measures how much energy is required to hold the mass in place, which is proportional to the ground acceleration.

However, seismic techniques have their limitations. Livermore seismologist Bill Walter explains, "We must sort through many signals to identify those we need to be concerned about. Also, because Earth isn't uniform in composition, signals travel to seismic stations at different speeds. Consequently, it is sometimes difficult to determine the exact origin point for an event without calibration." Seismic events are located by comparing arrival times at different stations of known



Researchers use a finite-element model to calculate forces for individual parts of an area on Earth's surface to predict how long a specific man-made or natural underground structure will take to produce detectable surface deformation under certain geologic conditions.



Coseismic surface-deformation signals from three underground nuclear tests (white dots) conducted at the Nevada Test Site in 1992 were collected by InSAR over a 14-month time span. The top images show nearby craters (red dots) from other underground tests prior to 1992, which is the first year archived data became available from the European Space Agency's ERS-1 SAR satellite. The color interferograms derived from the InSAR data (middle row) show surface displacement that occurred both during and following the explosions. The profile plots (bottom row) show near-vertical displacement (left scale) and surface topography (right scale).

locations—local and regional. Differences in geology cause variations in travel times that translate to errors in determining the event location. These errors can be reduced by analyzing many seismic sources whose locations are known.

InSAR is providing valuable data to help scientists more precisely pinpoint the origin of seismic events such as earthquakes. For example, InSAR provided a 20-kilometer correction to the origin of a 1998 earthquake in Iran determined by seismic methods.

Modeling Seismic Propagation

To better understand how Earth's surface changes over time after a seismic event, Livermore researchers perform computer simulations. In the late 1980s and early 1990s, Livermore computer scientist and geophysicist Shawn Larsen developed a finite-difference program that is now commonly used in seismic studies. The software, E3D, incorporates three-dimensional (3D) information about the propagation of seismic waves. The program simulates how waves are radiated from an earthquake's source to the surface, at what velocities they propagate, and how they interact with the geology and topography in their path.

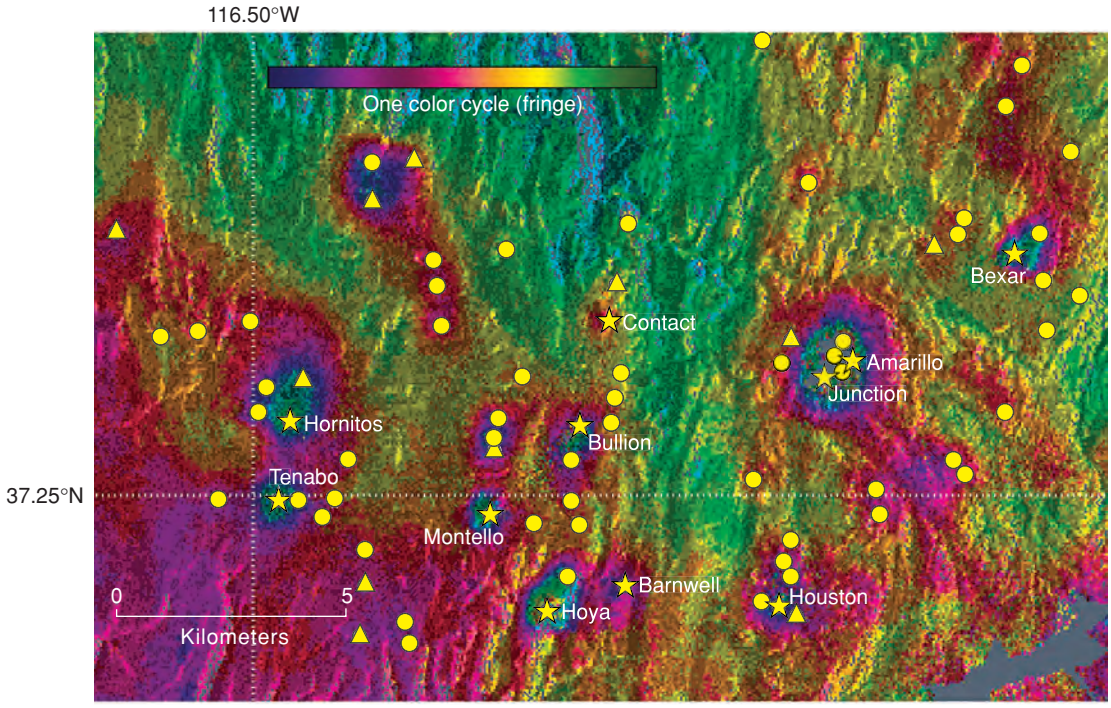
Researchers use another modeling approach for deformation studies called a finite-element method. This method simulates forces, such as gravity and friction, to predict the strain in surrounding rock from an underground cavity as the strain propagates to the surface. Although the code is computationally intensive, it is one of the best tools available to determine how gravity and other forces will affect cracked and stressed rock over time to produce surface deformation detectable with InSAR.

Examining Nuclear Test Explosions

Modeling has shown that for each type of seismic event of a particular magnitude, a distinctive pattern of ground movement is produced that is recognizable in a corresponding interferogram. To better understand surface deformation from underground explosions, in 1999, the team studied coseismic (during a seismic event) and postseismic (after a seismic event) movement using surface-deformation signals from the Nevada Test Site (NTS) that were captured by InSAR over 4 years (1992 to 1996).

Several interferograms were created from raw archived data of the entire test site, collected by the European Space Agency's ERS-1 and ERS-2 SAR satellites beginning in 1992. Underground nuclear tests were conducted at NTS from the 1960s to 1992. Interferograms revealed that postseismic signals can persist for months to years after a nuclear test and that various types of deformation can occur at different rates, depending on the geologic and hydrologic conditions of the explosion area.

The majority of the NTS tests produced either an immediate crater or a subsurface collapse minutes to days after the explosion. The most common type of postshot collapse after a nuclear explosion is chimneying, in which the explosion



Postseismic surface-deformation signals captured by InSAR show continued ground subsidence from underground nuclear tests at the Nevada Test Site. The variety of patterns reflect the different subsidence rates, which are affected by the subsurface geologic conditions for each test region. The signals were collected from 1992 to 1996. The stars indicate tests conducted after 1989, and the circles indicate tests prior to 1989. The triangles indicate the largest or deepest tests conducted from the late 1960s to mid-1970s.

cavity migrates upward as blocks of fractured rock fall to fill the cavity below. Such deformation usually takes place in a few seconds. If the chimney reaches the surface, a crater forms.

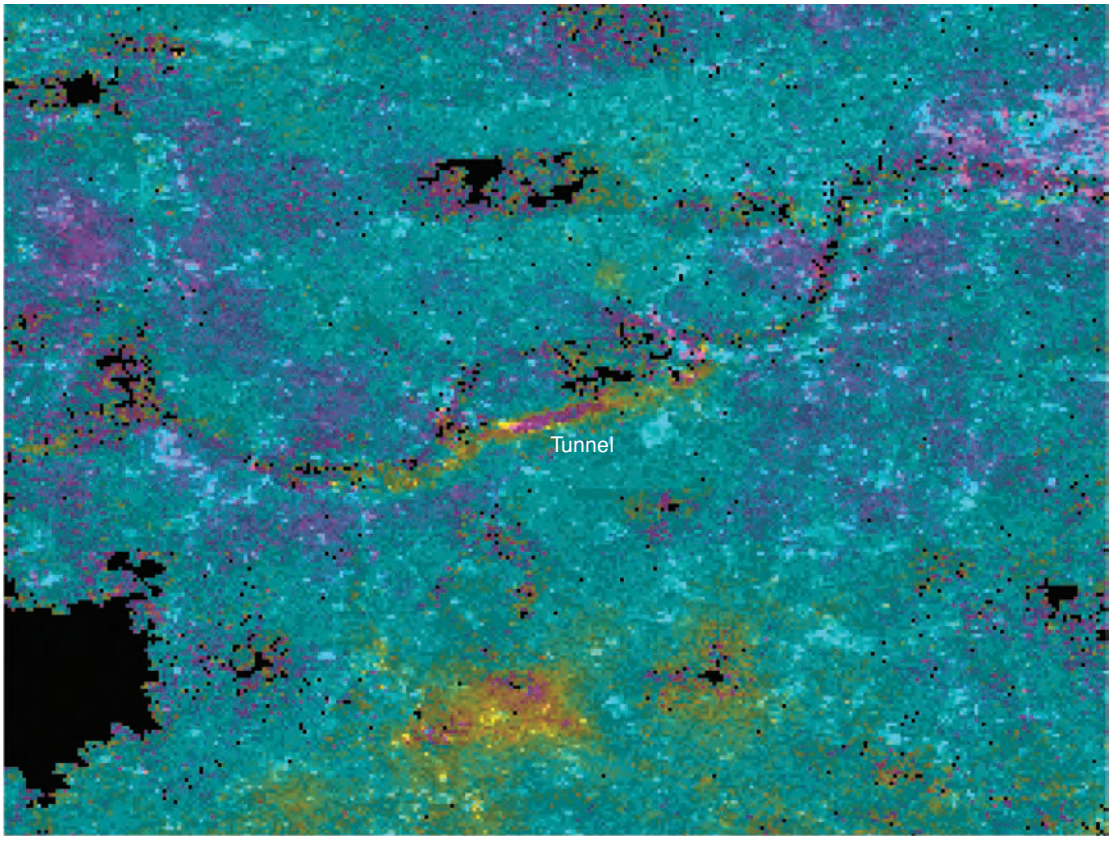
"One of the surprises," says Vincent, "was that the ground where tests had been conducted prior to 1992 is still subsiding." The InSAR data revealed both coseismic and postseismic subsidence signals that extended 1 kilometer or more across the surface, regardless of whether a surface crater was formed from the test. Rates of subsidence varied, although most of the signals indicated that this process occurs relatively slowly. The different rates may be due to several factors, including the number of tests conducted in a specific area. The rate of subsidence was also inversely proportional to the duration of the subsidence, suggesting that in areas with larger or deeper subsidence, the ground may take longer to settle.

The results of the Livermore studies at NTS indicate that InSAR could be used to detect surface deformation associated with underground nuclear explosions detonated at depths in excess of 600 meters. In addition, underground nuclear explosions may not need to be captured coseismically by radar images in order to be detectable. A suspect seismic event that is detected by seismic instruments can be imaged after an event and located to within 100 meters.

Discovering Underground Tunnels

InSAR also has the potential to detect and characterize underground facilities of interest, such as tunnels that might be associated with nuclear test preparations. Underground facilities create voids in the surrounding rock and soil, which often cause the overlying surface to subside. This subsidence is usually extremely small, for example, 1 centimeter of subsidence distributed over an area measuring one to several kilometers wide. Although surface craters and other coseismic surface effects may be detectable using high-resolution optical or other remote-sensing techniques, these broader, more subtle subsidence signals cannot be detected using other methods.

Recently, the Livermore team used InSAR to study London's Jubilee rail line, an extension to the city's underground rail system that was joined to its existing line in 1999. The team found a 2-centimeter surface subsidence above the tunnel. Once Livermore researchers have the radar data to create an interferogram, they can use a finite-element model to determine surface-deformation changes from a tunnel or cavity. They first define the size, shape, and depth of the space and then run a simulation imposing a partial collapse on the defined cavity's geometry and depth.



InSAR can be used to detect and characterize underground tunnels and cavities. In a study on London's underground railway system, InSAR revealed a previously undetected 2-centimeter surface subsidence above the Jubilee rail line.

Monitoring Movement in Real Time

Dynamic InSAR, a new technique based on InSAR, can be used to produce interferograms as an event is occurring. "Dynamic InSAR is a more difficult process to perform," says Vincent, "because we can't make the same assumptions when processing the data as we can with before and after images.

Because it can be used to track seismic waves in real time, dynamic InSAR has potential applications not only in national security but also in tracking natural hazards, such as earthquakes, volcanoes, and tsunamis. Vincent says, "Tsunamis travel at subsonic speeds of about 800 kilometers per hour and create less than 1 meter of wave amplitude (height) in open ocean water. SAR satellites orbiting the globe about 11 times per day could be used to track tsunamis in real time, providing an early warning system."

The Livermore team uses raw data obtained from satellites such as the European Space Agency's ERS-1, ERS-2, and Envisat satellites, as well as the Canadian Radarsat Satellite and the Japanese Earth Resources Satellite. An effort is also under way in the U.S. to build and launch an InSAR satellite.

Laboratory researchers think that all explosions, regardless of the terrain under which they occur, leave some surface or subsurface clues. As they use InSAR to refine their skills at interpreting the signatures left by each type of seismic event, the technology will increase its usefulness in national security, environmental hazards, and geologic planning.

—Gabriele Rennie

Key Words: Comprehensive Test Ban Treaty (CTBT), digital elevation model (DEM), E3D, finite-element model, interferogram, interferometric synthetic aperture radar (InSAR), International Monitoring System (IMS), nuclear explosion monitoring, remote sensing, synthetic aperture radar (SAR).

For further information contact Paul Vincent (925) 423-8281 (vincent7@llnl.gov).

Monitoring Tsunamis

Interferometric synthetic aperture radar (InSAR) may potentially be used to better monitor tsunamis. A tsunami is a series of ocean gravity waves caused by a high-magnitude earthquake, meteor impact, volcanic eruption next to or underneath the ocean, or large explosion from a man-made detonation. The term "tsunami" comes from the Japanese words "tsu" (harbor) and "nami" (wave).

At their source, tsunamis may measure only 1 meter in height, producing no more than about 1 meter of rolling waves on the ocean's surface. However, tsunamis are long-period waves; that is, their wave crests are far apart—sometimes tens of kilometers on the open ocean. Traveling at subsonic speeds of about 800 kilometers per hour, their long wavelengths allow them to travel across oceans with little loss of energy. When they reach shore, the ocean bottom forces the amplitudes (wave heights) of the tsunamis to increase as much as 10 meters. When tsunamis are traveling in deep oceans, however, their amplitudes are less than 1 meter and are not visible to optical satellites.

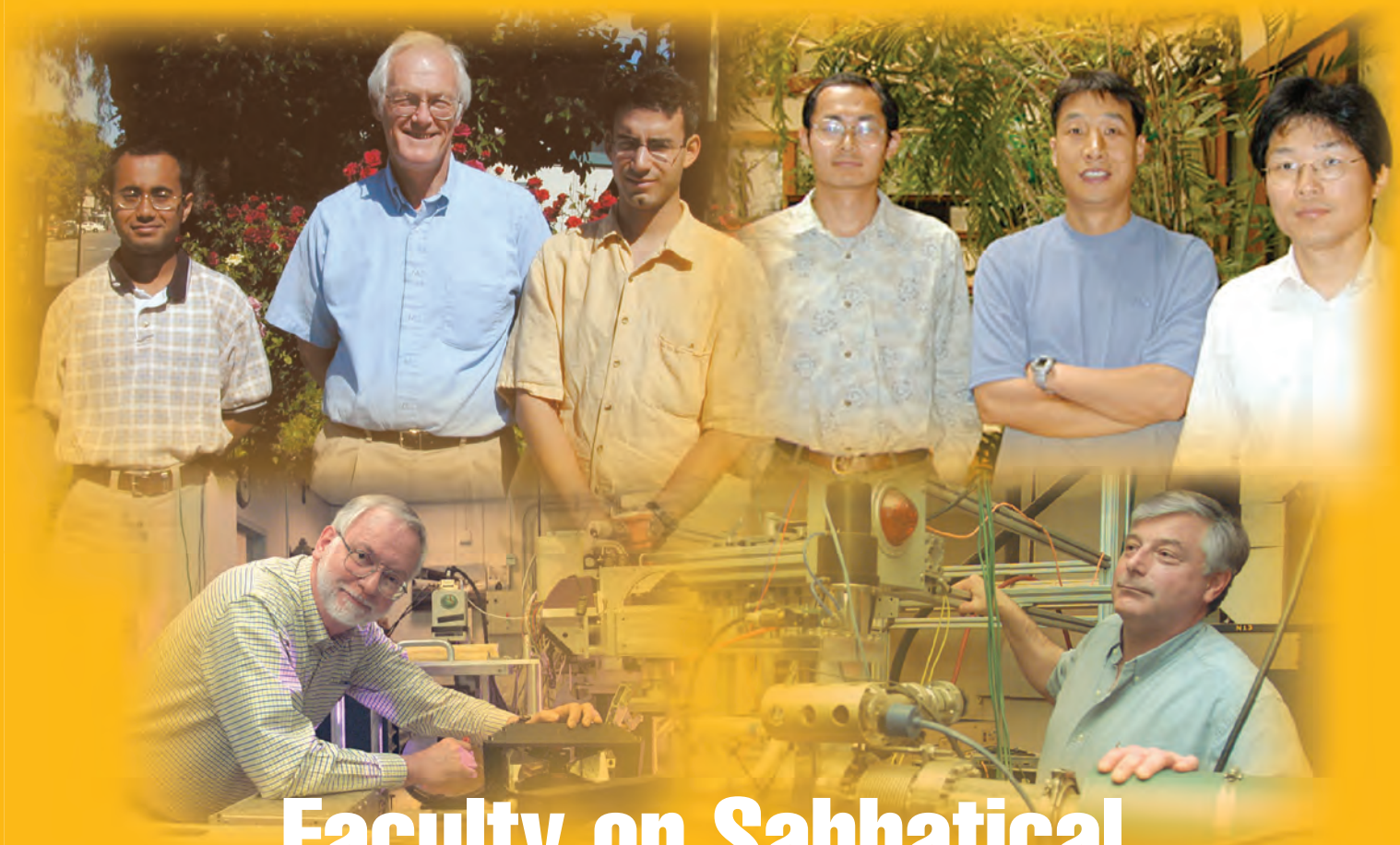
More than 80 percent of tsunamis occur in the Pacific Ocean and around Japan. Although they have occurred in other parts of the world, most areas, for example the Atlantic Ocean, lack the subduction thrust faults that trigger tsunamis.

In 1964, a 9.2-magnitude earthquake caused a tsunami in Alaska, killing more than 100 people and causing millions of dollars in damage to property and infrastructure in four countries. This event led the National Oceanic and Atmospheric Administration (NOAA) to establish a federal tsunami warning system for the Pacific Ocean. The NOAA's satellite network and ocean monitoring system gather data from seismic and tidal stations throughout the Pacific to evaluate potential tsunami threats.

The monitoring system includes tidal gauges and buoys scattered around coastlines and on the ocean floor. The buoys are attached to instruments that measure pressure changes and then send the data to the Geostationary Operational Environmental satellites in orbit above Earth. From there, the information is downloaded to computers at a center in Hawaii. The center assesses whether the temblor's location and severity could generate a tsunami. If so, it sends out a warning of an imminent hazard, detailing the wave's predicted arrival at estimated coastal locations within a given time. No system as extensive exists anywhere else in the world.

In the Indian Ocean, the world's third largest, no such buoys and tidal gauges exist. Among the 12 countries threatened by tsunamis in that region of the world, only Thailand has any warning system. Although tsunamis are rare in the Indian Ocean, the tsunami that struck on December 26, 2004, claimed approximately 286,000 lives in 11 nations and caused billions of dollars in damage. The incident demonstrated the need for a warning system in all the vulnerable regions of the world's oceans.

Dynamic InSAR, a form of the technology that can image seismic waves in real time, could be used to complement today's seismic instruments and provide a global tsunami monitoring system. For example, by using two satellites, each traveling around the globe 11 times per day, dynamic InSAR could detect a tsunami's amplitude wave change and track its speed. With this more precise information, decision makers could issue timely, accurate warnings and, thus, help save many lives.



Faculty on Sabbatical Find a Good Home at Livermore

Livermore's Sabbatical Scholars Program is attracting top academic scientists and their students to the Laboratory.

FOR university faculty members, a sabbatical leave is one of the most valued perks of academic life. Typically, a sabbatical means an opportunity every seventh year to conduct research for several months, or sometimes a full academic year, without a teaching workload. An increasing number of faculty members are choosing to spend their sabbaticals at Lawrence Livermore.

Livermore's Sabbatical Scholars Program was designed to bring topflight scientific and engineering expertise to the Laboratory. This program gives visiting professors the opportunity to conduct research at one of the world's premier applied science and engineering research centers, and Livermore scientists have the opportunity to collaborate with some of the best scientific minds in the world. The

established ties serve to strengthen the recruitment of outstanding young scientists and engineers.

"Our sabbatical program is a cost-effective way to take advantage of the outstanding scientists in the nation and the world," says Harry Radousky, deputy director of Livermore's University Relations Program (URP). URP was formed in 1995 to facilitate the growing number of collaborations between Laboratory researchers and academic institutions. "Strong interactions between the university community and Lawrence Livermore are vital to the continuing success of the Laboratory's missions," says Radousky. (See *S&TR*, October 2004, pp. 14–23.)

URP advertises the program annually in science journals, such as *Science* and *Nature,* and through promotions on selected university campuses, particularly those in the University of California (UC) system. In many cases, Laboratory researchers encourage their university collaborators to apply.

Painless Application Process

"We try to make the application process as painless as possible," says URP's Paul Dickinson, who manages the Sabbatical Scholars Program. Applicants fill out an interest form located on URP's Web site and submit a curriculum vita and brief description of the research they propose to conduct at Livermore. According to Dickinson, some applicants have already collaborated with Livermore researchers, know one or more Livermore scientists, or have visited the Laboratory. Others are attracted by Livermore's reputation in applied science and engineering.

Applications are due May 1 each year, but they are reviewed quarterly until available resources are committed. Applications are first screened by the potential host Laboratory directorate to determine if there is a good match for the applicant and a Livermore program that would benefit from the sabbatical. Applications are then formally reviewed by the same Laboratory-wide committee that selects the Lawrence Fellows (outstanding postdoctoral scholars; see *S&TR,* November 2002, pp. 12–21). Sabbatical candidates are evaluated on their records of achievement and the strength of their research proposals. The committee ranks all applicants and chooses four to six faculty members per fiscal year for sabbaticals that can range from 3 to 15 months.

A unique feature of the program is the inclusion of graduate students and postdoctoral researchers in a faculty member's sabbatical stay at the Laboratory. "Encouraging faculty to bring outstanding students and postdocs with them has proved to be very popular," says Dickinson. The number of students and the duration of their visit to Livermore are negotiated with each faculty participant. Dickinson explains that when faculty members return from a typical sabbatical, they have to "restart" their students' research programs. Under the Livermore program, students return to campus with little break in continuity of their studies.

Since the program's inception in 2000, 22 faculty members have been Livermore Sabbatical Scholars, and 33 of their students and postdoctoral researchers have joined them at Livermore. Faculty members have come from universities throughout the U.S. as well as France, Italy, the Netherlands, and Japan. Six of the 22 professors have come from the UC campuses at Berkeley (UCB), Davis (UCD), and Riverside (UCR). (See the box on p. 14.)

Livermore program directorates have been extremely pleased with the faculty–student teams that the Sabbatical Scholars Program has attracted. "In many cases, faculty–student teams working at the Laboratory for 3 to 12 months have made significant contributions to our technical programs or helped establish new capabilities," says Dickinson. "In most instances, collaborations were established that continue to grow in scope."

The program has also proven to be cost-effective. In most cases, faculty on sabbatical have some fraction (often 80 to 100 percent) of their salary paid by their home institution. As a result, Livermore's costs are usually limited to temporary housing and travel expenses for the professor and any students.

First Sabbatical Scholar

Richard Martin, professor of physics at the University of Illinois at Urbana-

In 2001, University of Illinois physicist Richard Martin (center) was the first participant in the Laboratory's Sabbatical Program. During Martin's sabbatical, three of his graduate students visited Livermore for extended periods, and two of his postdoctoral researchers (shown here with Martin) made short visits.

Champaign, was the first program participant, with a 14-month sabbatical that began in July 2001. At its conclusion, he characterized his sabbatical as "a stimulating, profitable, and enjoyable experience."

Martin, an expert on the electronic properties of solids, proved how productive a sabbatical at Livermore could be. Martin's hosts were physicists Andy McMahan and Giulia Galli in the Physics and Advanced Technologies (PAT) Directorate's H Division, which researches the behavior and structure of materials under extreme conditions. Martin was located in the Laboratory's Materials Research Institute (MRI), where he could interact with a wide range of Livermore scientists.

Martin worked with McMahan and physicists David Young and Jim Albritton on improving quantum models used to generate equations of state. In another project, Martin and McMahan researched

University Relations Program's Sabbatical Scholars Program

Name	University	Dates onsite	Students/ postdocs	Host directorate	Host
Richard Martin	University of Illinois, Urbana-Champaign	07/01–08/02	5	Physics and Advanced Technologies	Giulia Galli, Andy McMahan
James Hunt	University of California, Berkeley	09/01–08/02	2	Energy and Environment/ Chemistry and Materials Science	Ken Jackson, Jesse Yow
James Orr	University of Pierre and Marie Curie (France)	09/01–08/02	2	Energy and Environment	Ken Caldeira
Joonhong Ahn	University of California, Berkeley	01/02–10/02	2	Energy and Environment	Bill Halsey
Herbert Edelsbrunner	Duke University	01/02–06/02	2	Computation	David Keyes
James Carlson	University of California, Davis	04/02–06/02	1	Physics and Advanced Technologies	Steve Visuri
Carlo Bottasso	Politecnico di Milano (Italy)	06/02–11/02	2	Engineering/Computation	Dennis Parsons
Stanley Prussin	University of California, Berkeley	08/02–05/03	2	Nonproliferation, Arms Control, and International Security	Tom Gosnell
Stephen Park	University of California, Riverside	09/02–05/03	0	Energy and Environment	Jeff Roberts
Joyce Penner	University of Michigan	09/02–09/03	3	Energy and Environment	Doug Rotman
Peter Pacheco	University of San Francisco	09/02–05/03	1	Computation	Patrick Miller
James Badro	University of Pierre and Marie Curie (France)	12/02–03/03	0	Energy and Environment	Daniel Farber
R. Paul Drake	University of Michigan	01/03–09/03	2	National Ignition Facility Programs	Bruce Remington
Michael Walter	Okayama University (Japan)	01/03–03/04	0	Chemistry and Materials Science	Joseph Zaug
John Trangenstein	Duke University	01/03–05/03	2	Computation	Richard Hornung
Alexander Tielens	Kapteyn Astronomical Institute (Netherlands)	06/03–08/03	3	Physics and Advanced Technologies	Wil van Breugel
J. Ilja Siepmann	University of Minnesota	08/03–07/04	1	Chemistry and Materials Science	Chris Mundy
George Hepner	University of Utah	10/03–02/04	1	Energy and Environment	Bill Pickles
James Brennan	University of Toronto	03/04–05/04	0	Energy and Environment	Rick Ryerson
Edison Liang	Rice University	03/04–08/04	2	National Ignition Facility Programs	Bruce Remington
Edward Morse	University of California, Berkeley	09/04–05/05	0	National Ignition Facility Programs/ Physics and Advanced Technologies/ Nonproliferation, Arms Control, and International Security	Mike Moran
Scott Davis	Naval Postgraduate School	10/04–03/05	0	Nonproliferation, Arms Control, and International Security	Bill Conaway

strong electron correlation, a phenomenon encountered in some materials of Laboratory interest. In these materials, one cannot make the assumption that each electron in a solid interacts independently of all the other electrons. Martin also worked with physicists Andrew Williamson, Jeff Grossman, Galli, and others on Monte Carlo simulations and time-dependent density functional theory. Adding time dependence improves modeling capabilities based on this theory, such as the ability to predict energy gaps in solids.

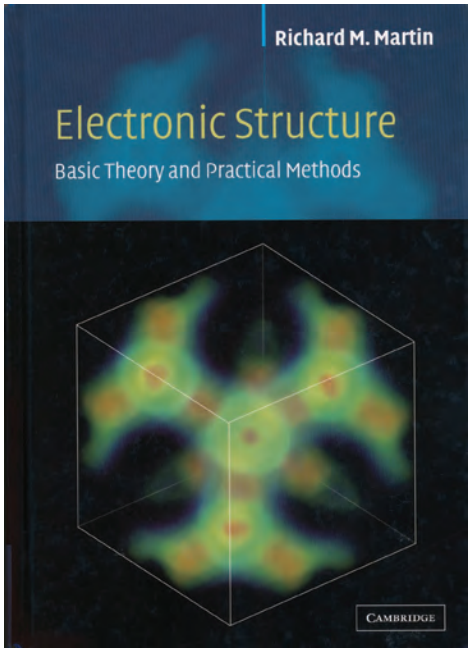
Three of Martin's graduate students visited Livermore for extended periods, and two of his postdoctoral researchers made short visits. Martin started an ongoing collaboration that included one of his students with physicist Mal Kalos of the Defense and Nuclear Technologies Directorate.

During Martin's stay, he also completed the book *Electronic Structure: Basic Theory and Practical Methods*, which was recently published by Cambridge University Press. "One outcome of Richard's many interactions with Laboratory staff was he became a member of the H Division Advisory Committee. He continues to visit the Laboratory about twice a year to sit on this oversight panel that assesses the division's progress," says McMahon.

Sabbatical scholars who have followed Martin include climate experts, nuclear physicists, engineers, computer scientists, and chemists. James Orr, an oceanographer whose research focuses on the cycling of carbon within the ocean and the exchange of carbon between the atmosphere and ocean, completed a year-long sabbatical in 2002. Orr is a scientist with the Laboratoire des Sciences du Climat et de l'Environment of the French Commissariat à l'Energie Atomique and the l'Institut Pierre-Simon Laplace. He is the international coordinator of the Ocean Carbon-Cycle Model Intercomparison Project, which compares and improves three-dimensional numerical models of the ocean.

During his sabbatical, Orr worked with Livermore's Climate and Carbon Cycle Group in the Atmospheric Sciences Division of the Energy and Environment Directorate to achieve the highest resolution simulations of carbon transport with an atmospheric model that had yet been produced. This work led to new projects funded by the National Aeronautics and Space Administration and the Department of Energy (DOE). A strong collaboration continues between Livermore and Orr's group in France.

Joonhong Ahn, associate professor in nuclear engineering at UCB, spent a nine-month sabbatical at Livermore in 2002. Ahn and two of his graduate students studied the relationship between the nuclear fuel cycle and geologic disposal. Their work led to the development of a nuclear fuel cycle mass-flow model for transmuting wastes with an accelerator. Ahn's sabbatical resulted in an expanded collaboration between Livermore



Joonhong Ahn (left), associate professor in the Department of Nuclear Engineering at the University of California at Berkeley, spent a nine-month sabbatical at Livermore in 2002 with two of his graduate students. The three researchers studied the relationship between the nuclear fuel cycle and geologic disposal.

and UCB's Department of Nuclear Engineering.

From Scholar to Chief Scientist

Another member of UCB's Department of Nuclear Engineering, Professor Stanley Prussin, had served for several years as a consultant to Livermore's Nonproliferation, Arms Control, and International Security (NAI) Directorate before his sabbatical from August 2002 to May 2003. During his Livermore sabbatical, Prussin became interested in a Laboratory Directed Research and Development (LDRD) project to develop a method for detecting the clandestine transport of nuclear weapons materials inside shipping containers. The challenge for NAI was to detect a very small amount of highly enriched uranium or plutonium buried inside a typical freight container. Such a detection system is required at the nation's seaports because currently only 2 percent of nearly 7 million shipping containers that enter the U.S. are inspected.

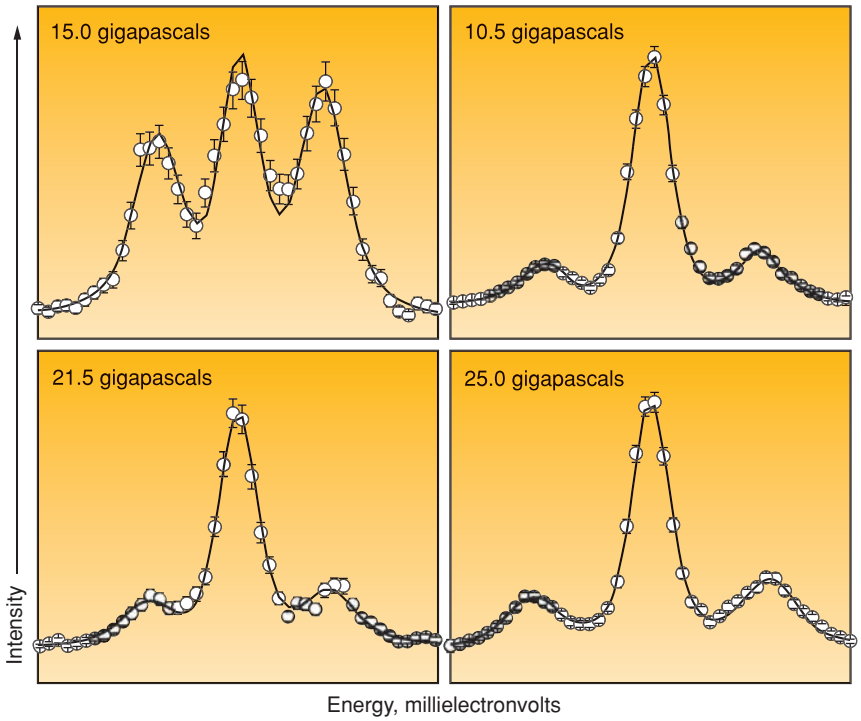
NAI physicist Tom Gosnell, who was Prussin's host, recalls Eric Norman of Lawrence Berkeley National Laboratory visiting Prussin at Livermore. Gosnell observes, "When you give two really smart guys an office and time to think, they can come up with great things." Prussin and Norman were instrumental in developing a detection system that may be 10,000 times more sensitive than other approaches under certain conditions. The system bathes suspicious containers with neutrons to actively search incoming shipments for smuggled nuclear materials. Prussin is currently project chief scientist. (See *S&TR*, May 2004, pp. 12–15.)

Two graduate students accompanied Prussin. One of them, Dave Peterson, was awarded a Student Employee Graduate Research Fellowship (SEGRF). Livermore's URP, in partnership with UC, provides these 4-year fellowships to students pursuing a Ph.D. at UC who are conducting their thesis research at the Laboratory. In 2004, there were about 50 SEGRF students at Livermore.

James Carlson, associate professor in the Department of Medical Pathology in the School of Medicine, and director of the Clinical Microbiology Laboratory at UCD's Medical Center, completed a three-month sabbatical at Livermore in 2002. He worked with Livermore's Medical Technology Program to define a project in the rapid diagnosis of respiratory viruses. While on sabbatical, he and one of his graduate students were able to carry out experiments using biomedical equipment developed at Livermore. Carlson is currently collaborating on a project funded by LDRD to develop a point-of-care pathogen-detection instrument.

Long-Term Collaboration

Geophysicist James Badro, from the Institut de Physique du Globe de Paris, France, was on sabbatical at Livermore from December 2002 to March 2003. His host was long-time collaborator Dan Farber, a high-pressure physicist in the Earth Sciences Division in the Energy and



Livermore physicist Daniel Farber and geophysicist James Badro, a sabbatical scholar from the Institut de Physique du Globe de Paris, France, have advanced scientific understanding of inelastic x-ray scattering of crystals, which measures a crystal's vibrations. These plots show some of the highest pressure and highest resolution single-crystal phonon dispersion (crystal lattice vibration) data ever collected. A beam of 20,000 electronvolts was directed in a longitudinal direction (left column) and then a transverse direction (right column) on a crystal of cobalt. The researchers recorded tiny (about 10-millielectronvolt) shifts in the crystal's vibrational energy, seen in the left- and right-hand peaks flanking the large central peak in each graph.

Environment Directorate. The two first met in Europe in 1994 at a conference. Two years later, Farber came across one of Badro's research papers. "It was one of the few times I've been stunned by a scientific paper," he says.

Later, Farber and Badro worked together for two years at the European Synchrotron Radiation Facility (ESRF) studying inelastic x-ray scattering of crystals. "We developed a technique that measures the modes of vibrations in crystals," says Farber. The work paved the way for a team that included Farber and was led by Livermore chemist Joe Wong to study phonon dispersions (crystal lattice vibration) of plutonium at ESRF. The team, funded by LDRD, produced new phonon data that greatly enhanced scientists' basic knowledge of the phases of plutonium. (See *S&TR*, January/February 2004, pp. 12–14.)

Badro's sabbatical continued the work on inelastic x-ray scattering and allowed the two physicists to generate ideas for new research that take advantage of Livermore's capabilities. Badro has returned to the Laboratory several times since his sabbatical ended in 2003. He and Farber currently have a long-term project supported by the Livermore branch of UC's Institute for Geophysics and Planetary Physics. The project focuses on new ways to obtain data on high-pressure, high-temperature materials.

"Livermore is attractive to many faculty members," says Farber. "We have great technical capabilities, and the campus encompasses a broad range of interests. Faculty members can interact with people doing different things and that can generate new collaborations. The sabbatical program encourages visitors to share their ideas and techniques and allows us to stay engaged with the broader scientific community."

Stephen Park, professor of geophysics with the Department of Earth Sciences and a researcher in the Institute of Geophysics and Planetary Physics branch at UCR, completed a nine-month sabbatical at the Laboratory in the summer of 2003. He partnered with Livermore physicist Jeff Roberts on a project funded by LDRD involving electrical resistivity monitoring of the San Andreas Fault at Parkfield, California. The scientists measured electrical conductivity of sediments adjacent to the fault. The measurements suggested the active portion of the fault at Parkfield may be offset by as much as 1,000 meters from the mapped surface break. (See *S&TR,* March 2005, pp. 22–23.)

Michael Walter, professor from Okayama University, Japan, spent a 13-month sabbatical (January 2003 through March 2004) that was jointly supported by Okayama University and Lawrence Berkeley and Lawrence Livermore national laboratories. Walter designed and constructed an advanced laser-heated diamond anvil cell (LHDAC) system for the new high-pressure beam line 12.2.2 at the Advanced Light Source (ALS) facility at Lawrence Berkeley, one of the world's brightest sources of ultraviolet and soft and hard x-ray beams.

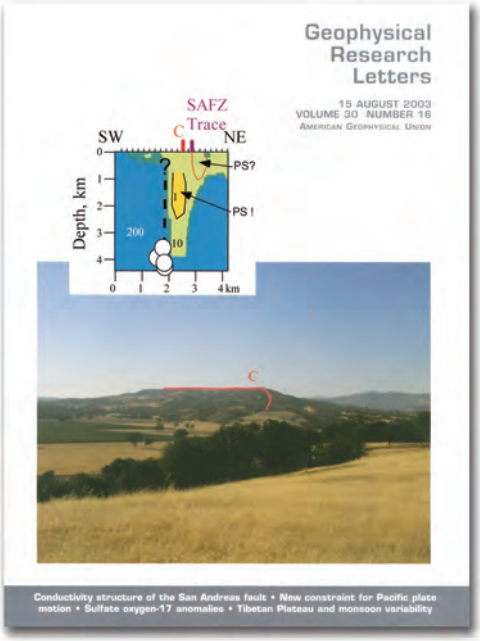
A diamond anvil cell (DAC) is a small mechanical press that forces together the small, flat tips of two diamond anvils, thereby creating extremely high pressures on a tiny sample of a material. Using a laser is an effective way to heat DAC samples. The ALS beam line enables scientists to study the structure of the sample being squeezed and heated in the DAC.

Walter has shared his LHDAC expertise with researchers in Livermore's Chemistry and Materials Science Directorate. In March 2004, he demonstrated how the LHDAC system heats water to well over 2,000 kelvins. "Walter was instrumental in building a laser heating system at the ALS that will enable us to learn about materials using x-ray diffraction as a probe when sample conditions extend to 3,000 or 4,000 kelvins and over 100 gigapascals," says Livermore chemist Joe Zaug, who was Walter's host.

Current Scholars

The most recent sabbatical scholars—Edward Morse from UCB and Scott Davis from the Naval Postgraduate School (NPS) in Monterey, California—arrived at Livermore in the fall of 2004. Morse is the third faculty member from UCB's Department of Nuclear Engineering to participate in the sabbatical program. As a reflection of Morse's unusually broad research interests, his stay is supported by three directorates: National Ignition Facility (NIF) Programs, NAI, and PAT.

Morse has been involved with Livermore for several years. His graduate student, Carlos Barrera, is completing his Ph.D. researching NIF physics. Barrera, in February 2005, was awarded a fellowship at Livermore under the SEGRF Program.



Geophysicist Stephen Park, a sabbatical scholar from the University of California at Riverside, partnered with Livermore physicist Jeff Roberts on a project involving electrical resistivity monitoring of the San Andreas Fault at Parkfield, California. Their work was reported in the August 15, 2003, issue of *Geophysical Research Letters*. (Copyright 2003 American Geophysical Union; reproduced by permission.)

Morse is working with Mike Moran and other Laboratory laser scientists to develop a neutron imaging diagnostic for NIF. Morse has overseen tests of the new detector using neutrons generated at both Livermore and UCB facilities. He has also developed detectors that use diamonds to achieve unprecedented sensitivity. "We're trying to design the diagnostics of the future," he says.

"Morse has been an important resource for us," says Moran, Morse's host. "He has maintained a relationship with Livermore that has evolved as our priorities, needs, and programs have evolved."

For PAT, Morse works closely with Livermore experts in neutron generation and detection. He runs a neutron generator at UCB that previously was located at Livermore. He is currently working with PAT managers on ways to make Livermore's Pelletron, a positron accelerator used to study radiation damage, available to UCB researchers. As an example of the close relationship between Livermore and UCB, Brian Wirth, a former Laboratory physicist, is the newest member of UCB's Nuclear Engineering staff and will oversee UCB access to the Pelletron.

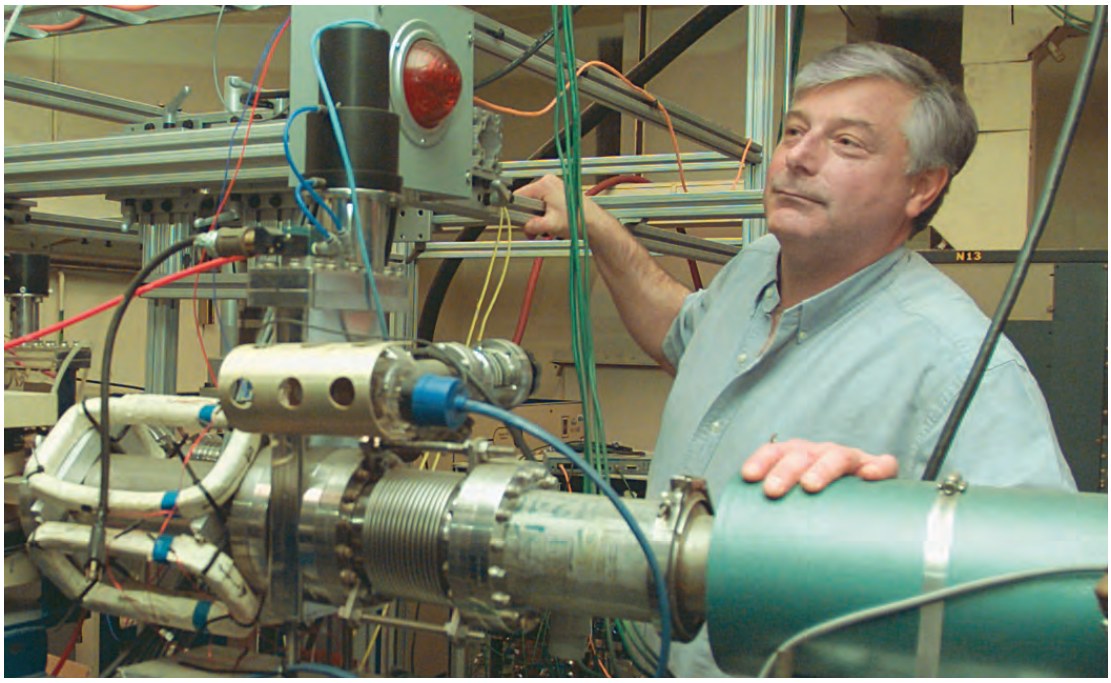
Morse has developed a graduate-student course on nuclear nonproliferation for the Western Nuclear Science Alliance, a DOE-sponsored consortium of college nuclear engineering programs. The two-week course, Analytical Methods of Nonproliferation, was presented last fall at the Idaho National Engineering and Environmental Laboratory and will be taught this summer to between 20 and 40 students from across the nation by what Morse describes as a "dream team" of Livermore scientists.

"The course introduces graduate students to the key issues of nonproliferation issues and national policy," Morse explains. "I thought Livermore would be a good place to host the course," he says, adding that the course will serve as a way to attract talented graduate students to Livermore. Teaching will be coordinated by Simon Labov, director of the Laboratory's Radiation Detection Center.

Physics Professor Scott Davis works in atomic, molecular, and optical physics to develop new generations of sensors at NPS for the Department of Defense. Davis says, "A few years ago, Bill Kruer from Livermore worked for a couple of years at NPS and planted a seed in my brain about spending some time at Livermore." Davis was already familiar with the Laboratory—years ago, he had brought his graduate students to Livermore for a tour of the Nova laser.

After applying to the program, Davis was invited to Livermore to present a colloquium on ultraviolet (UV) imaging spectrometers developed at NPS. Davis arrived for a six-month stay in October 2004. He worked on two advanced remote-sensing techniques that are part of NAI's efforts to detect clandestine weapons of mass destruction.

The first research effort was a collaboration with chemist Nerine Cherepy to develop UV imaging and spectroscopy methods to detect radionuclides in the environment. This effort, funded by LDRD, takes advantage of the fact that alpha and beta particles cause UV fluorescence; that is, they glow in air. A UV imaging



Sabbatical scholar Edward Morse from the University of California at Berkeley (UCB) examines Livermore's Pelletron, a positron accelerator. Materials experiments will be performed on this accelerator by a UCB–Livermore team.

detection system could, for example, be used to assess and aid in the cleanup of an area contaminated by a "dirty bomb" or a radionuclide spill. Current experiments are being performed to evaluate airglow brightness for different response scenarios and to optimize detection efficiency.

A second effort Davis participated in investigated new types of infrared (IR) imaging spectrometers to identify chemical species at low concentrations in the atmosphere and quantify their concentrations based on their IR signatures. "IR signatures are generally specific to each type of molecule," says Davis. One aspect of the project explored new design options for a near-IR imaging spectrometer with higher resolving power than is available with current models. A second aspect investigated the potential application of new detector technologies to long-wavelength IR imaging spectroscopy, an area in which Livermore is an acknowledged leader. IR imaging spectrometers mounted on ships, airplanes, or unmanned airborne vehicles might, for example, remotely detect and measure effluents from facilities and provide insight into whether the facilities were involved in the manufacture of nuclear or chemical weapons.

Davis's host in NAI, Bill Conaway, notes that Livermore's long-standing relationship with NPS was strengthened last April when U.S. Navy Rear Admiral Patrick Dunne and Laboratory Director Michael Anastasio signed a Memorandum of Understanding establishing a framework for stronger collaboration in the area of national security. Conaway says a short-term benefit from Davis's stay was cross-fertilization among scientists, while a long-term benefit was building bridges between Livermore and the NPS. "Scott has excellent students as well as experience with sponsors different from ours," says Conaway. "We want to continue the momentum that he began."

New Emphasis

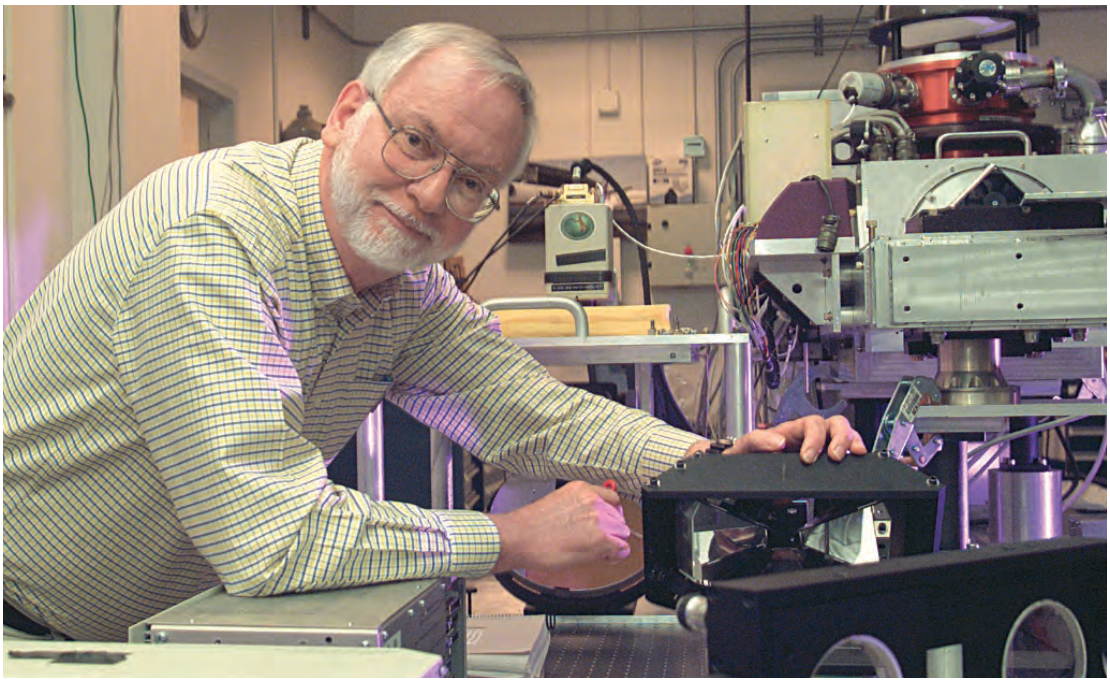
With the Sabbatical Scholars Program in its fifth year, the benefits continue to grow. There are an increasing number of opportunities to recruit scientific and engineering talent from the graduate students and postdoctoral researchers accompanying faculty. Many of these researchers stay in contact with their Livermore hosts, some return to the Laboratory as part of continuing collaborations, and two have become Livermore employees.

"The Sabbatical Scholars Program has been enormously successful," says Radousky. "The benefits keep coming."

—Arnie Heller

Key Words: Advanced Light Source (ALS), European Synchrotron Radiation Facility (ESRF), laser-heated diamond anvil cell (LHDAC), Naval Postgraduate School (NPS), Sabbatical Scholars Program, University Relations Program (URP).

For further information contact Harry Radousky (925) 422-4478 (radousky1@llnl.gov).



Sabbatical scholar Scott Davis from the Naval Postgraduate School works in Livermore's infrared imaging spectroscopy laboratory.

Finding Genes by Leaps and Bounds

Xenopus tropicalis (shown) is a much better choice for functional genomic studies than the traditionally used laboratory frog *Xenopus laevis*.

HAVING completed the sequencing of the human genome—as well as those of other vertebrates such as the mouse and the chicken—researchers in functional genomics are now trying to understand exactly when and where during human development individual genes turn on or off and what exactly they do.

To answer these questions, researchers at Lawrence Livermore are using computational methods to compare the genomes of different species to find common gene sequences (strings of nucleotides and the building blocks of DNA). Although it may seem that looking to frogs and mice for answers to questions about the human genome is a leap, it is not a very long one. Biologists reason that if a gene (and its function) is the same—or has been "conserved"—between a frog and a mouse, whose last common ancestor lived 340 million years ago, chances are very good that the gene will also be conserved between the mouse and the human, whose last common ancestor lived only 75 million years ago.

According to Gabriela Loots, in the Genome Biology Division of the Biosciences Directorate, the thought is that if evolution has selected the conservation of these genes from species to species, they probably confer some important, basic developmental function in the vertebrate embryo, such as tissue differentiation or organ specification. "All vertebrate embryos go through similar development during the early stages of embryogenesis," says Loots. "Whereas each vertebrate species eventually develops its own identity, many similarities exist across different groups of species throughout all developmental stages. It is fair to assume that similar proteins perform similar biological functions."

Scientists reason that if a gene sequence is conserved between species residing at extremes of the evolutionary tree, for example humans and fishes, those gene sequences likely share an ancestral biological function. By identifying these regions of commonality, biologists can home in on those genes that perform critical functions during the early development of human embryos.

Understanding which genes trigger which biological processes can help scientists pinpoint gene defects that cause disease. Researchers hope to use this knowledge to develop diagnostic tests and predictive tools as well as new drugs, therapies, and interventions for both genetic and acquired diseases. In addition, the gathered information will broaden understanding of how complex genomes are organized and how genes cooperate with one another to initiate cascades of regulatory networks.

Mammalian genomes encode for an estimated 25,000 unique genes. The process of elucidating the function for each transcript has been lagging behind scientists' ability to sequence large vertebrate genomes. So far, less than 50 percent of all known genes in the human genome have been experimentally tested to decipher how they function in a living organism. Enormous resources have been invested in cataloging expressed sequence tags (a stretch of coding DNA that has been derived from RNA) to determine the full-length messenger RNA (mRNA) sequences for the most abundantly transcribed vertebrate genes. However, the process of determining the exact biological role of each transcript in a living organism has been slow, and researchers are still far from linking all known gene sequences to what they do in vivo. Livermore scientists are developing novel high-throughput methods to study how individual genes function during embryonic development in living organisms.

So, What About the Frogs?

Loots's group is using a tropical frog, *Xenopus tropicalis*, to create a model that allows controlled gene expression and can be monitored in vivo. Funded in part by Livermore's Laboratory Directed Research and Development Program, this frog model will help in identifying and characterizing the biological functions of some of the evolutionarily conserved genes. The Department of Energy's Joint Genome Institute in Walnut Creek, California, is sequencing the *X. tropicalis* genome. This work is expected to be completed by summer 2005.

The benefits of using frogs instead of mice for this research are compelling. One of the most obvious benefits is that researchers can watch a frog embryo change through various stages of early development in a petri dish. Because frogs have large eggs (over 1 millimeter in diameter), the resulting embryos are easily viewed under a standard dissecting microscope. Also, *X. tropicalis* females can be induced to lay eggs "on command" at any time of the year. After inducing female frogs with hormones, the researchers harvest their eggs by gently squeezing them. The eggs are then fertilized in a petri dish.

Another key advantage is that *X. tropicalis* is the only amphibian that is diploid. That is, it has two sets of chromosomes rather than the usual four sets (tetraploidy) possessed by all other frogs, including the classic laboratory frog *Xenopus laevis*. Because *X. tropicalis* has half the genome of *X. laevis*, it is an ideal subject for silencing gene expression (and, subsequently, gene function) in laboratory experiments. Loots and her group use synthesized strands of genetic material called morpholino oligonucleotides (MOs) to perform the loss-of-function experiments in the frog embryos. These MOs are single-stranded sequences that target the gene of interest and silence that gene before it has a chance to initiate protein production.

Step by Step

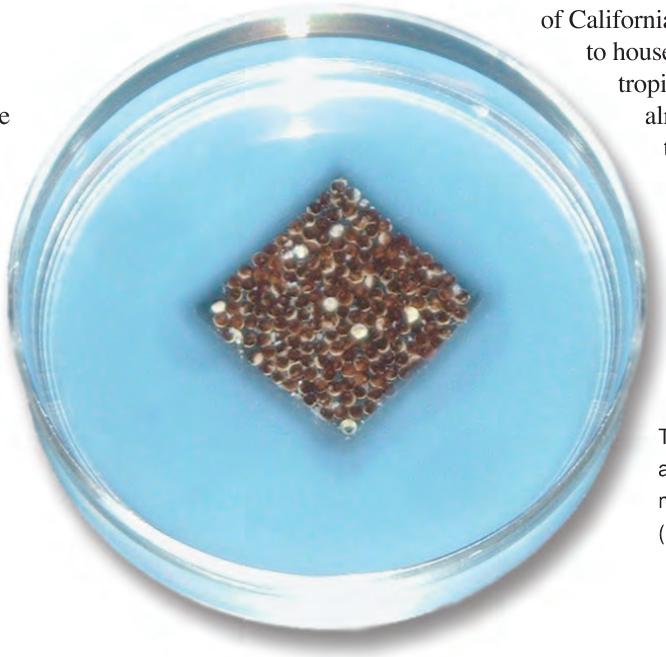
Before any work is done in the laboratory, researchers carry out comparative sequence analyses between all available vertebrate genomes. These analyses emphasize similarities between the frog and the human genomes using computational methods developed by bioinformatician Ivan Ovcharenko. From the resulting data, regions of high conservation are identified and a gene set of interest is defined.

To validate this gene set, the main task is to determine when and where each gene is turned on. This task is accomplished by making a complementary copy of the gene's mRNA sequence that is labeled with a marker. The resulting sequence is called the anti-sense probe. This probe is used to detect where the target gene's mRNA is present, a process by which the probe finds its exact complementary match and attaches, or hybridizes, to it. Then, a color reaction is used to locate where the probe binds to RNA. These locations are imaged and cataloged into a database. Loots's group has refined this approach to permit high throughput: They can detect the embryonic expression of hundreds of different genes in one reaction using a robotic system that expedites the process.

Loots's group uses MOs to silence specific genes in the *X. tropicalis* eggs and then studies the visible genetic traits and the morphological changes in form and structure of the resulting embryos at different stages of development. Similarly, the group evaluates the effects of over-expressing a gene by injecting mRNA for these genes into the eggs.

Ultimately, researchers hope to identify genes that are important during early development, when too much or too little of a gene product can dramatically affect normal biological processes. In particular, Loots's group will be investigating novel genes that specialize in patterning the vertebrate skeletal and muscular structures. "If we can say 'here's a group of genes that are all expressed in the eye,' then that opens up all sorts of opportunities for collaboration and discovery," says Loots. "And if a particular gene functions the same in a frog and a mouse, we can postulate that the gene will likely work the same in humans."

Loots and her colleagues are working with fixed frog embryos that are transferred as needed from Richard Harland's laboratory in the Molecular and Cell Biology Department at the University of California at Berkeley (UCB). However, Loots plans to house a self-sustaining colony of these aquatic, tropical frogs in a facility at Livermore that is already fitted with a filtering warm-water tank system. Frogs from UCB and other licensed vendors will be transferred to the new facility once it has been approved by California's Department of Fish and Game. Loots is eager to ramp up the pace. "Getting the new frog facility up and running will streamline the

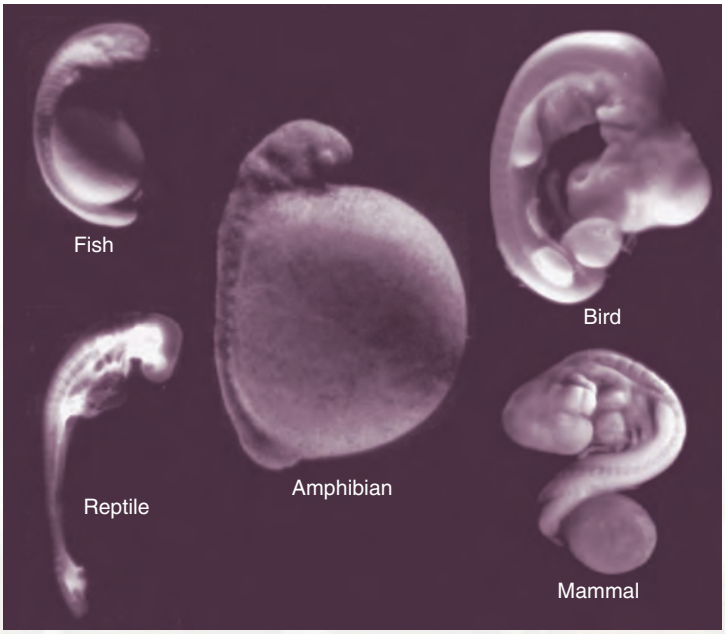


The eggs harvested from *Xenopus tropicalis* are easy to view under a standard dissecting microscope because of their large size (1 to 1.2 millimeters in diameter).

X. tropicalis project and will facilitate novel high-throughput research using this animal model as a vector for in vivo experimentation," says Loots.

One Man's Junk . . .

In an interesting biological twist, it appears that many genes are controlled by important regulatory elements that lie in regions previously considered "junk" DNA because these sequences did not code for proteins. However, scientists now realize that some of these noncoding sequences are also highly conserved across multiple species. Thus, the notion that a group of these DNA segments are junk is being scrapped. Instead, researchers posit that the sequences have an important function in acting on aspects of biology other than encoding for proteins. The current hypothesis is that a significant fraction of these highly conserved, noncoding stretches of DNA might play a critical regulatory role in gene expression, or in turning on and turning off neighboring genes that do code for proteins.



This photograph shows the morphological similarities in embryogenesis across vertebrate species at similar stages of development.

Developing *X. tropicalis* as a high-throughput model for in vivo experimentation expands the horizons in genome biology research. Once a thorough catalog of gene expression has been obtained and the function of each transcript understood, the next major challenge will be to link each transcriptional regulatory element to the gene it regulates. Loots is looking forward to exploiting this novel model organism and leaping into the future of vertebrate genome research.

—Maurina S. Sherman

Key Words: Biosciences Directorate, comparative sequence analysis, evolutionary gene conservation, frogs, functional genomics, gene sequence, Joint Genome Institute, *Xenopus tropicalis*.

For further information contact Gabriela Loots (925) 423-0923 (loots1@llnl.gov).

Into the Wide Blue Yonder with BlueGene/L

The unusual slant to BlueGene/L's cabinets is a necessary design element to keep cooled air flowing properly around each cabinet's 2,000-plus processors.

NEW vistas in numerical simulations are opening to scientists at Livermore and elsewhere with the arrival of the BlueGene/L supercomputer, a new class of highly scalable platform. IBM Research designed BlueGene/L for the Advanced Simulation and Computing (ASC) Program, a part of the Department of Energy's National Nuclear Security Administration. Last November, BlueGene/L's first segment—one-fourth the size of the ultimate machine—captured the number-one spot on the Top500 list of the world's fastest supercomputers (www.top500.org/lists/2004/11/), clocking in at 70.72 trillion operations per second (teraops) on the industry standard LINPACK benchmark. It beat the previous record holder, Japan's Earth Simulator, by a factor of two.

The second delivery of racks for BlueGene/L (originally called BlueGene/Light) arrived at Livermore's new Terascale Simulation Facility in March 2005, and the final set is scheduled for delivery this summer. The 360-teraops machine will handle many challenging ASC-related scientific simulations, including ab initio molecular dynamics; three-dimensional (3D) dislocation dynamics; and turbulence, shock, and instability phenomena in hydrodynamics. BlueGene/L is also a computational science research machine for evaluating advanced computer architectures.

BlueGene/L is a world apart from other scalable computers not only in terms of performance but also in size, appearance, and design. The machine is scaled up with a few unique components and IBM's system-on-a-chip technology developed for the embedded microprocessor marketplace. Another unusual feature is that for applications the computer's nodes are interconnected in three different ways instead of the usual one. Two principles drove the design of the hardware and software of this highly scalable machine: "keep it simple" and "divide and conquer."

Strength in Numbers

"The major difference between BlueGene/L and other computers is its scalability, that is, the sheer number of nodes we are strapping together in a single unit," says computer scientist Mark Seager, head of Advanced Technology in the Integrated Computing and Communications Department of the Computation Directorate. The most basic building block of BlueGene/L's design is the node. BlueGene/L has 65,536 nodes, compared with ASC White's 512, ASC Q's 2,048, and 1,536 in Purple, the newest mainline ASC system being constructed by IBM in Poughkeepsie, New York. "With this many nodes, achieving a reasonable hardware stability level required design simplicity, including a minimum number of chips per node," says Seager. Whereas a desktop computer can have 50 to 60 chips, a BlueGene/L node has just 10—9 memory chips and 1 compute application specific integrated circuit (ASIC) chip.

The ASIC chip is a complete system-on-a-chip that includes two IBM PowerPC 440 processors, five interconnects, and 8 megabytes of embedded dynamic random access memory. A memory controller for the nine external memory chips provides double-bit error detection and single-bit error correction. The result is a compact, low-power building block.

"The compute node has its good and bad points," notes Seager. "On the down side, it uses weak processors. On the plus side, it provides many operations per watt because it's not pushing the performance envelope. Power usage is an important consideration when you're running 65,536 nodes." The machine scales up in an orderly fashion, resulting in an extremely high-compute-density system with attractive cost performance and relatively modest power and cooling requirements.

Networking for Efficiency

Another difference between BlueGene/L and other platforms is that it has not one but three interconnects for applications: a 3D torus network, a binary-tree (combining and broadcasting) network, and a barrier network.

The 3D torus interconnect is used for high-bandwidth communication between nearest-neighbor nodes and works well on grid-based applications. This interconnect is similar to a mesh. Each node is connected to its six nearest-neighbor nodes, but the ends of the mesh loop back to the nodes, making it a torus. Seager says, "This configuration makes programming for BlueGene/L

much easier than programming for a system with edges that do not have six nearest neighbors."

Another plus is that a torus network requires far fewer cables than other types of interconnects at this scale. "When you build very large machines such as BlueGene/L, the cable issue becomes critical," says Seager. "If we'd used a different network design, the sheer number of cables would have made building the machine impossible."

BlueGene/L's binary-tree network is useful for low-latency global operations that share data and synchronize programs. This interconnect determines how a highly parallel computer program "talks" to *all* the nodes quickly and efficiently. "Different ways exist to deliver a message to a large number of nodes," says Seager. "In a binary-tree network, one node talks to two neighbors, those two talk to two of their neighbors, and so on. Getting the message out to 65,536 nodes is a very efficient process, taking only 16 tree operations, or hops."

The binary tree can operate in broadcast mode to replicate information across the machine or in combining mode to gather data distributed across the machine into a single location. Both broadcast and combining modes are used in operations performed millions of times in real scientific applications. In BlueGene/L, the binary-tree interconnect is implemented in the hardware rather than in the software, making those hops extremely fast. Performing those operations in the hardware, says Seager, is a huge leap forward in making BlueGene/L scalable and fast.

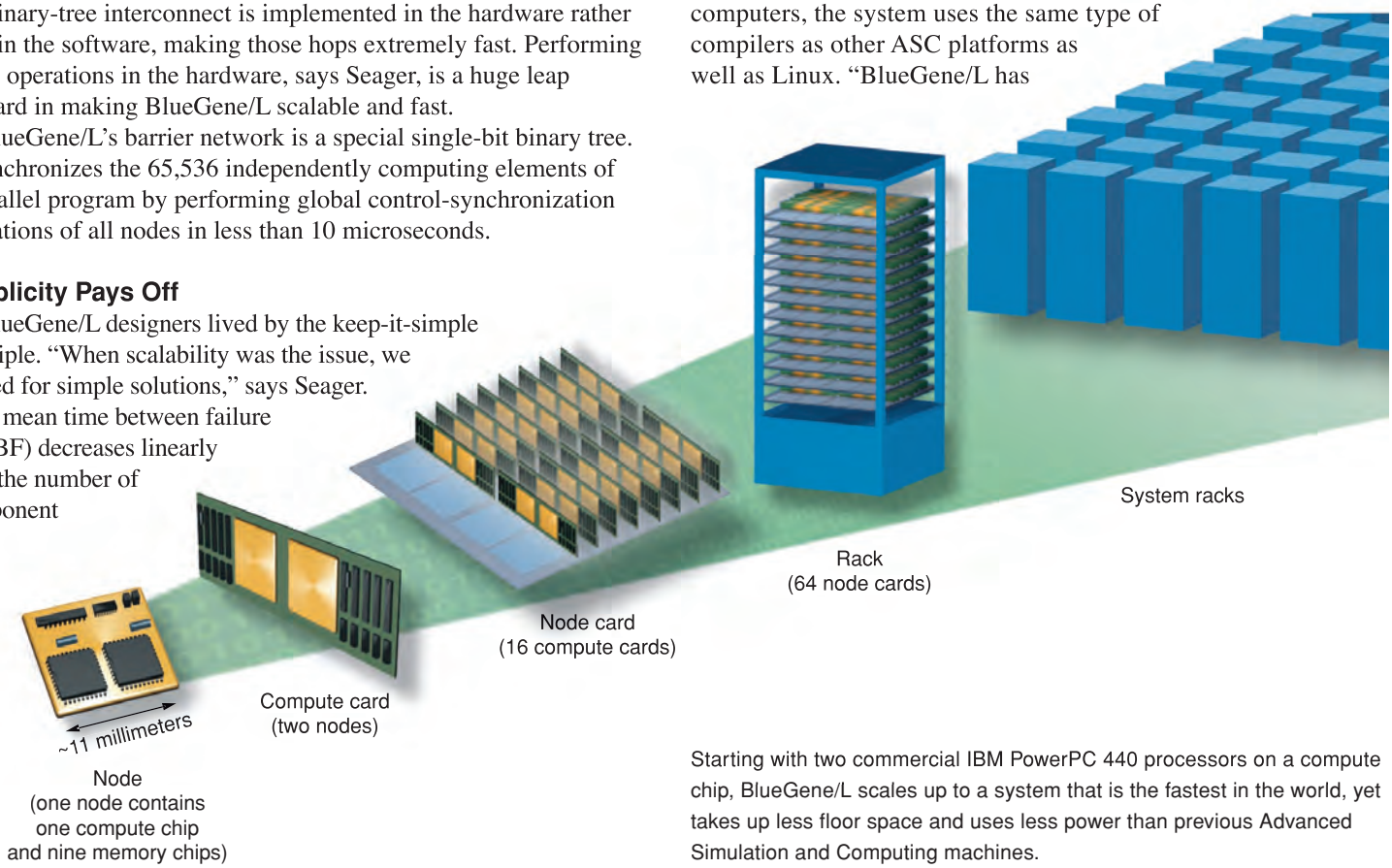
BlueGene/L's barrier network is a special single-bit binary tree. It synchronizes the 65,536 independently computing elements of a parallel program by performing global control-synchronization operations of all nodes in less than 10 microseconds.

Simplicity Pays Off

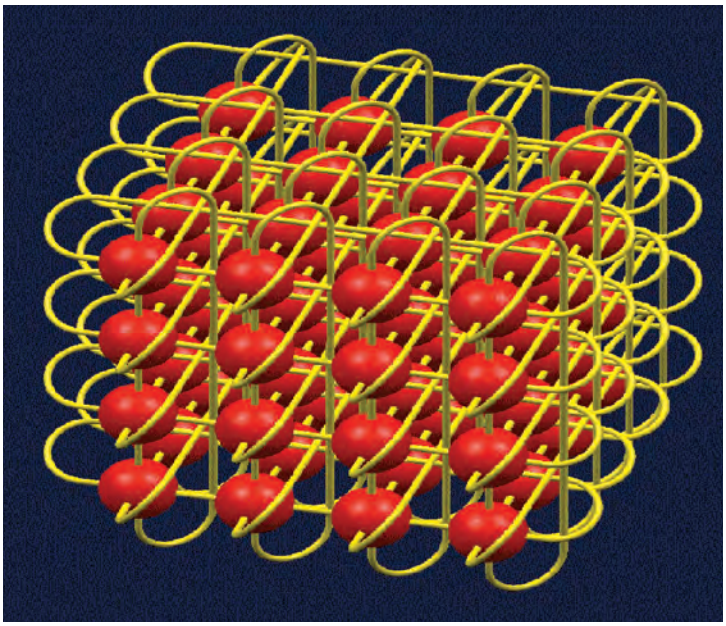
BlueGene/L designers lived by the keep-it-simple principle. "When scalability was the issue, we looked for simple solutions," says Seager. "The mean time between failure (MTBF) decreases linearly with the number of component replications. To achieve exceptional component MTBF, we simplified component designs as much as possible." The compute node contains the minimum number of chips, and the compute node kernel (or operating system) is also stripped down to the minimal functionality. "The compute node kernel is almost stupid, really," says Seager.

Many functions that typically reside in an operating system, such as process migration, memory management, and file input/output (I/O), are either eliminated or pushed out to a specially designed I/O node. Sixty-four compute nodes share a single I/O node, a configuration that embodies the divide-and-conquer principle, according to Seager. The configuration divides the problem into a simple part and a complicated part. The simple part (the compute node kernel) is replicated 65,536 times, and the complicated part (the I/O node kernel) is replicated 1,024 times—all with high reliability. Pushing functions to the I/O node kept BlueGene/L's MTBF at six-and-a-half days to the amazement of some computer scientists, says Seager. Given the number of components, they had predicted the MTBF would never rise above a couple of minutes.

The keep-it-simple philosophy also extends to the programming environment. To make BlueGene/L readily accessible to researchers programming on other ASC computers, the system uses the same type of compilers as other ASC platforms as well as Linux. "BlueGene/L has



Starting with two commercial IBM PowerPC 440 processors on a compute chip, BlueGene/L scales up to a system that is the fastest in the world, yet takes up less floor space and uses less power than previous Advanced Simulation and Computing machines.



BlueGene/L uses a three-dimensional (3D) torus network in which the nodes (red balls) are connected to their six nearest-neighbor nodes in a 3D mesh. In the torus configuration, the ends of the mesh loop back, thereby eliminating the problem of programming for a mesh with edges. Without these loops, the end nodes would not have six near neighbors.

the code development tools and an environment common to a desktop Linux system," says Seager. The new machine, as with Livermore's other Linux clusters, will also use the Lustre global parallel file system. Once BlueGene/L is integrated onto the unclassified network, users will be able to view the generated data on Livermore's Linux visualization cluster or analyze the data on other Linux clusters.

BlueGene/L and Beyond

BlueGene/L's recent record-breaking performance is just the beginning. The real acclaim will come with the scientific breakthroughs that are sure to occur as the world's most powerful computer tackles pressing science questions.

"BlueGene/L will help us to better understand the complex physics phenomena necessary to ensure the safety and reliability of the nation's nuclear deterrent," says Dona Crawford, Livermore's associate director for Computation. "This capability, in turn, is applicable to other domains, allowing us to advance multiple national agendas in science, national security, and industrial competitiveness."

Even as ASC users at Livermore and elsewhere prepare for BlueGene/L, Livermore's computer scientists are focusing on the next step. BlueGene/L, powerful as it is, still will not be powerful enough to simulate all the complexities of matter at extreme pressures and temperatures, so a petaops (1 quadrillion operations per second) computer will likely be necessary by 2008. "We have several interesting options," says Seager.

A next-generation, petaops-sized BlueGene/P beckons. Livermore is also partnering with Stanford University, which is developing a 4-petaops streaming computer as part of its work for the ASC Alliance Program. "And we're looking at using the Intel/AMD ecosystem to build a petaops machine out of mass-market commodity components," adds Seager. "The petaops era is on the horizon. When it arrives, we'll be ready."

—Ann Parker

Key Words: Advanced Simulation and Computing (ASC) Program, barrier interconnect, binary-tree interconnect, BlueGene/L, node, scalability, stockpile stewardship, supercomputer, three-dimensional torus interconnect, Top500 list.

For further information contact Mark Seager (925) 423-3141 (seager1@llnl.gov).

Continued from p. 2

Researchers gain insight into galaxy formation

Observations using the Very Large Array at the National Radio Astronomy Observatory in New Mexico, the Keck telescopes in Hawaii, and the Hubble Space Telescope, have shown astronomers Wil van Breugel and Steve Croft of IGPP that Minkowski's Object, a peculiar starburst system in the NGC 541 radio galaxy, formed when a radio jet was emitted from a black hole and collided with dense gas.

The researchers carried out the observations after computer simulations performed by Livermore's Chris Fragile, Peter Anninos, and Stephen Murray showed that jets—undetectable in visible light but revealed by radio observations—may trigger the collapse of interstellar clouds and induce star formation. Van Breugel says, "It brings poetic justice to black holes because we think of them as sucking things in, but we've shown that when a jet emits from a black hole, it can bring new life by collapsing clouds and creating stars."

Radio jets are formed when material falls into massive black holes. Magnetic fields around the black holes accelerate electrons to almost the speed of light. These electrons are then propelled out in narrow jets and radiate at radio frequencies because of their motion in the magnetic fields. The jets may affect the formation of stars when they collide with dense gas. But only recently have van Breugel and Croft determined how this happens.

The region between stars in a galaxy, commonly called the interstellar medium, is filled mainly with gas and dust. The gas appears primarily in two forms: as cold clouds of atomic or molecular hydrogen, or as hot ionized hydrogen near young stars. The Livermore researchers observed that when a radio jet ran into a hot, dense hydrogen medium in NGC 541, the medium started to cool down and formed a large neutral hydrogen cloud and, in turn, triggered star formation. Although the cloud did not emit visible radiation, it was detected by its radio-frequency emission.

Other collaborators included the University of California at Davis and Santa Barbara, Columbia University, ASTRON of The Netherlands, and Australian National University.

Contact: Wil van Breugel (925) 422-7195 (vanbreugel1@llnl.gov).

Patents and Awards

Each month in this space, we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Edge-Facet-Pumped, Multi-Aperture, Thin-Disk Laser Geometry for Very High Average Power Output Scaling

Luis E. Zapata
U.S. Patent 6,834,070 B2
December 21, 2004

The average power output of a laser is scaled by increasing the transverse dimension of the gain medium while proportionately increasing the thickness of an index-matched light guide. Strategic facets cut at the edges of the laminated gain medium provide a method by which the pump light is trapped and repeatedly passed through the gain medium. Spontaneous emission escapes the laser volume via these facets. A multifaceted disk geometry with grooves cut into the thickness of the gain medium is optimized to passively reject spontaneous emission generated within the laser material, which would otherwise be trapped and amplified within the high-index composite disk. This geometry allows the useful size of the laser aperture to be increased, enabling the average laser output power to be scaled.

Impedance Measurements for Detecting Pathogens Attached to Antibodies

Robin R. Miles, Kodumudi S. Venkateswaran, Christopher K. Fuller
U.S. Patent 6,835,552 B2
December 28, 2004

Impedance measurements are used to detect pathogens attached to antibody-coated beads. In a fluidic device, antibodies are immobilized on the surface of a patterned, interdigitated electrode. Pathogens in a sample fluid streaming past the electrode attach to the immobilized antibodies, producing a change in impedance between two adjacent electrodes. This impedance change is measured and used to detect the presence of a pathogen. The signal can be amplified by adding beads coated with antibodies. When these beads stick to the pathogen, they cause a greater change in the impedance between the two adjacent electrodes.

Method and System for Ultra-Precision Positioning

Richard C. Montesanti, Stanley F. Locke, Samuel L. Thompson
U.S. Patent 6,839,970 B2
January 11, 2005

An apparatus and method is disclosed for ultraprecision positioning. A slide base provides a foundational support. A slide plate moves with respect to the slide base along a first geometric axis. Either a ball screw or a piezoelectric actuator, working separately or in conjunction, displaces the slide plate with respect to the slide base along the first geometric axis. A linking device directs a primary force vector into a centerline of the ball screw. The linking device consists of a first link that directs a portion of the primary force vector to an apex point, located along the centerline of the ball screw, and a second link that directs another portion of the primary force vector to the apex point. A set of rails, oriented parallel to the centerline of the ball screw, direct movement of the slide plate with respect to the slide base along the first geometric axis and is positioned such that the apex point falls within a geometric plane formed by the rails. The slide base, slide plate, ball screw, and linking device together form a slide assembly. Multiple slide assemblies can be distributed about a platform. In such a configuration, the platform may be raised and lowered or tilted by jointly or independently displacing the slide plates.

Quantitation of Absorbed or Deposited Materials on a Substrate That Measures Energy Deposition

Patrick G. Grant, Olgica Bakajin, John S. Vogel, Graham Bench
U.S. Patent 6,844,543 B2
January 18, 2005

This invention provides a system and method for measuring an energy differential that correlates to quantitative measurement for a mass of an applied localized material. Such a system and method are compatible with other methods of analysis, such as quantitating the elemental or isotopic content, identifying the material, or using the material in biochemical analyses.

Colloidal Spray Method for Low-Cost Thin-Coating Deposition

Ai-Quoc Pham, Robert S. Glass, Tae H. Lee
U.S. Patent 6,846,558 B2
January 25, 2005

A dense or porous coating of material is deposited onto a substrate by forcing a colloidal suspension through an ultrasonic nebulizer and spraying a fine mist of particles in a carrier medium onto a sufficiently heated substrate. The spraying rate is essentially matched to the evaporation rate of the carrier liquid from the substrate to produce a coating that is uniformly distributed over the surface of the substrate. Following deposition to a sufficient coating thickness, a single sintering step may be used to produce a dense ceramic coating. With this method, coatings ranging in thickness from about one to several hundred micrometers can be obtained. When a plurality of compounds is used in the colloidal suspension, coatings of mixed composition can be obtained. When a plurality of solutions, separate pumps, and a single or multiple ultrasonic nebulizer(s) are used and the individual pumping rates or the concentrations of the solutions are varied, a coating of mixed and discontinuously graded or continuously graded layers may be obtained. This method is particularly useful for depositing ceramic coatings. Dense ceramic coating materials on porous substrates are useful in providing improved electrode performance in devices such as high-power-density solid-oxide fuel cells. Dense ceramic coatings obtained by this method are also useful for other items, such as gas turbine blade coatings, sensors, and steam electrolyzers. The method has general use in the preparation of systems requiring durable and chemically resistant coatings or coatings having other specific chemical or physics properties.

Method for Detecting Pathogens Attached to Specific Antibodies

Robin R. Miles, Kodumudi S. Venkateswaran, Christopher K. Fuller
U.S. Patent 6,846,639 B2
January 25, 2005

This method uses impedance measurements to detect the presence of pathogens attached to antibody-coated beads. In a fluidic device, antibodies are immobilized on the surface of a patterned, interdigitated electrode. Pathogens in a sample fluid streaming past the electrode attach to the immobilized antibodies, which produces a change in impedance between two adjacent electrodes. The impedance change is measured and then used to detect the presence of a pathogen. To amplify the signal, beads coated with antibodies are introduced. The beads stick to the pathogen, causing a greater change in impedance between the two adjacent electrodes.

Awards

The **American Physical Society** (APS) has selected five Laboratory scientists as **APS Fellows**.

Tina Back, a project leader for radiation transport experiments at the National Ignition Facility, was honored for "the quantitative application of x-ray spectroscopy that has advanced the understanding of high-energy-density plasmas in the areas of x-ray hohlraums, radiation transport, and high-efficiency radiation production."

Tom Rognlien of the Physics and Advanced Technologies Directorate's Fusion Energy Program was cited for "seminal contributions to the modeling of tokamak edge plasmas and their interaction with bounding surfaces and to the understanding of heating and transport in collisional and RF-excited plasmas."

Louis Terminello, materials program leader for the Defense and Nuclear Technologies and Chemistry and Materials Science (CMS) directorates, was cited for his "innovative use of synchrotron radiation spectroscopies in revealing the electronic and atomic structure of new materials."

Chemist **Craig M. Tarver** of CMS was selected "in recognition of his contributions to shock-wave physics and, in particular, his development and implementation of the ignition and growth model for reactions in energetic materials and the nonequilibrium ZND theory for detonating energetic materials."

David J. Eaglesham of CMS, who recently left the Laboratory, was cited for "his seminal discoveries and technical leadership in semiconductor crystal growth and structural defects in epitaxial materials."

Each year, no more than one-half of one percent of the current APS membership is recognized by their peers through election to the status of Fellow. APS fellowship recognizes members who have made advances in knowledge through original research and publication, or those who have made significant and innovative contributions in the application of physics to science and technology. APS Fellows also may have made significant contributions to the teaching of physics or service and participation in the activities of the society.

In December 2004, physicist **Camille Bibeau** received the national **2004 Excellence in Fusion Engineering Award** at the Fusion Power Associates annual meeting in Gaithersburg, Maryland. Bibeau heads the National Ignition Facility's Mercury Laser Project—the Laboratory's next-generation laser in the quest toward fusion energy. The award recognizes Bibeau's "many technical contributions to the design, construction, and operation of laser systems" and "her outstanding communications skills in providing clear and understandable presentations on highly complex topics to a variety of audiences."

Abstracts

Monitoring Earth's Subsurface from Space

International concern about the possibility that a nuclear test could be hidden from detection by minimizing its seismic signals has sparked interest in developing tools that can complement monitoring techniques. One such method is interferometric synthetic aperture radar (InSAR), in which radar images are used to detect surface deformations of less than 1 centimeter resulting from subsurface changes. InSAR has become a standard tool for mapping changes to Earth's surface from such sources as earthquake faults; glaciers; and oil, gas, and geothermal reservoirs. Data from InSAR can reveal both coseismic and postseismic subsidence signals and can be used to characterize an explosion's dimensions and the type of deformation it causes. InSAR also has the potential to detect underground tunnels or facilities that might be associated with underground nuclear test preparations. The Livermore team has developed a new application of InSAR, called dynamic InSAR, to produce interferograms as an event is occurring. Dynamic InSAR has applications both in national security and in tracking natural hazards such as earthquakes, volcanoes, and tsunamis.

Contact:
Paul Vincent (925) 423-8281 (vincent7@llnl.gov).

Faculty on Sabbatical Find a Good Home at Livermore

Livermore's Sabbatical Scholars Program, begun in 2000, brings topflight scientific and engineering expertise to the Laboratory. The program is administered by the University Relations Program, which facilitates a growing number of collaborations between Laboratory researchers and academic institutions, principally University of California (UC) faculty. One feature of the Sabbatical Scholars Program is the inclusion of graduate students and postdoctoral researchers in a faculty member's sabbatical stay at the Laboratory. Their participation serves to strengthen the recruitment of outstanding young scientists and engineers. Since the program's inception, 22 faculty members have participated. Livermore sabbatical scholars have come from universities across the U.S. as well as France, Italy, the Netherlands, and Japan.

Contact:
Harry Radousky (925) 422-4478 (radousky1@llnl.gov).

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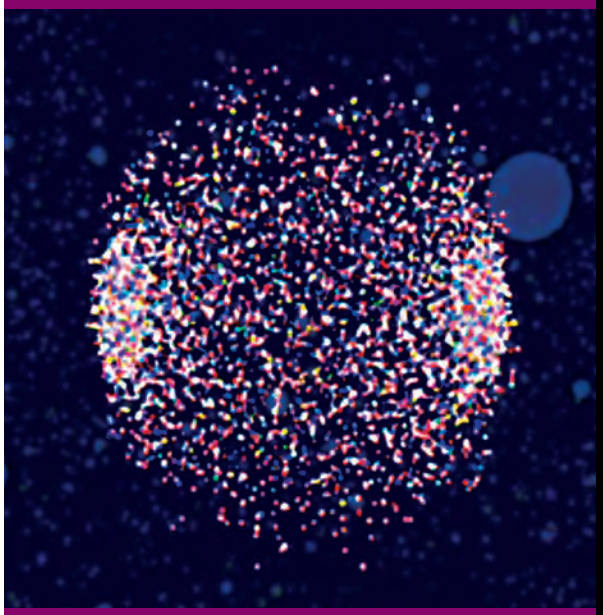
Building on Genius



One hundred years after Albert Einstein formulated his theories of relativity, his discoveries continue to shape Livermore's research across myriad scientific disciplines.

Also in May

- *Laboratory researchers examine a technique for burying carbon dioxide deep underground to thwart further increase in atmospheric concentration of greenhouse gas.*
- *Using data from past underground nuclear tests, a Livermore team is modeling radionuclide migration at the Nevada Test Site.*
- *Livermore chemists are applying sol-gel chemistry to create novel materials for a range of applications, including optics coating, waste remediation, energy storage, and nanoelectronics.*

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