March/April 2008

# Science & Technology REVIEW

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory

## Imaging Planets outside Our Solar System

*Also in this issue:*

- Diagnostic Improves Electron-Beam Welding
- Nanomaterials Designed with Diamondoids
- Visualizing Science through Animation

## About the Cover

An international collaboration led by Livermore scientists is developing the Gemini Planet Imager (GPI) to study planets outside our solar system that cannot be detected using current technology. With the new imager, astrophysicists can better understand how planets and solar systems form and evolve. GPI is designed for use on the Gemini South telescope in Chile. On the cover, a late twilight photograph shows the open dome of the Gemini Observatory (lower-right corner) with the telescope visible through the three-story-high vents. In the background is a Hubble Space Telescope image of the Antennae Galaxies NGC 4038–4039. (Observatory photo courtesy of Gemini Observatory and the Association of Universities for Research in Astronomy. Hubble image courtesy of the National Aeronautics and Space Administration, European Space Agency, and Brad Whitmore of the Space Science Telescope Institute.)


Cover design: Amy Henke

## About the Review

At Lawrence Livermore National Laboratory, 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 six 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.

The Laboratory is operated by Lawrence Livermore National Security, LLC (LLNS), for the Department of Energy's National Nuclear Security Administration. LLNS is a partnership involving Bechtel National, Inc.; University of California; BWX Technologies, Inc.; Washington Group International, Inc.; and Battelle in affiliation with Texas A&M University. More information about LLNS is available online at www.llnsllc.com.

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 Web at www.llnl.gov/str.



National Nuclear Security Administration
LAWRENCE LIVERMORE NATIONAL SECURITY LLC

Prepared by LLNL under contract DE-AC52-07NA27344

Science & Technology REVIEW

March/April 2008

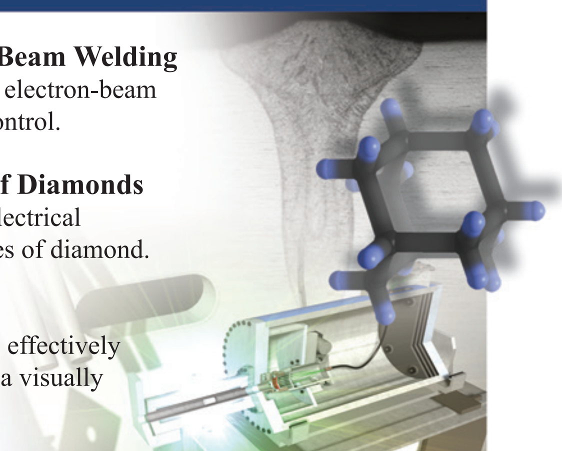
Lawrence Livermore National Laboratory

# Contents

## Features



## Research Highlights





## Departments



## *S&TR* Staff

**Scientific Editor**
Diane J. Chinn

**Managing Editor**
Ray Marazzi

**Publication Editor**
Carolin Middleton

**Writers**
Arnie Heller, Kristen Light, Caryn Meissner, and Katie Walter

**Art Director and Designer**
Amy Henke

**Proofreader**
Pamela MacGregor

**Print Coordinator**
Charlie M. Arteago, Jr.

*S&TR*, a Director's Office publication, is produced by the Technical Information Department under the direction of the Office of Planning and Special Studies.

*S&TR* is available on the Web at www.llnl.gov/str.

Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

UCRL-TR-52000-08-3/4
Distribution Category UC-99
March/April 2008

### New system detects small samples of viruses

Scientists and engineers from Lawrence Livermore and the University of California (UC) at Davis have developed a system that can detect viruses in samples 1 million times smaller than those required by current commercial instruments and with about half of the analytical steps. The team's microfluidic system permits polymerase chain reaction (PCR) analysis—or DNA copying—to be performed inside 10-picoliter droplets (about 10 trillionths of a liter) on a silicon chip.

Using the PCR-on-a-chip system, the team has analyzed hundreds of droplets in tests, demonstrating that the core technology works. The microfluidic system reduces the number of PCR heating and cooling cycles required for detecting a pathogen from 40 to about 20.

"Our goal is to take a sample that contains lots of viruses and break it down into small droplets, each of which contains no more than a single virus," says biomedical engineer Bill Colston, who leads Livermore's Chemical and Biological Countermeasures Division. "Then we can individually analyze all of the droplets that have viruses." The team also wants to develop assays that detect newly emerging or unknown viruses.

This project is part of a larger Livermore-funded effort, called the Viral Discovery Platform, to identify emerging, engineered, or unknown viral threats in days rather than weeks or months. Results from the team's research were featured on the cover of the November 15, 2007, issue of *Analytical Chemistry*.

***Contact: Bill Colston (925) 423-0375 (bcolston@llnl.gov).***

### Unraveling the behavior of detonating explosives

Although high explosives have been used for more than a century, little is known about their microscopic properties during detonation. To improve understanding of this physical process, researchers from Livermore and the Massachusetts Institute of Technology have created a quantum molecular dynamics simulation of a shocked explosive near detonation conditions. The research, which was funded by Livermore's Laboratory Directed Research and Development Program, provides the first "observation" of material behavior behind a detonation shock wave.

The simulation modeled nitromethane, an optically transparent and electrically insulating high explosive that is more energetic than TNT. Results showed that, behind the shock wave, nitromethane becomes optically reflective and semimetallic for a short time and then transforms back into a transparent, insulating material. The quantum molecular dynamics simulation of nitromethane serves as the first step in understanding molecular properties of shocked explosives at detonation conditions.

The research team, led by Livermore scientist Evan Reed, published its results in the January 2008 edition of *Nature Physics*. "We are continuing work to improve these capabilities," says Reed. "Ultimately, we want to create simulations that can analyze the detonation properties of new, yet-to-be synthesized designer explosives."

***Contact: Evan Reed (925) 424-4080 (reed23@llnl.gov).***

### Grant boosts work on point-of-care diagnostics

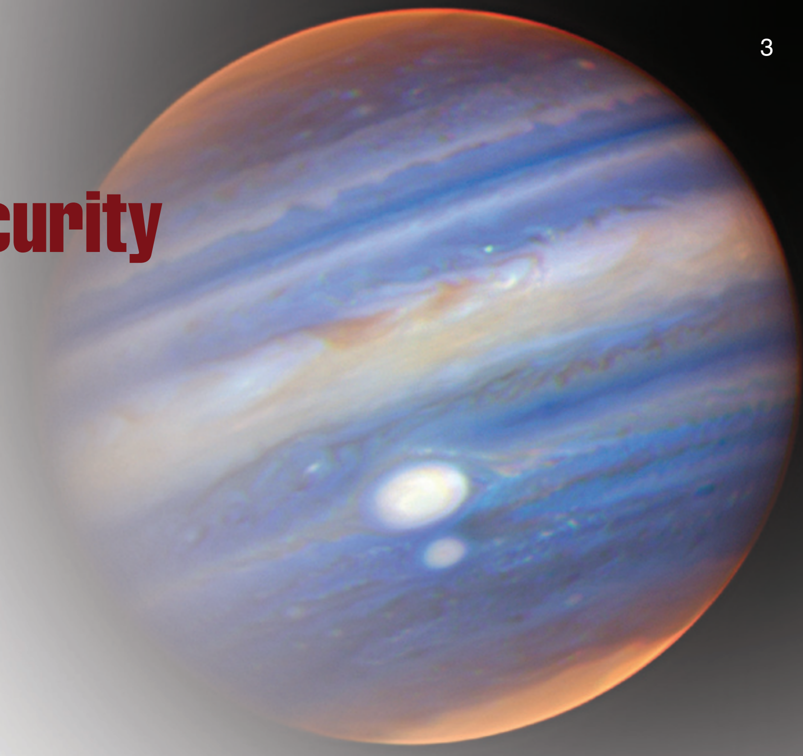
Lawrence Livermore and the UC Davis Health System have teamed up to develop point-of-care diagnostic instruments for use in hospitals, rural areas, and disaster sites. Through a five-year, $8.5 million grant from the National Institute of Biomedical Imaging and Bioengineering, the team will develop two prototype instruments that simultaneously detect five bacterial and fungal pathogens: Methicillan-resistant *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Streptococcus pneumoniae*, and Candida yeast infections.

Livermore chemist Ben Hindson and chemical engineer John Dzenitis direct the grant work at the Laboratory. "We see these technologies as helping medical personnel make fast, accurate diagnoses, so they can administer the proper medicine and save lives during natural disasters," says Hindson. In collaboration with UC Davis researchers, Livermore's Pathogen Informatics Group will develop unique DNA signatures or assays for use with the new instruments. The instruments will process blood samples using a new method called loop-mediated amplification and will run a simultaneous test for all five pathogens in one hour. Eventually, the team wants the instruments to process several samples within an hour.

Other Livermore-developed biodetection technologies, such as the Autonomous Pathogen Detection System, will provide technologies for the new instruments, which must be easy to use and require minimal user training. To help prepare the nation for disasters, the Livermore–UC Davis team will also evaluate exploratory diagnostic technologies.

***Contact: Ben Hindson (925) 423-8667 (hindson1@llnl.gov).***

# Science and Security in Sharp Focus



THE military and economic security of nations has always gone hand-in-hand with the advance of basic science. In her highly acclaimed book *Longitude*, Dava Sobel describes how the fortunes of navies and nations suffered for the lack of a precision chronometer that would enable mariners to determine their longitude as accurately as the sextant determined their latitude. Kings and governments invested fabulous sums of money to discover a solution. In so doing, they financed some of the most remarkable discoveries in astronomy and science from the 15th to 19th century, including the first accurate determination of the speed of light based on the eclipse of the Jovian moons, by Olaf Roemer in 1675.

The intertwining and leveraging of mission-driven and exploratory science—exemplified by the problem of measuring longitude—are hallmarks of Lawrence Livermore. The Laboratory's program in adaptive optics technology is a perfect example of this interplay. The adaptive optics team at Livermore, arguably the best in the world, supports a wide spectrum of national security applications, and its work regularly appears on the covers of prestigious journals such as *Science*.

What is adaptive optics? The familiar twinkling of a star at night is due to density fluctuations in the atmosphere that distort the wavefront of starlight, thus changing its optical path as the light travels to our eyes. Adaptive optics uses a reference object—a real or artificial star—that *ought* to be a stationary point in the field of view, to correct the wavefront in real time. With the reference object corrected, other sources in this field of view, such as galaxies or planets, are also transformed from blurry blobs into ultrasharp images.

In the early 1980s, Livermore physicist Claire Max and Will Happer of Princeton University wrote a then-classified paper setting out the principle of the "laser guide star," by which a laser beam would fluoresce the sodium layer in the upper atmosphere. This technique would allow astronomers to place a reference star anywhere at will. Max, who now serves as director of the Center for Adaptive Optics at the University of California (UC) at Santa Cruz, pioneered the application of this technique in astronomy and later won the E. O. Lawrence Award. Today, virtually every large telescope in the world has or will have laser guide star capability.

Livermore researchers have applied adaptive optics technology to a range of mission areas. The National Ignition Facility simply would not work without adaptive optics correctors to preserve a near-diffraction-limited spot from each of its beams. Laboratory expertise in this technology led to the Coherent Communication, Imaging, and Tracking Program for the Defense Advanced Research Projects Agency and to high-average-power lasers developed for the Army. The Laboratory's adaptive optics team has carried out pioneering work in retinal vision sponsored by both the Department of Energy and the National Institutes of Health. In 2002, a collaboration involving Livermore and UC Santa Cruz was awarded a coveted National Science Foundation (NSF) Science and Technology Center to develop adaptive optics for applications in astronomy and medicine. All the while, front-cover astronomy flourished, accompanied by prestigious awards and recognition for Livermore scientists and engineers.

The article beginning on p. 4 explores a project that takes a major leap in adaptive optics to directly image—see—other solar systems for the first time. The Gemini Planet Imager (GPI) is an important scientific instrument being built by an international team led by Livermore astrophysicist Bruce Macintosh. Macintosh's team was awarded the project in an NSF competition pitting the team against lower-cost proposals that failed to win the confidence of the sponsors. When completed, GPI will be the most capable adaptive optics system in the world. It will discover new solar systems, tell us what they're made of, and provide insight into how our own system formed.

---

■ William H. Goldstein is associate director for Physical Sciences.

# Extending the Search for

***A new imager will allow astrophysicists to study the atmospheres of distant planets.***

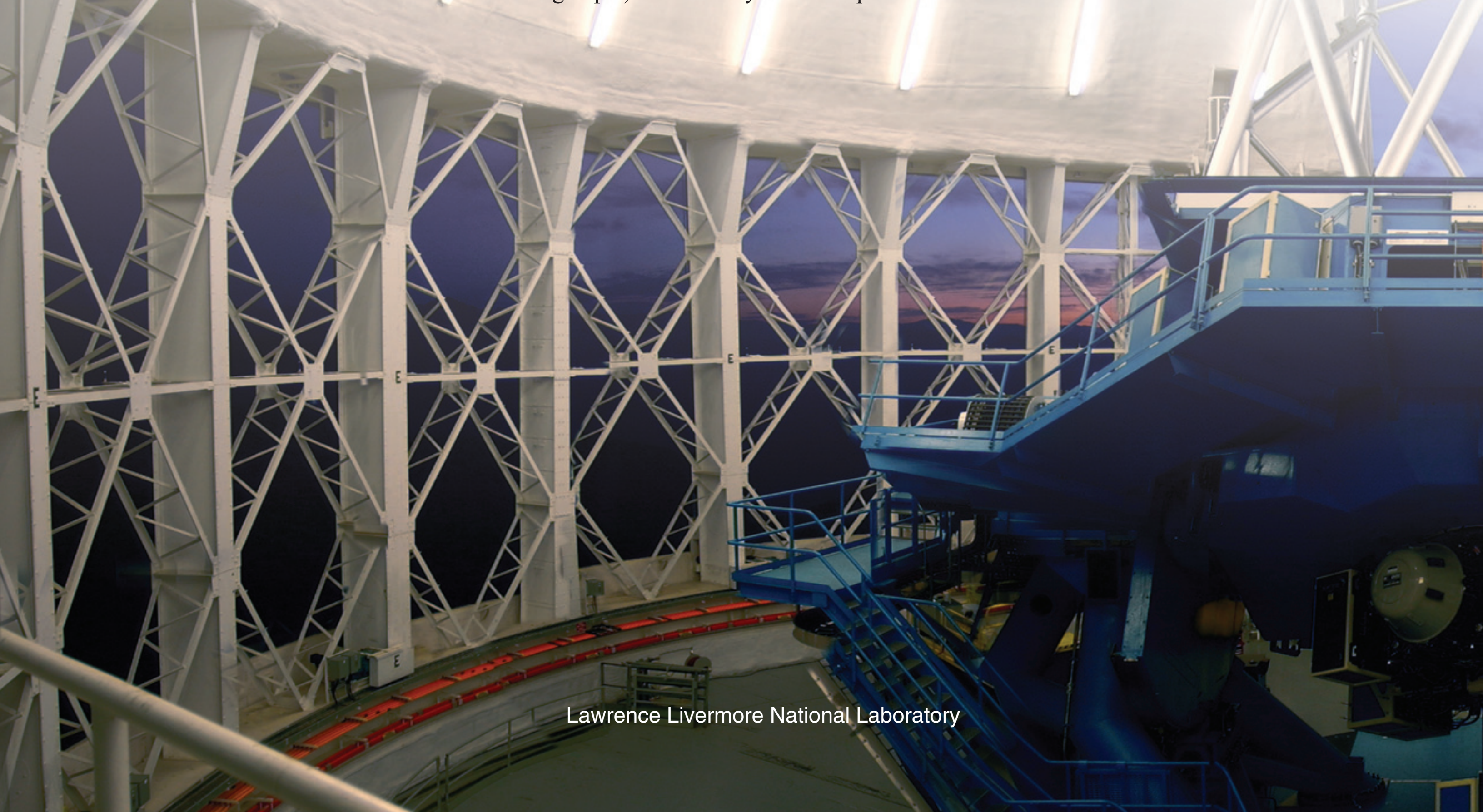
THE discovery of other solar systems beyond ours has been the stuff of science fiction for decades. Great excitement greeted the positive identification of the first planet outside our solar system in 1995. Since then, scientists have identified approximately 250 extrasolar planets (exoplanets), but they have had no way to study the majority of these planets or their atmospheres.

That will change when the Gemini Planet Imager (GPI) comes online at the Gemini South telescope in Chile in 2010. The imager's primary goal will be to detect more planets outside our solar system, providing important new data about how planets form and solar systems evolve. The most intriguing component on the imager is a spectrograph, which will measure the infrared light emitted by a planet's atmosphere. With it, GPI (pronounced gee-pie) will identify the atmosphere's chemical composition. Scientists can use the atmospheric data to make inferences about a planet's temperature, pressure, and gravity.

Lawrence Livermore scientists are part of an international collaboration developing GPI. Livermore astrophysicist Bruce Macintosh leads the design team, and engineer Dave Palmer is project manager. Macintosh notes, "For the first time, we will be able to study the atmospheres of planets in other solar systems."

## The Detection Challenge

GPI's extreme adaptive optics correct for the distortions caused by our atmosphere, allowing researchers to directly observe planets that are not now visible from Earth or from the orbiting Hubble Space Telescope. Most exoplanets discovered thus far were identified not by direct observation but rather by noticing a wobble in a star's motion. The wobble



# Extrasolar Planets

indicates a large object is nearby, and its gravity is affecting the star's motion.

This indirect detection process, called the radial velocity method, can probe objects up to 5 astronomical units (AU) from their parent stars, or 5 times the distance from Earth to the Sun. To determine whether an object is a planet, scientists must observe it completing an orbit around its parent star. But the farther a planet is from its star, the longer its orbit, and high-accuracy radial velocity measurements have been available for only 11 years. Scientists would need to record data for another year to find a perfect twin to the giant Jupiter, which takes 12 years to circle the Sun. Identifying a planet like Saturn, with an orbit of more than 30 years, would take decades.

Another method of detecting a planet uses direct observation of a star's light. When a planet orbits a star, the star's light appears to dim at regular intervals as the planet moves between its parent star and Earth. However, because of the time involved, observing such transits is effective only when planets are closer to their stars than Mercury is to the Sun.

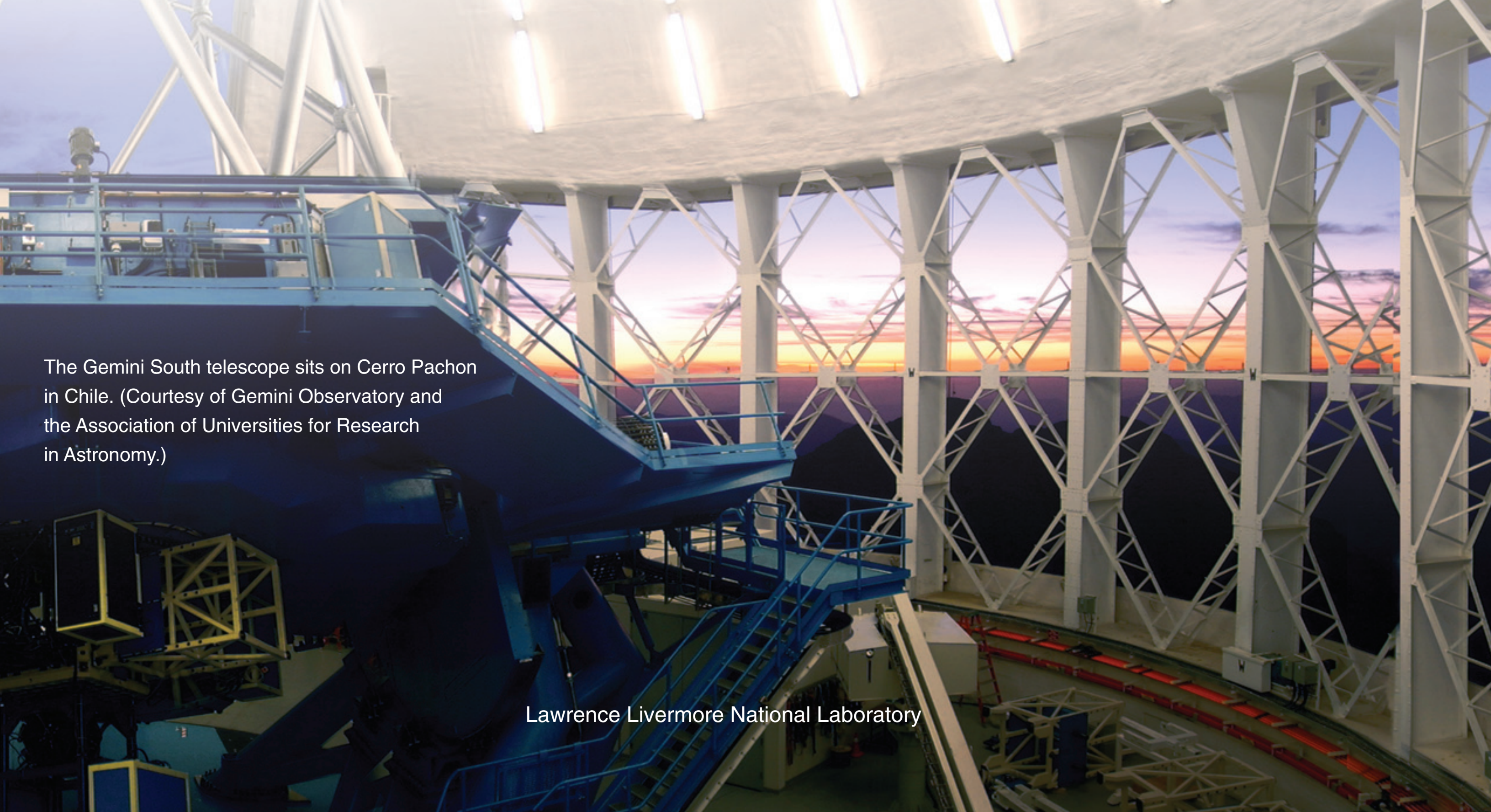
Yet another detection technique is to observe the microlensing effect, in which a star aligned between Earth and a second star causes light from the second, more distant star to brighten visibly. A planet orbiting the closer star will modify the lensing effect, adding a spike of brightness to the otherwise smooth magnification curve. (See *S&TR*, July/August 2006, pp. 11–16.)

These detection methods typically reveal young, hot, giant planets that are close to their stars. Some of the planets detected to date are more massive than Jupiter, and their orbits may last only a few days, much shorter than the orbit of any planet in our solar system. An Earth-like planet is too small to observe with current technology.

Planet discoveries by direct observation are limited because light from a hot, giant exoplanet and that from the star it orbits blur in the sky. Distinguishing the planet's light from the much brighter star is virtually impossible with today's instruments. In addition, as stars and planets age, their heat dissipates, dimming the light they emit. For example, Jupiter is a billion times fainter than the Sun and would be challenging to detect in another solar system even with a 30-meter telescope.

A young planet (about 100 million years old) with the mass of Jupiter would retain more heat from its initial formation and thus would appear much brighter than Jupiter. But this planet would still be a million times dimmer than its parent star.

"Trying to observe exoplanets is like trying to find a firefly next to a searchlight," says Macintosh. "GPI provides an efficient way to get rid of the searchlight, to the



The Gemini South telescope sits on Cerro Pachon in Chile. (Courtesy of Gemini Observatory and the Association of Universities for Research in Astronomy.)

extent possible, and capture high-contrast images of planets.” (See the box on p. 8.) With GPI, astronomers can detect objects more than 10 million times fainter than the parent stars and find planets in more distant orbits.

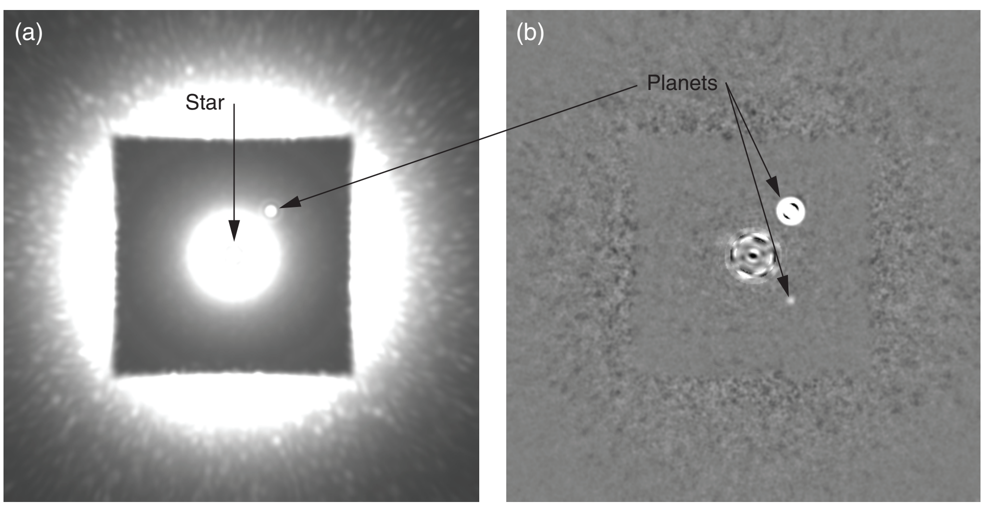
## Why Find More Planets?

Data collected from ground- and space-based telescopes indicate that direct imaging will yield hundreds of planets, many of them beyond 5 AU. The real value of identifying these distant planets is finding clues about how solar systems evolve and how planets migrate into their orbits. Until recently, scientists used observations of our solar system to make assumptions about the evolution of other systems. However, data on systems beyond ours are showing important differences. While our planets revolve in relatively circular orbits around the Sun, many exoplanets have highly elliptical orbits. In addition, dozens of other solar systems have very large Jupiter-like planets close to their suns.

Radial velocity techniques work poorly on stars younger than a few hundred million years old. The intensely bright portion of a star’s light is hot and roiling, producing spurious measurements as sunspots rotate around the star. “These adolescent stars will be GPI’s prime hunting ground,” says Macintosh, “allowing us to study the evolution of solar systems over time.”

## Planets under Construction

Solar systems are thought to start as disks of gas and dust rotating around a young star. Dust accounts for about 1 percent of the disk’s initial mass, while the remainder is primarily hydrogen and helium. Dust grains bump into one another and stick together, gradually accreting into larger particles. As particle growth continues, larger objects called planetesimals form and eventually grow into protoplanetary cores. Researchers had theorized that the small, rocky, terrestrial planets close to the Sun formed from such cores after several million years.




(a) In a simulated image of a 100-million-year-old star, the Gemini Planet Imager removes most of the scattered starlight over a square “dark-hole” region to reveal a planet. (b) Postprocessing the image using multiple wavelengths eliminates the remaining scattered starlight, revealing a second Jupiter-size planet.

According to this theory, called core accretion, the gas giants Saturn and Jupiter formed farther from the Sun where the planet-building material contained ices. Their cores of rock and ice collected large amounts of the disk’s gases, forming their thick atmospheres. Uranus and Neptune captured less of the gaseous material and are thus largely composed of ice.

The discovery of exoplanets much more massive than Jupiter and very close to their stars punched holes in the core accretion model. Those gigantic gas planets would take up to 100 million years to develop by core accretion, and protoplanetary gas disks are known to dissipate within 10 million years. In addition, not enough mass is close to the star for core accretion to generate such large planets.

An alternative proposal is that gas giants form not only by core accretion but also by gravitational disk instabilities. As the young disk of gas and dust orbits its star, clumps of gas can form quickly in unstable areas of the disk to become massive, gassy protoplanets. The astrophysics community is uncertain, however, whether these instabilities can arise in the inner regions of protoplanetary disks, where many giant exoplanets are found today.

Gravitational interaction between nascent planets and the gaseous disk may change a planet’s orbit. Protoplanet interactions are effectively chaotic, shoving material into new orbits, either toward a star or away from it. With this migration process, a rapidly orbiting planet could form far from its star and move inward. In our solar system, Jupiter may have migrated inward to its present location, while Neptune may have moved outward.

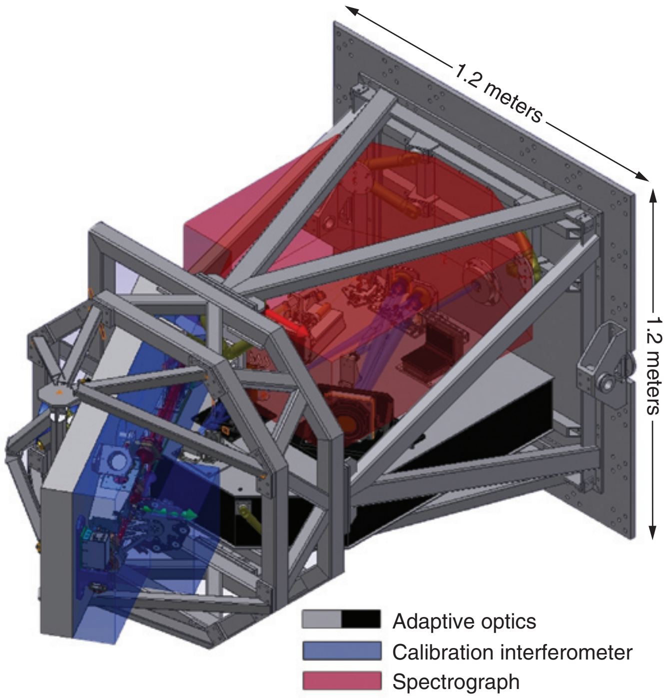
“The number of exoplanets beyond 5 AU holds clues to their formation processes and migration mechanisms,” says Macintosh. If Jupiter-like planets form by gravitational disk instabilities as well as core accretion, then the outer regions of solar systems may have many planets with Jovian and super-Jovian masses and, thus, will be similar to our solar system. If migration processes dominate, large planets will cluster closer to their stars, as many of the identified exoplanets do. "It is entirely possible that our solar system is an anomaly," says Macintosh.

### Dust to Dust

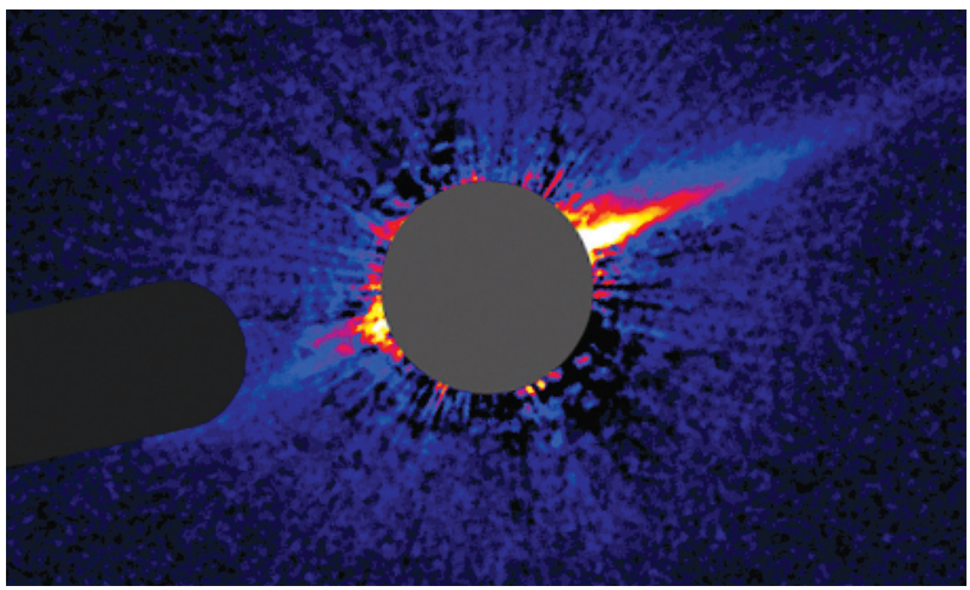
Gas disks dissipate as the primordial dust grains blow away or spiral into the star. Any remaining solids, such as cometary and asteroidal planetesimals, continue to orbit the star, and their collisions replenish a disk of dusty debris similar to the Kuiper Belt at the outer edge of our solar system. The Kuiper Belt, which extends from the orbit of Neptune outward, is composed of icy dust, comets, and other objects, including the dwarf planet Pluto.

Dusty debris disks, cousins to our Kuiper Belt, surround at least 100 stars. However, researchers have studied only about 20 in detail because observing dust so close to a bright star is difficult. Most of these disks must be viewed along their edges, an orientation that eases detection. Michael Fitzgerald, a postdoctoral researcher at Livermore, has studied debris disks for several years and looks forward to the vistas that GPI will open.

"With GPI, we will be able to identify not only the edge-on disks but also those viewed toward their faces," says Fitzgerald. "Our instruments are too weak now to separate light from a star and that from a debris disk observed face on." Until GPI is available, Fitzgerald and his colleagues use the best optics they can find—the telescopes at the W. M. Keck Observatory in Hawaii and data from the Hubble Space Telescope.




The components of the Gemini Planet Imager will be mounted on the Gemini South telescope's instrument support structure. Livermore is developing the adaptive optics system, the Jet Propulsion Laboratory is building the calibration interferometer, and the University of California at Los Angeles is building the spectrograph. The imager will be in an enclosure with electronics mounted on the sides. (Rendering by Darren Erickson, Herzberg Institute of Astrophysics.)



The extremely lopsided disk of debris around star HD 15115 has a needlelike shape (blue) in this image from the Hubble Space Telescope. A star about 10 light years away may be responsible for the formation. The Gemini Planet Imager will greatly improve information about dusty debris disks around stars, leading to insight into how planets and solar systems form. (Courtesy of the National Aeronautics and Space Administration, European Space Agency, and Paul Kalas of the University of California at Berkeley.)

## Inside the Gemini Planet Imager

In a package measuring about 1 by 1 by 2 meters, the Gemini Planet Imager (GPI, pronounced gee-pie) will incorporate the world's most advanced astronomical optics systems to find and study distant planets. GPI will be installed at the Gemini South telescope at the Gemini Observatory in the high-altitude desert of Chile. GPI's adaptive optics system will correct for atmospheric turbulence. A coronagraph will reduce diffraction patterns, and an interferometer will measure instrument aberrations that cause speckles in images. Perhaps the most intriguing device in GPI is a spectrograph to distinguish planets from any remaining speckles and examine planetary atmospheres.

Since time immemorial, stargazers have had to contend with the distortions caused by Earth's atmosphere. Starlight passes through temperature layers and winds in the atmosphere that cause the star to appear to "twinkle." The planets in our solar system do not twinkle because they are much closer to Earth than the stars, comparatively reducing the effects of atmospheric distortion.

Adaptive optics "straightens" the wavefronts of light, improving the image resolution and contrast. A wavefront sensor samples the light collected by the telescope's primary mirror and sends the data to a computer that controls a deformable mirror, a mirror whose surface shape can be changed. Tiny actuators move the mirror faces hundreds of times per second to compensate for atmospheric conditions. Deformable mirrors have improved astronomical imaging at land-based telescopes by a factor of 10. Adaptive optics systems work best with longer wavelength light—the infrared and near-infrared regions of the radiation spectrum rather than the visible.

GPI will take adaptive optics a large step toward even greater contrast and resolution. Its deformable mirror will have 1,600 active actuators. A conventional deformable mirror would have to be almost 40 centimeters across to hold that many actuators, far too large for use on the Gemini South telescope. Instead, GPI's primary deformable mirror will be a silicon microelectromechanical system (MEMS) device, lithographically patterned and etched like a microchip. Versions with 1,024 actuators have been extensively tested using the extreme adaptive optics system at the University of California (UC) at Santa Cruz and are now available. The larger version for GPI is under development.

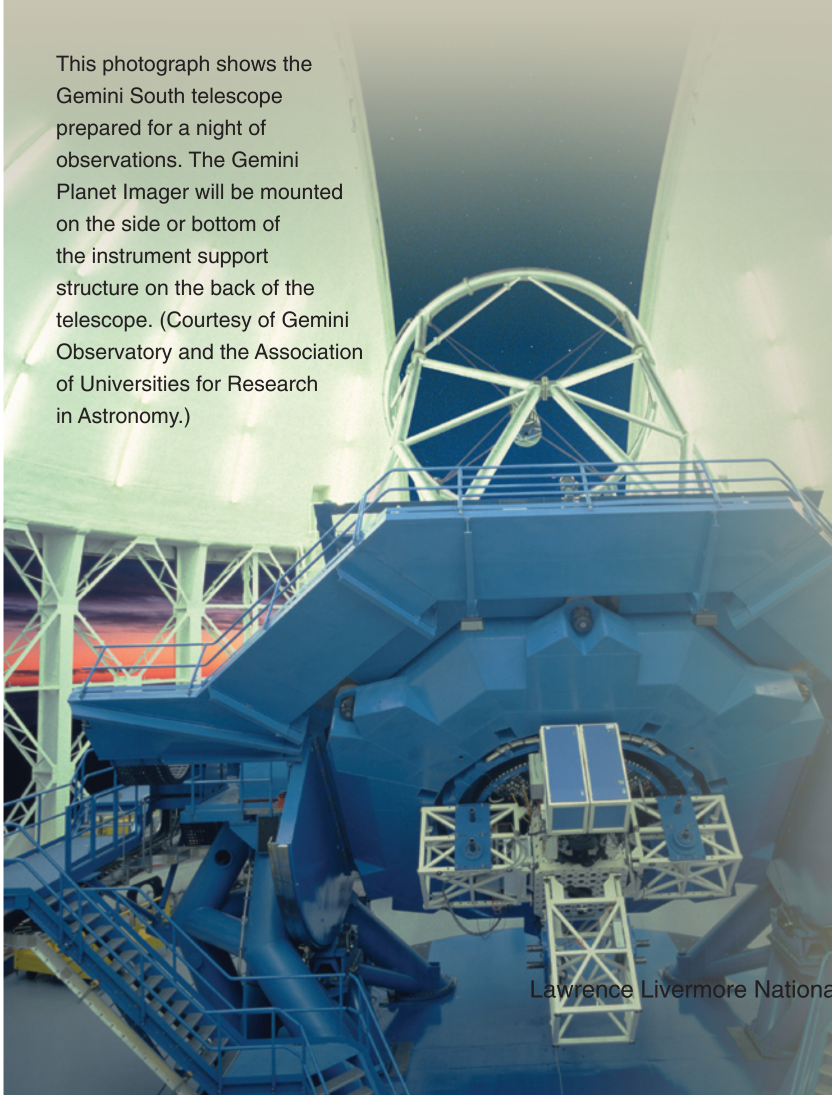
One limitation of current MEMS technology is that its range of motion is just 4 micrometers, not enough to fully correct atmospheric distortions on an average night. GPI will include a second conventional deformable mirror synchronized with the MEMS mirror. This combination is analogous to the woofer–tweeter arrangement on a home sound system, but instead of providing the full range of sound, GPI gathers the full range of light.

A coronagraph, originally developed for blocking light from the Sun to study the corona, will be an important component. GPI's coronagraph will incorporate an apodization device that changes the input intensity profile and thus reduces diffraction edge effects. In addition, an infrared interferometer will constantly measure the visible-light wavefront with nanometer accuracy and remove small errors that produce speckle patterns.

All of these tools correct incoming light to make visible new stars, extrasolar planets, protoplanets, stellar dust, and other celestial objects. A near-infrared integral field spectrograph will use the enhanced data on incoming light to simultaneously produce a spectrum for every pixel in GPI's field of view, creating three-dimensional cubes of data. Researchers expect spectrographic results to show that methane and ammonia dominate planetary atmospheres. The spectrograph will also characterize planetary temperatures and surface gravities, and its dual-channel polarimetry mode will facilitate the study of circumstellar debris disks.

The GPI design collaboration includes scientists from Lawrence Livermore, University of Montreal, American Museum of Natural History, Herzberg Institute of Astrophysics, UC Santa Cruz Center for Adaptive Optics, UC Berkeley and Los Angeles, and Jet Propulsion Laboratory. Livermore is designing the optical layout and the real-time adaptive optics system. The project began in June 2006 and is scheduled for completion in late 2010.

GPI has a broad range of science missions. Scientists will use its high-contrast imaging capability to map bright objects such as moons and planetary atmospheres in our solar system, binary stars that cannot now be identified, and brown dwarf and white dwarf companions. "Because ultrahigh-contrast imaging has never been available for such explorations, we expect many discoveries," says Livermore astrophysicist Bruce Macintosh. "But the most exciting applications for GPI will be to find more extrasolar planets and learn about their atmospheres."



This photograph shows the Gemini South telescope prepared for a night of observations. The Gemini Planet Imager will be mounted on the side or bottom of the instrument support structure on the back of the telescope. (Courtesy of Gemini Observatory and the Association of Universities for Research in Astronomy.)

Debris disks are old and therefore cold, so detecting their thermal emission is a challenge. They can, however, be identified by imaging the light scattered by the dust. Lumps and wiggles in the processed images indicate dust linked to a planet's gravitational pull in what are called resonances. As a planet migrates toward or away from its star, material can become caught in these resonances. For example, Pluto and other objects in the Kuiper Belt appear to be caught in Neptune's resonances. Such dust perturbations arising from planets offer important clues about the evolution of planetary systems.

Fitzgerald was part of a team that identified a highly unusual debris disk around a star known as HD 15115. Images taken with the Hubble and Keck telescopes show a needlelike shape, which may result from the gravity of another star about 10 light years away. The needle's blue color indicates the presence of small, freshly produced grains.

"Observing debris disks nearly face on will make resonances more easily visible," says Fitzgerald. "Spectral data from GPI will tell us about the dust's composition, and GPI's high-contrast images will allow us to disentangle grain sizes, properties, and distributions in the disk. As we learn more about the distribution of dust grain sizes, we can study the dynamics of the disk."

The polarimetry feature in GPI will produce entirely new measurements of debris disks. "What we want to achieve is a census of planetary system structures," says Fitzgerald. "By examining the connection between the distributions of planets and primitive bodies that produce the debris disks, we can gain insight into the relative importance of migration processes that affect how planetary systems form and evolve."

## Best Yet Direct Image

Another researcher eager for GPI to come online is astrophysicist Christian Marois. Marois recently completed a postdoctoral fellowship at Livermore and is now at the Herzberg Institute of Astrophysics in Canada. As a graduate student at the University of Montreal, he developed a tool called angular differential imaging (ADI) for directly observing distant planets. ADI is currently the most efficient way to look for planets and can also be used to image debris disks.

ADI was a critical component of the Gemini Deep Planet Survey, which used the Gemini North telescope on Mauna Kea in Hawaii. Simulations indicated that ADI at Gemini could detect planets two times the mass of Jupiter located 40 to 200 AU from their stars. In fact, for the 85 young stars studied in the survey, ADI detected 300 candidate planets. "Unfortunately," says Marois, "later investigation revealed that all the candidates are background stars instead of planets."

ADI collects a long sequence of exposures for one star with an imaging camera whose field of view rotates with the telescope tracking the target star. In this configuration, the optics of the telescope and the imaging camera stay aligned. Speckles arising from optical and atmospheric aberrations look like planets in the images, but their positions do not rotate with the changing field of view. To improve

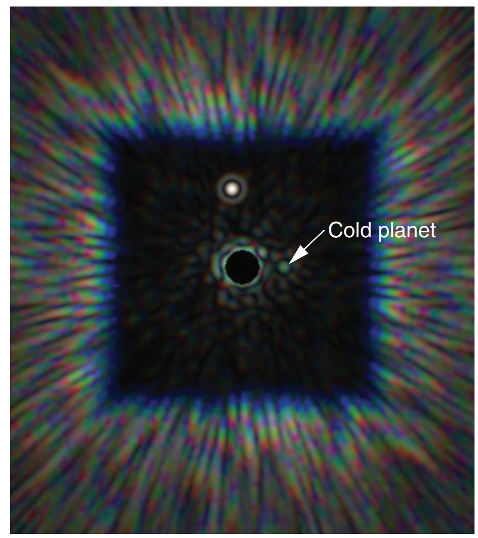
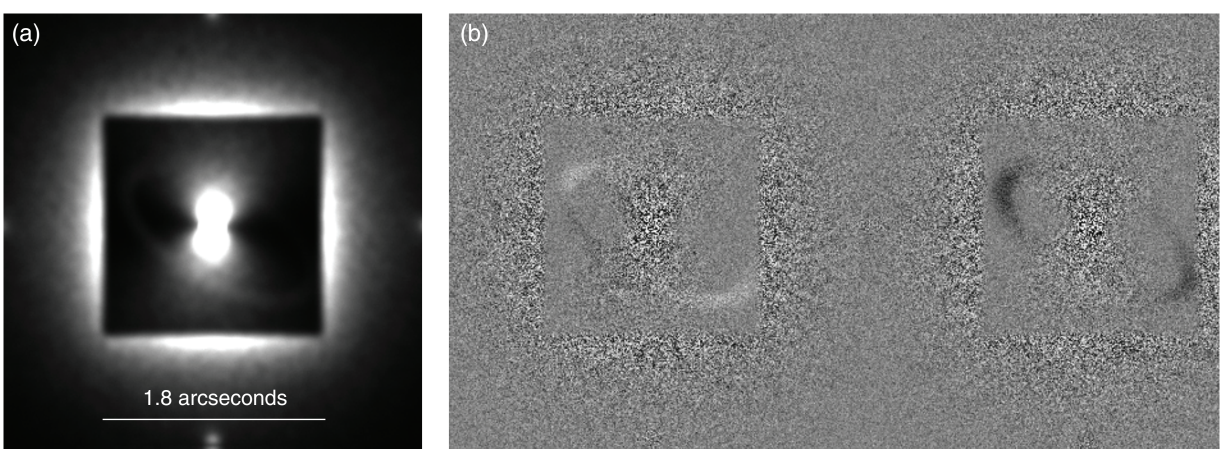



Image-processing techniques developed for the Gemini Planet Imager will suppress bright starlight and atmospheric aberrations to make faint planets visible. As this image from a simulation shows, researchers will be able to detect a hot, massive planet or background object (white) and a faint, cold planet (green).

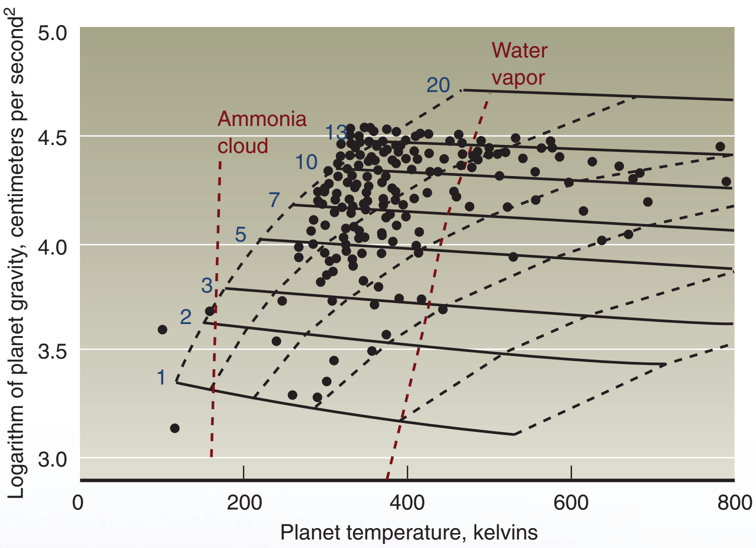



A device on the Gemini Planet Imager will measure the polarization of light to help astrophysicists examine dusty debris disks around stars. This simulation of a debris ring demonstrates the level of sensitivity that can be achieved (a) in conventional imaging and (b) by analyzing the polarization of light.

the images, Marois developed a subtraction process to suppress the speckle "noise." The collection of residual images is then rotated to align the field, further reducing the noise. With current instrumentation, this ADI method effectively identifies planets with 40- to 200-AU orbits, but it is limited for planets with orbits inside 40 AU.

"Our next step," says Marois, "is to improve the field-of-view rotation with a multiple-wavelength speckle suppression technique." With this technique, a coronagraphic mask placed in front of the star eliminates the star's brightest light, allowing researchers to image a background object or faint planet.

At Livermore, Marois calculated the level of image contrast based on the contribution of GPI's many optics. Then using the age and mass of Jupiter as a control point, he ran a Monte Carlo computer simulation to predict the sizes and ages of planets that GPI will detect. Jupiter is massive enough but too old and cool—165 kelvins—for GPI to detect if it were in another solar system. Earth at 287 kelvins is hot enough but too small for detection.



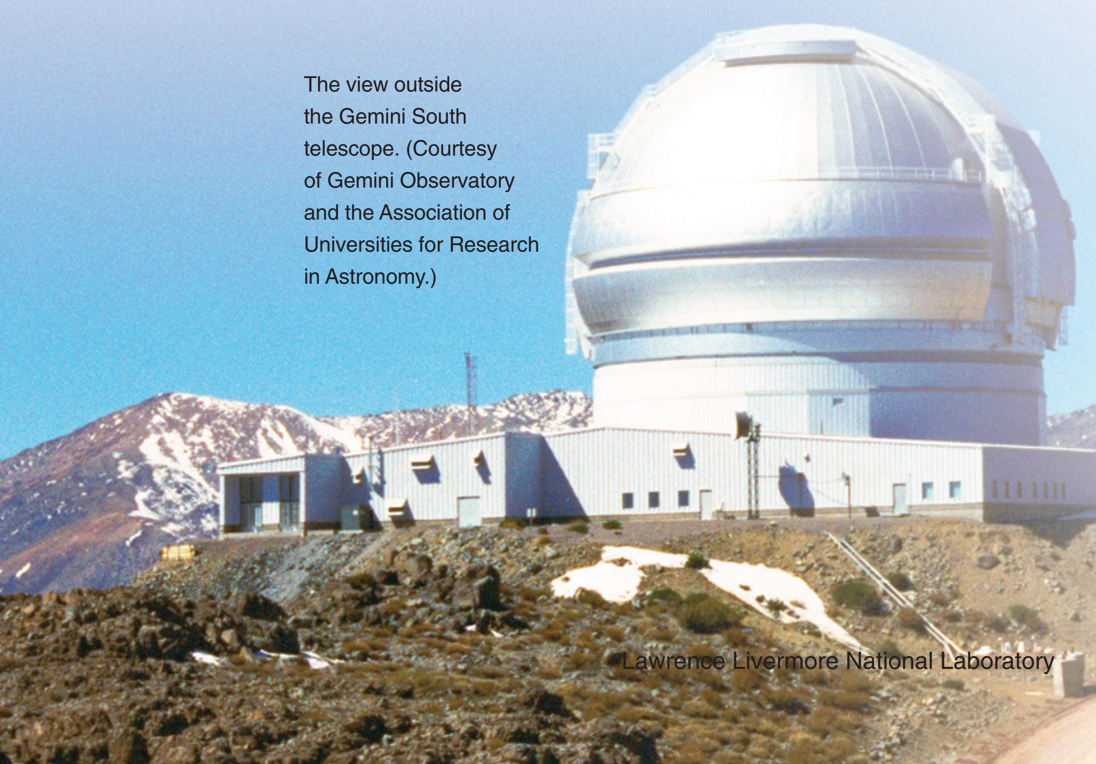

This graph from a simulated sky survey estimates the number of extrasolar planets (dots) that could be found using the Gemini Planet Imager. Planets will range from 1 million to 1 billion years old and have temperatures between 200 and 400 kelvins. Blue numbers indicate the mass of a planet compared to that of Jupiter. Red dashed lines show the conditions in which water vapor and ammonia clouds form. Jupiter, with a temperature of 165 kelvins, is the only planet to be observed to date within the temperature range shown on the graph. (Graph courtesy of James Graham, University of California at Berkeley, based on planet models by Adam Burrows, University of Arizona.)

## Finding Life

And what about finding a planet that might harbor life? Earth orbits the Sun in what astronomers call the "Goldilocks" zone: not too hot, not too cold, but just right for living things to grow and thrive. A small exoplanet like Earth that is warm, rocky, and close to its star cannot be detected even with GPI.

In 10 to 20 years, the National Aeronautics and Space Administration plans to launch the Terrestrial Planet Finder, a wandering spacecraft designed to detect Earth-like planets. "Until then, we have GPI," says Macintosh. "Who knows what we might find."

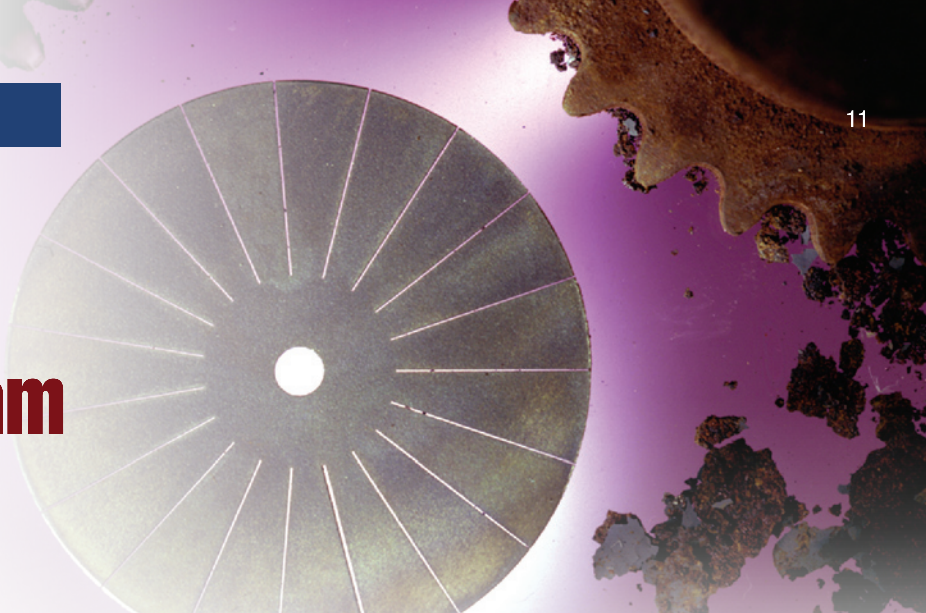
*—Katie Walter*



The view outside the Gemini South telescope. (Courtesy of Gemini Observatory and the Association of Universities for Research in Astronomy.)

**Key Words:** adaptive optics, angular differential imaging (ADI), astrophysics, coronagraph, debris disk, diffraction imaging, extrasolar planet (exoplanet), Gemini Deep Planet Survey, Gemini Observatory, Gemini Planet Imager (GPI).

***For further information contact Bruce Macintosh (925) 423-8129 (macintosh1@llnl.gov).***



In the EBeam Profiler, a tungsten disk similar to the one shown here is placed on top of a Faraday cup to measure the current of an electron beam (EBeam) at different angles.

# Standardizing the Art of Electron-Beam Welding

WELDED materials are an integral part of everyday life. Appliances, cars, and bridges are all made by welding materials together. But not all welds are created equal. Welding methods vary in complexity, time, and cost, depending on a product's requirements and purpose. In electron-beam (EBeam) welding, an electron beam generated in a vacuum creates a fusing heat source that can unite almost any metals. This method produces deep welds without adding excessive heat that can adversely affect the properties of the surrounding metal.

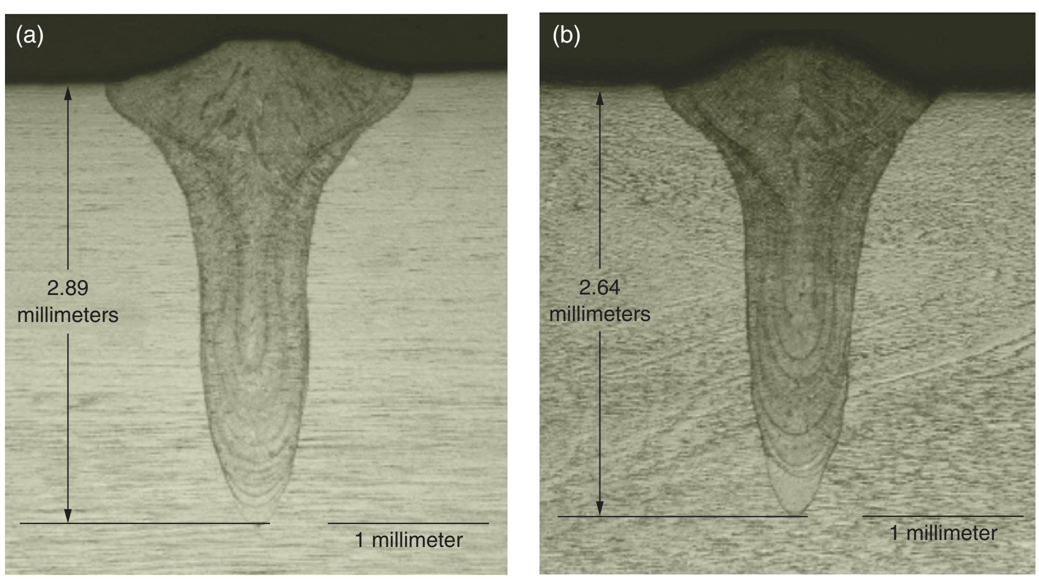
In the nuclear energy and aerospace industries, electron-beam welding is preferred for manufacturing high-value welds—those in which defects cannot be tolerated. The Department of Energy's (DOE's) nuclear weapons complex also relies on electron-beam welding for joining critical components. Welds at this level of importance must be reliable, consistent, and reproducible, regardless of the machine used or an operator's skill.

Until a few years ago, achieving this gold standard was a major challenge. Electron-beam welding was predominantly a manual process that required an operator to pinpoint the beam's focal point, known as the "sharp focus." Because electron beams are invisible, operators could not see the beam and, therefore, could not focus it directly. Instead, they pointed the beam at a surrogate block of refractory metal, heating a spot until it was white hot. Then they adjusted the focus until the spot's optical brightness appeared to be at a maximum.

Operators and welding engineers agree that the sharp focus is the most difficult parameter to determine consistently because many factors can affect optical brightness. For example, an operator's optics may be dirty, or the electron beam could penetrate the surrogate block, obscuring the spot being viewed.

To improve the quality of high-value welds and mitigate weld variations, Lawrence Livermore scientist John Elmer, electrical engineer Alan Teruya, and their colleagues built the EBeam Profiler. "The profiler is a diagnostic tool that measures an electron beam's properties," says Elmer, who works in the Chemistry, Materials, Earth, and Life Sciences Directorate. Because the quality of a weld depends on a beam's power

Electron-beam parameters measured by the Laboratory's EBeam Profiler can be transferred from one machine to another, resulting in welds of similar quality. These micrographs show electron-beam welds made at (a) Livermore and (b) the Y-12 National Security Complex.



density, accurately measuring beam properties is essential for quality control.

The EBeam Profiler has a modified Faraday cup—a metal cup that catches charged particles in vacuum—to measure electron-beam currents. Computed tomography is then used to analyze a beam's power distribution. The system allows an operator to quantify the beam's power-density distribution, determine its sharp focus, and correlate machine settings with beam properties. With this tool, engineers can precisely reproduce an electron beam on the same machine time and again and transfer beam parameters from one machine to another. Thus, a weld developed for a specific step in the manufacturing process of a given part can be reproduced hours, days, or even years later.

## Seventeen Is the Winning Number

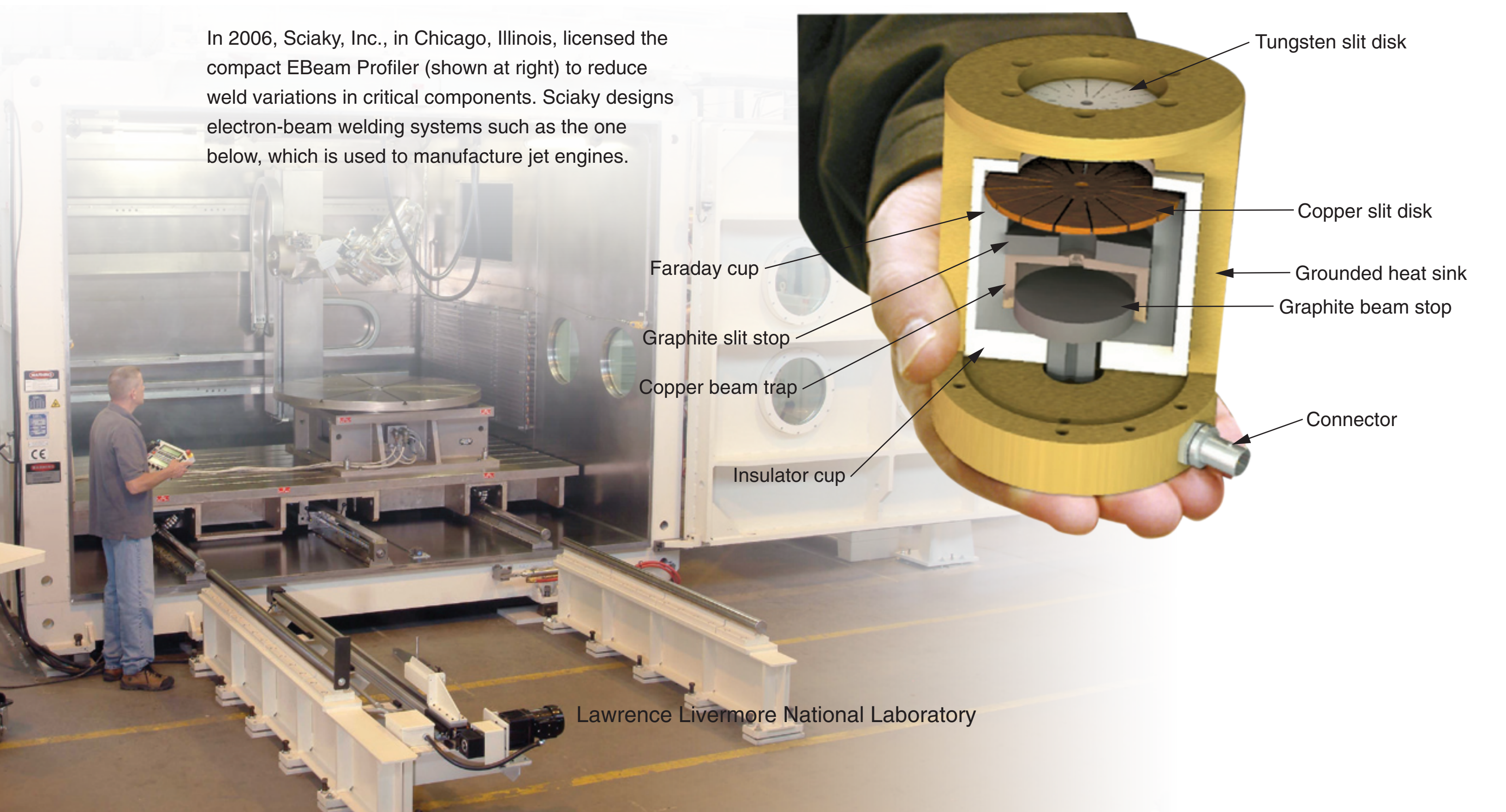
An electron beam's intensity must be measured at a number of angles to obtain an accurate power distribution for computed tomography imaging. In the early 1990s, when Elmer and Teruya began their research, measuring the intensity was a time-consuming process. An electron beam was swept perpendicularly across a single narrow slit on top of the Faraday cup. A digital oscilloscope sampled the beam current captured by the cup and recorded the time–current history of the beam as it passed over the slit.

To measure an electron beam at different angles, Elmer and Teruya rotated the slit and the beam's scan direction, repeating the process as needed to gather the required data. They then saved profiles to floppy disks and manually transferred them to a VAX workstation, which created the computed tomography images. "With that method, it could take us up to a week to get one data point," says Teruya, who works in the Laboratory's Engineering Directorate.

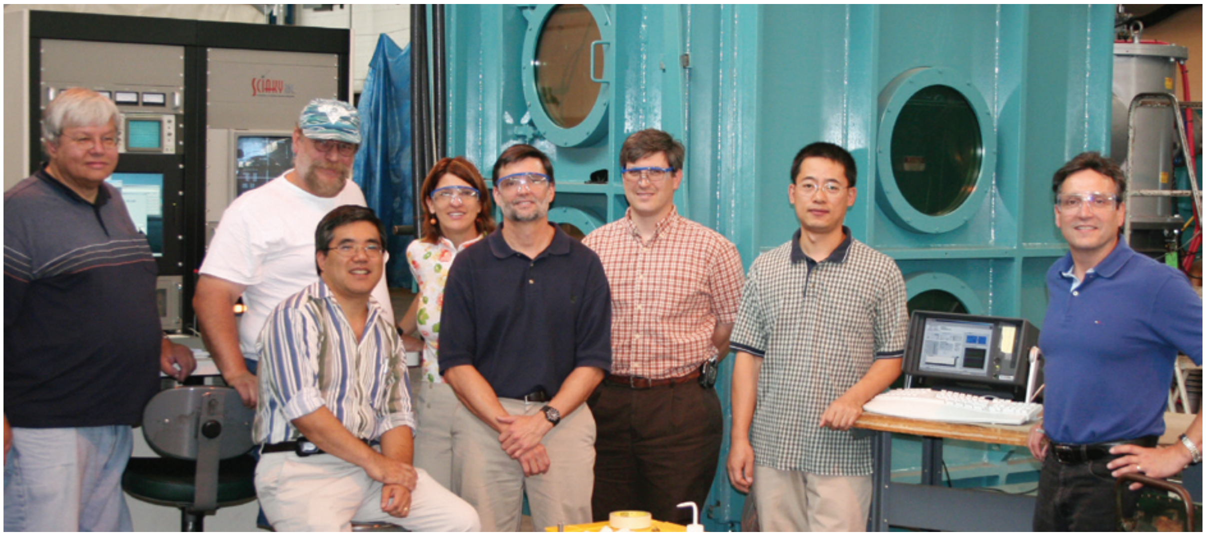
To automate the data-acquisition process, Elmer and Teruya designed a tungsten disk with a number of slits positioned in a radial pattern. Each slit is much smaller than the beam's width, and one slit is slightly wider than the others, allowing an operator to determine the beam's orientation within the vacuum chamber. Onboard deflection coils, a standard component of electron-beam welders, rapidly sweep the beam in a circular motion across the tungsten disk on top of the Faraday cup. The beam passes over each slit at a different angle, and the Faraday cup collects its current. A computer-based data-acquisition device then measures the voltage. None of the slits is directly across from another slit in the tungsten disk to ensure that separate readings are made of the beam at each angle.

Seventeen turns out to be the magic number of slits for electron-beam welders because of the beam's size and the diameter of its circular sweep. Most welders can deflect an electron beam within a circle 2.54 centimeters in diameter. With this deflection and the 17-slit arrangement, the EBeam Profiler can measure defocused beams up to 4 millimeters in diameter. In addition, a beam's size must be smaller than the distance between any two slits so that the data from one slit do not intermingle with adjacent current profiles. Thus, having more than 17 slits limits the beam size that can be measured in the defocused state.

After the beam measurements are recorded, Livermore-developed computed tomography algorithms generate a three-dimensional map of the beam's power-density distribution. This map serves as a reference for machine operators and allows




In 2006, Sciaky, Inc., in Chicago, Illinois, licensed the compact EBeam Profiler (shown at right) to reduce weld variations in critical components. Sciaky designs electron-beam welding systems such as the one below, which is used to manufacture jet engines.



The design team for the EBeam Profiler includes (from left) Mike Bell and Robert Wadman of Sciaky, Inc.; Livermore employees Alan Teruya, Annemarie Meike, John Elmer, and Todd Palmer (now at Pennsylvania State University); and James Wang and Kenn Lachenberg, also of Sciaky.

them to transfer welding parameters—peak power density, beam width, and beam diameter—from one machine to another. Data on a beam's power density can also be included in calculations that model the welding process.

The EBeam Profiler is compact and versatile. The modified Faraday cup assembly weighs less than 1.13 kilograms, has no moving parts, and works with conventional electron-beam welding machines without modifying the welder. The software can be altered to meet customers' needs, and data on a beam's power-density distribution may be incorporated into spreadsheet, plotting, and word-processing applications.

The current EBeam Profiler can handle beam powers up to 2 kilowatts. When modified to work with higher beam powers, the profiler could be used in more powerful welders or in equipment for high-current beam applications such as electron-beam coating or melting. Other proposed upgrades include custom-designed and more user-friendly interfaces and the capability to automatically focus the beam through a closed-loop feedback control system.

Annemarie Meike, a business development executive in Livermore's Industrial Partnerships Office, worked with Elmer and Teruya to meet DOE demands for the profiler and position the technology for licensing and commercial development. Says Meike, "The EBeam Profiler is a great example of how even robust technology moves into the marketplace, gaining its place incrementally over several years."

## Turning toward Commercialization

DOE's Advanced Design and Production Technologies Program funded the effort to turn the EBeam Profiler into a tool for ensuring the safety and reliability of the nation's nuclear weapons stockpile. With this funding, the Livermore team delivered five diagnostic systems to DOE laboratories and manufacturing sites, including Los Alamos and Sandia national laboratories, the Y-12 National Security Complex, and the Kansas City Plant. The Laboratory subsequently worked with DKO, Inc., in Castro Valley, California, on a contract-by-contract basis to manufacture additional units for other government agencies.

Advances in technology allowed Elmer and Teruya to revise the profiler's design so that data acquisition and computed tomography can be completed on a single computer. As a result, the time needed to measure the beam and review the results has decreased from several days to mere seconds. "That change has made the profiler a commercially viable diagnostic," says Teruya. In 2006, Sciaky, Inc., in Chicago, Illinois, licensed the profiler to investigate the properties of electron beams in the company's welders and to determine customer interest in using the diagnostic. The company now holds a full commercial license and sells the technology under the name EBeam 20/20 Profiler.

"Customers in the nuclear and aerospace fields are placing more emphasis on quality control," says Elmer. "It is only a matter of time before such diagnostics become standard additions on machines used to manufacture high-value and safety-critical electron-beam welds."

*—Caryn Meissner*

**Key Words:** computed tomography, electron-beam (EBeam) reproducibility, EBeam Profiler, electron-beam welding, modified Faraday cup, power distribution, quality control diagnostics, sharp focus.

***For further information contact John Elmer (925) 422-6543 (elmer1@llnl.gov).***

# Molecular Building Blocks Made of Diamonds

DIAMOND, a form of crystalline carbon, has long been treasured as a precious jewel. However, for many years, tiny diamond particles, equivalent to a billionth of a billionth of a carat, have plagued oil workers when the particles clump together and clog pipelines. These particles, called diamondoids, can be found in crude oil at concentrations up to thousands of parts per million. Similar diamondlike carbon nanoparticles occur in meteorites, interstellar dust, and protoplanetary nebulae. High-explosive detonations have produced much larger, less pure diamond nanoparticles.

A team of Livermore researchers led by physicist Trevor Willey is helping to transform diamondoids from pesky pipeline sludge and astronomical curiosity into building blocks for new materials. The researchers are also investigating the microscopic particles' fundamental electrical properties, which could lead to their use in electronic devices.

Diamondoids comprise one to many units of the compound adamantane (from "adamas," the Greek word for diamond). First discovered in 1933, adamantane is the smallest cage structure of the diamond crystalline lattice, consisting of 10 carbon atoms and 16 hydrogen atoms. A single adamantane molecule terminates in atoms of hydrogen. However, when the units repeat billions of times in three dimensions, the carbon atoms of other adamantane cages replace the terminal hydrogen atoms, forming the bulk diamonds used in jewelry and industry.

Adamantane, diamantane (two units of adamantane), and triamantane (three units) are referred to as lower diamondoids because each has only one shape. The "higher" diamondoids—those with more than three linked adamantane units—can assume several possible shapes. The lower diamondoids can be easily synthesized, but chemical synthesis of larger diamondoids has proven impossible except for one form of tetramantane (four units of adamantane).

### Diamondoids as Semiconductors

Livermore's diamondoid work is an outgrowth of semiconductor research that began in the mid-1990s with funding from the Laboratory Directed Research and Development Program. A semiconductor is a crystalline solid exhibiting electrical properties between those of metals and insulators. In that initial project, Willey worked with physicist Tony van Buuren and postdoctoral researcher Christoph Bostedt (now at the Technical University of Berlin) to determine how quantum confinement affects the electronic properties of silicon and germanium.

Quantum confinement, which restricts an electron's motion, occurs in a minute sample, typically 10 nanometers or less. The Livermore team discovered that quantum confinement increases the band gap (the energy required for an outer electron to become conductive) in silicon and germanium as molecule size decreases. The band gap is important because it indicates which wavelengths, or colors, of light a semiconductor can absorb or emit. By adjusting, or tuning, the band gap, researchers can design applications from efficient photovoltaic cells (which convert sunlight into electricity) to color-tunable lasers and light-emitting diodes.

In 2003, the team began examining carbon, specifically nanodiamonds obtained from high-explosive detonation residue. In the periodic table of elements, carbon (diamond) is in the same column (called Group IV) as silicon and germanium. Elements grouped in columns often have similar chemical and electronic properties, so carbon might behave like other semiconductor materials.

However, the smallest diamondoids the physicists could isolate measured 2 to 3 nanometers—too large for observing quantum confinement and other changes in electronic structure. Moreover, the surface of the recovered diamondoids resembled buckyballs, 60-atom molecules whose properties are more like graphite (another form of crystalline carbon) than diamond. Ideally, the researchers wanted samples that terminated in hydrogen atoms to preserve the diamondoid characteristics.

The Livermore research effort took an unexpected turn when Chevron scientists, who had been studying clogged oil pipelines in the Gulf of Mexico, published a paper in the January 3, 2003, issue of *Science*. The paper described the discovery of higher diamondoids ranging from less than 1 to about 2 nanometers (that is, with 2 to 11 adamantane units). These diamondoids, presumably created deep underground with crude oil, seemed perfect for the Livermore research effort: They were less than 2 nanometers, the size predicted for observing quantum confinement effects in diamond, and they terminated in hydrogen atoms.

Van Buuren contacted the Chevron researchers, and the Livermore team soon began collaborating with Molecular Diamond Technologies, a business unit established by Chevron to research and commercialize diamondoids. "With the samples from Molecular Diamond Technologies, we could study the evolution of the electronic structure in carbon as a function of size," says Willey. He notes that methane (natural gas), a single carbon atom surrounded by four hydrogen atoms, and other small hydrocarbons have properties very different from diamond. "Diamondoids bridge the gap between small hydrocarbons and bulk diamond," says Willey. "Their availability opens a wealth of possibilities in nanoscience and technology."

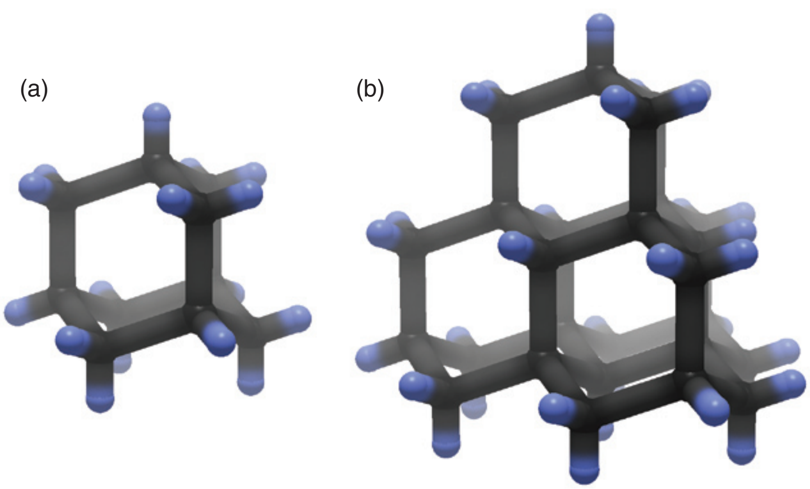
Five researchers from the Chemistry, Materials, Earth, and Life Sciences Directorate are currently involved in the diamondoid research effort, which is funded by the Department of Energy's Office of Basic Energy Sciences. In addition to Chevron, collaborators include the Technical University of Berlin; Stanford University; Justus-Liebig University in Giessen, Germany; and several national laboratories.

Using soft-x-ray absorption and emission spectroscopy, the research team found that the electrical properties of diamondoids differ from those of other semiconductor nanocrystals. In silicon and germanium, for example, the conduction band minimum (the lowest energy level at which a semiconductor allows electrical conduction) increases as the molecule's size decreases. With diamondoids, the conduction band stays constant, presumably because hydrogen atoms are present.

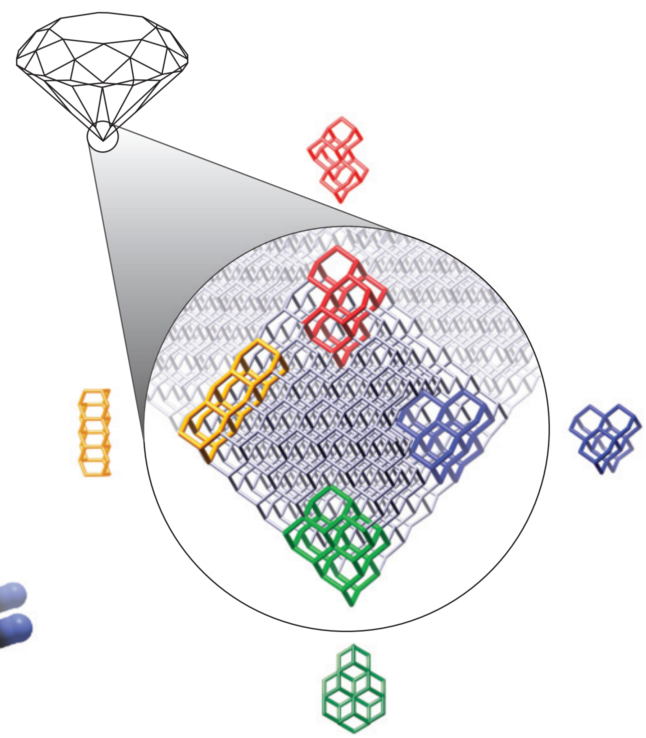
"That finding is a big surprise because carbon is in the same column as silicon and germanium," says Willey. "The lowest unoccupied state is at the surface of the diamondoid, where calculations and experiments show the electron gets emitted spontaneously." Scientists refer to such molecules as having negative electron affinity. This property makes diamondoids ideal for many nanotechnology applications that require efficient electron emission.

### Building Monolayers

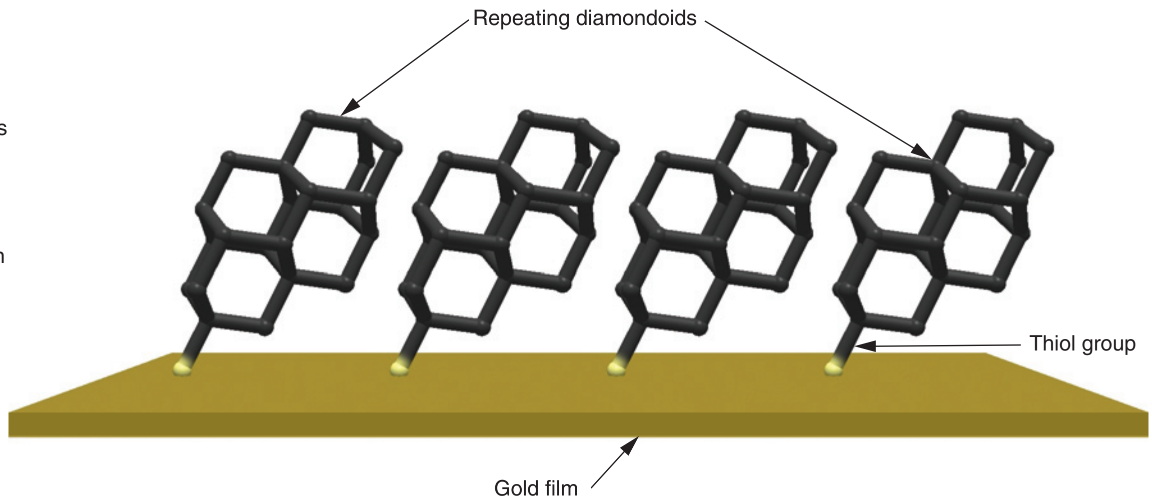
As part of this project, Willey is building diamondoid monolayers, single layers of diamondoid molecules attached to a film of inert metal, typically gold. Monolayers are joined by




(a) Adamantane consists of 10 carbon (black) and 16 hydrogen (blue) atoms. Diamondoids form when multiple adamantane units, or cages, join together. (b) Pentamantane (five units) can be viewed as one adamantane cage surrounded by four additional cages.



Diamond's crystalline structure is made of repeating units of adamantane. The colored molecules depict four configurations of pentamantane, a diamondoid composed of five adamantane cages. (Courtesy of Chevron Corporation.)




One layer of diamondoid molecules can be attached to a film of inert metal, typically gold, by replacing a hydrogen atom with a thiol group (one sulfur atom and one hydrogen atom). The diamondoid monolayer shown here is tetramantane.

replacing a hydrogen atom with a thiol group (one sulfur atom and one hydrogen atom). Thiol groups are used in building monolayers of hydrocarbons, which Willey previously researched.

Building monolayers is the first step toward using diamondoids as molecular building blocks for nanotechnology components. Other carbon or hydrogen atoms could be replaced with desirable chemical groups, for example, to attach diamondoids to different surfaces, join diamondoids to build precise and rigid molecular-scale objects, or link diamondoids to biological or other macromolecules.

The Livermore team has characterized the monolayers using synchrotron sources of very bright x rays, including the Advanced Light Source at Lawrence Berkeley National Laboratory, Stanford Synchrotron Radiation Laboratory, and several facilities in Germany. In studies with near-edge x-ray absorption fine-structure spectroscopy, they found that the orientation of diamondoids within each monolayer depends on both the location of the thiol group (the specific hydrogen atom the thiol group replaces) and the diamondoid composing the monolayer. To date, the team has formed monolayers of adamantane, diamantane, triamantane, and tetramantane. When excited by ultraviolet photons, these monolayers generate large emissions of electrons, which are also monoenergetic. That is, most of the electrons lie within a single energy peak, which has an energy distribution width of less than 0.5 electronvolts.

## From Microscopes to Pharmaceuticals

Within a few years, diamondoids could be used in products ranging from electron microscopes to pharmaceuticals. Because diamondoids can absorb substantial heat without breaking down, they could be used as fuel additives and material coatings. As electron emitters with a narrow energy distribution, they could improve electron microscopes, which usually have a broad and thus inefficient energy distribution. With their high efficiency, they might also decrease the energy consumption in field-emission flat-panel displays.

Because diamondoids are inert, nontoxic, rigid, and available in various shapes and sizes, they may work in biological applications as well. "The pharmaceutical industry is excited about the possibilities," says Willey. An adamantane derivative called aminoadamantane is used in drugs designed to fight viruses and reduce the effects of Alzheimer's and Parkinson's diseases.

Another potential application is in polymers and material coatings. Many polymers use hydrocarbon building blocks—floppy molecules that produce a malleable product. In contrast, diamondoids are rigid at the molecular level, leading to tunable polymer properties. Diamond monolayers are potentially superior to current substrates used to grow synthetic diamonds. "Producing perfect diamonds has been a Holy Grail for many chemists," says Willey.

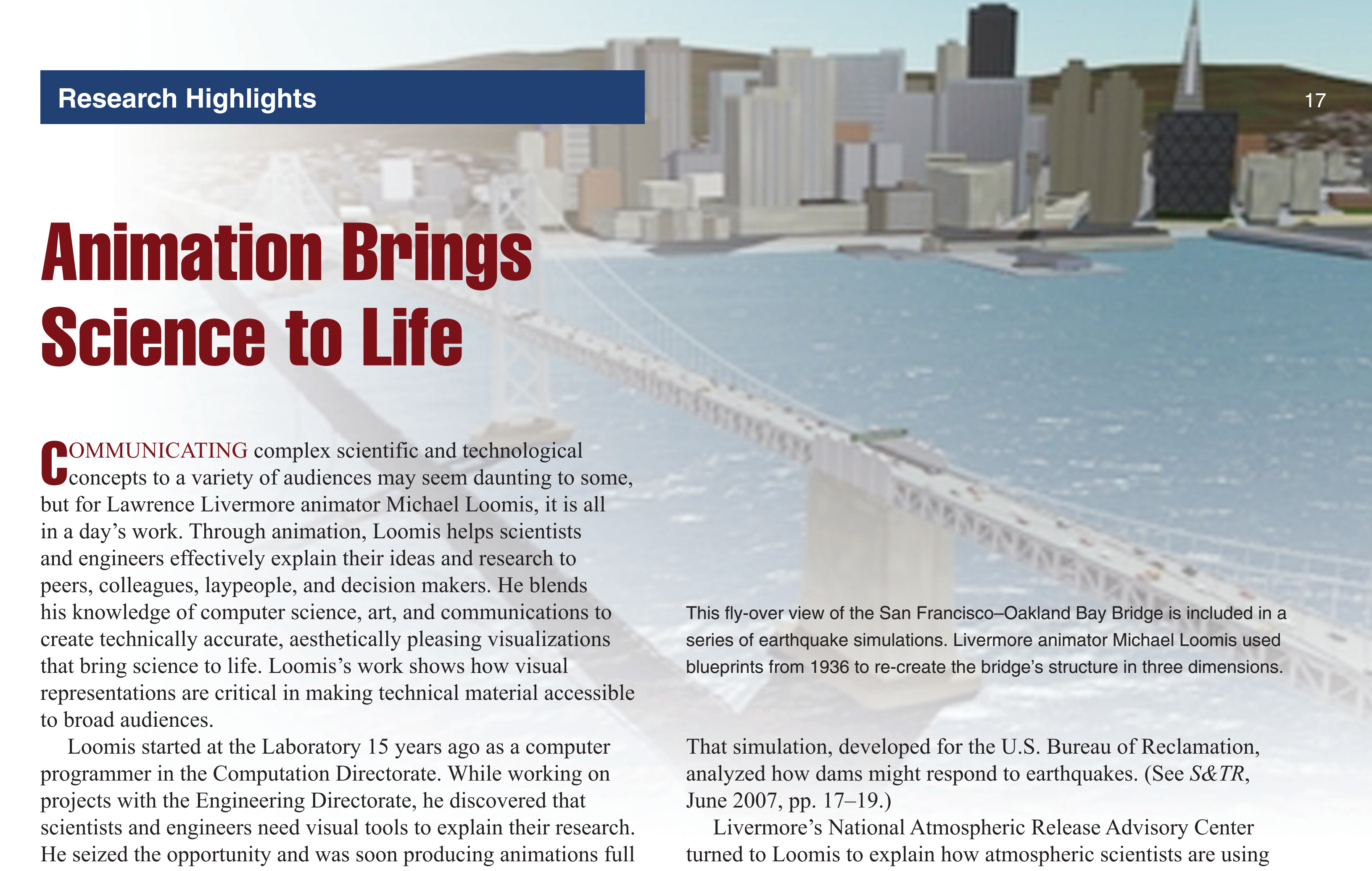
In his current research effort, Willey is determining the three-dimensional orientation of the diamondoids comprising monolayers. He also plans to build monolayers from higher diamondoids. In the growing world of nanotechnologies, diamondoids will likely play an important role as adaptable building blocks for new materials and products.

*—Arnie Heller*

**Key Words:** adamantane, band gap, conduction band, diamond, diamondoid, monolayer, semiconductor.

***For further information contact Trevor Willey (925) 424-6084 (willey1@llnl.gov).***

# Animation Brings Science to Life



This fly-over view of the San Francisco–Oakland Bay Bridge is included in a series of earthquake simulations. Livermore animator Michael Loomis used blueprints from 1936 to re-create the bridge's structure in three dimensions.

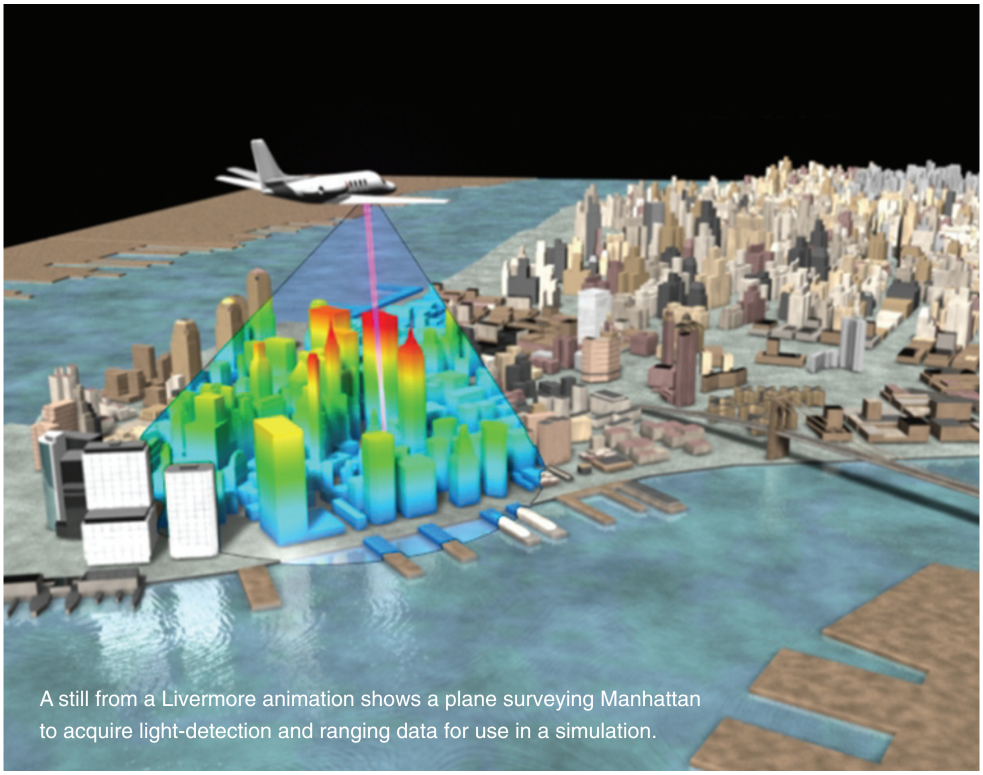
COMMUNICATING complex scientific and technological concepts to a variety of audiences may seem daunting to some, but for Lawrence Livermore animator Michael Loomis, it is all in a day's work. Through animation, Loomis helps scientists and engineers effectively explain their ideas and research to peers, colleagues, laypeople, and decision makers. He blends his knowledge of computer science, art, and communications to create technically accurate, aesthetically pleasing visualizations that bring science to life. Loomis's work shows how visual representations are critical in making technical material accessible to broad audiences.

Loomis started at the Laboratory 15 years ago as a computer programmer in the Computation Directorate. While working on projects with the Engineering Directorate, he discovered that scientists and engineers need visual tools to explain their research. He seized the opportunity and was soon producing animations full time. Today, he is the primary animator for the Engineering Visualization Theater, a production studio and presentation facility at Livermore. Working with the same software filmmakers use to render an animated feature, Loomis constructs original designs or imports material, such as computer-aided design (CAD) models or simulation data. He then develops raw images and pieces them together to generate a video.

## Explaining Simulations

Loomis works on a range of projects with researchers throughout the Laboratory. Using blueprints from 1936, he re-created a three-dimensional model of the San Francisco–Oakland Bay Bridge to produce a fly-by animation, giving viewers the perspective of flying over the bridge from one side to the other. This animation provided a context for a series of simulations examining how earthquakes might affect large structures. In a separate research project, Loomis used animation to describe results from a simulation of seismic activity at the Morrow Point Dam in Colorado. That simulation, developed for the U.S. Bureau of Reclamation, analyzed how dams might respond to earthquakes. (See *S&TR*, June 2007, pp. 17–19.)

Livermore's National Atmospheric Release Advisory Center turned to Loomis to explain how atmospheric scientists are using



A still from a Livermore animation shows a plane surveying Manhattan to acquire light-detection and ranging data for use in a simulation.

the Adaptive Urban Dispersion Model to simulate hazardous material dispersions in urban areas. The animation illustrates the process by which the model's grid-generation program uses light-detection and ranging data from aerial surveys to create three-dimensional meshes of cityscapes such as Manhattan. It then shows how a computer simulation uses these meshes and up-to-date data from weather satellites to predict where materials will disperse through a particular area. Results from such simulations help researchers accurately predict the spread of airborne hazards.

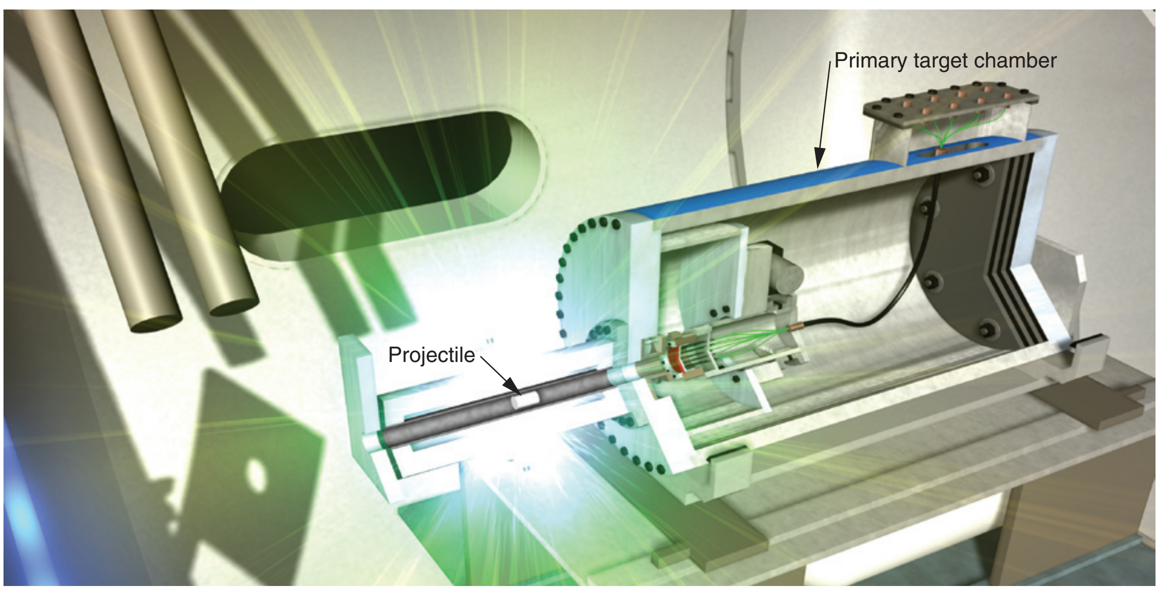
## Animated Support for National Security

Loomis has created several animations for projects that support the Laboratory's national security mission. One animation profiles a gas-gun experiment at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility in Nevada. The 30-meter-long, two-stage gas gun tests how plutonium reacts under extreme pressures and temperatures. Data from such experiments are used to determine plutonium's equation of state (which expresses the relationship between pressure, density, and temperature) to help researchers understand the effects of aging on the nation's stockpile.

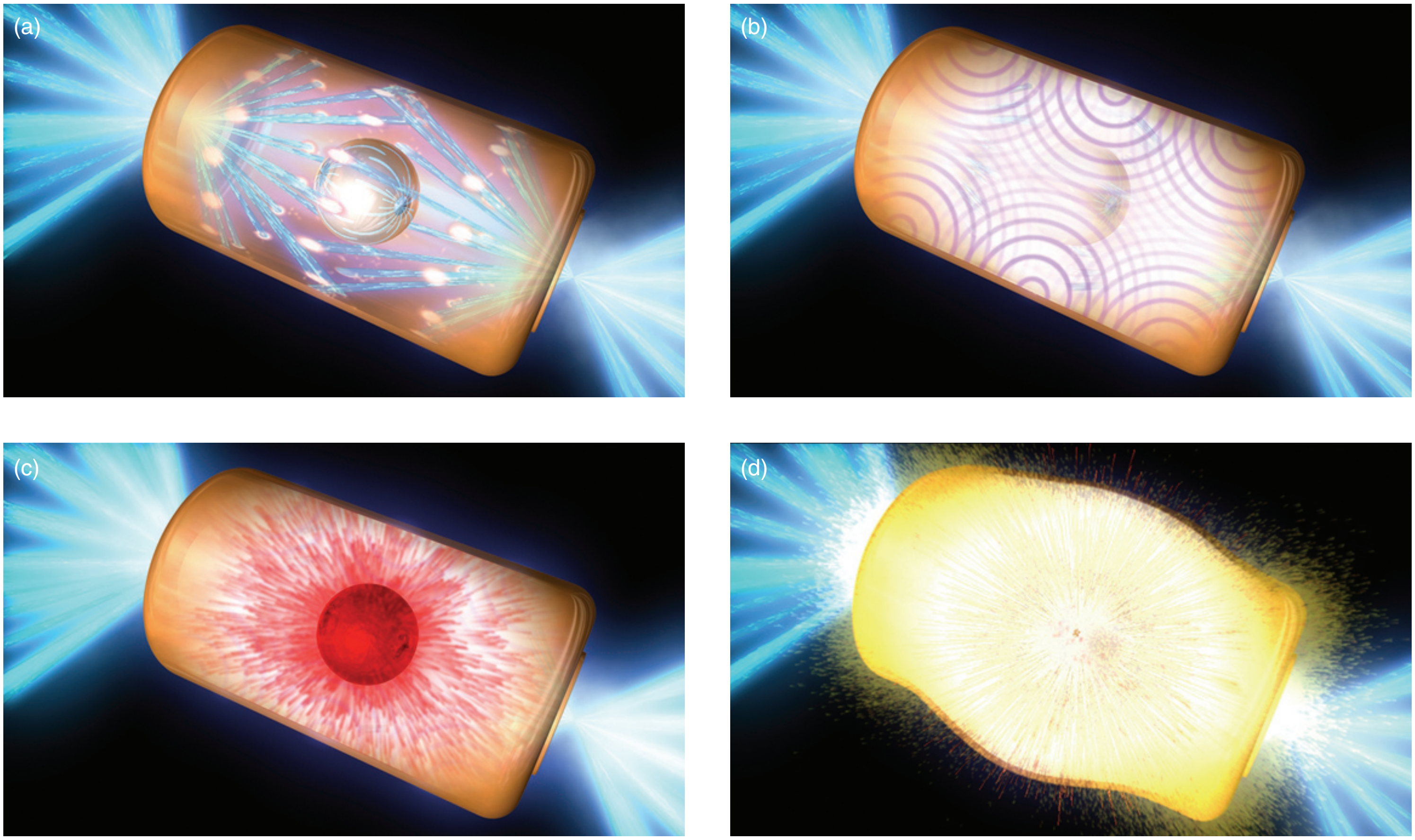
"Animation allows audiences to see a process in more detail," says Loomis. "It shows areas of diagnostic equipment or physical processes that are normally hidden from view in a standard video." For example, in the gas-gun animation, viewers can "see through" the gun's outside structure to observe its inner workings, as if looking through an x-ray lens. They can watch step-by-step as the gas gun fires a projectile down the launch tube into the primary target chamber, where it impacts a plutonium target. This animation helps visitors to the JASPER Facility understand how the technology works.

Loomis continues to work with programs that directly support stockpile stewardship. Currently, he is developing animations for technical videos on the National Ignition Facility (NIF). NIF will provide researchers with a laboratory in which they can study the physical processes occurring in stars, planets, and exploding nuclear weapons.

Bryan Quintard, a Livermore photographer and videographer working with Loomis on the NIF videos, says, "These animations will allow us to see NIF in action. Michael is able to animate in a real sense what is happening with laser and light." The videos will help audiences visualize processes never seen before, such as the fusion reaction that will occur when NIF's 192 lasers strike a fuel capsule inside a tiny metal case called a hohlraum. In another video, whimsically referred to by Loomis as "NIF—The Ride," viewers will be put in the "front seat" of a laser beam as it travels through the laser bay and into the target chamber.




This cutaway view of the gas gun at the Joint Actinide Shock Physics Experimental Research Facility shows a projectile (white) being launched toward the primary target chamber.




Stills from an animated video of the National Ignition Facility (NIF) illustrate the fusion reaction that will occur when all 192 lasers are fired at a target inside a hohlraum. (a) Laser beams enter the hohlraum in the first one-billionth of a second (1 nanosecond) and (b) create x rays within 10 nanoseconds. (c) At about 15 nanoseconds, the target begins to implode. (d) NIF achieves fusion ignition by 20 nanoseconds.

Ten years ago, Loomis had to use conceptual drawings to develop animations of the NIF laser bay. Today, he can create far more realistic visuals using CAD drawings and working in high definition. When completed, the videos will effectively portray NIF's scientific capabilities and help scientists explain results from the first NIF experiments.

Loomis's work has been instrumental in helping scientists and engineers communicate their research. With his animated videos, audiences from various backgrounds can visualize complex processes and better understand how technologies work. As science and technology continue to advance, the capability to visually explain new breakthroughs is not just an advantage, it's a necessity.

*—Caryn Meissner*

**Key Words:** animation, computer simulation, Engineering Visualization Theater.

***For further information contact Michael Loomis (925) 422-0364 (loomis3@llnl.gov).***

*Each issue 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

**Diode Pumped Alkali Vapor Fiber Laser**
**Stephen A. Payne, Raymond J. Beach, Jay W. Dawson, William F. Krupke**
U.S. Patent 7,286,575 B2
October 23, 2007
This apparatus produces or amplifies near-diffraction-limited laser light in diode-pumped alkali vapor photonic-band-gap fiber lasers or amplifiers. Laser light is generated and propagated in an alkali gas instead of a solid to circumvent the nonlinear and damage limitations of conventional solid-core fibers. Alkali vapor is introduced into the center hole of a photonic-band-gap fiber, which can be configured as an amplifier or pumped with light and operated as an oscillator with a seed beam.

**Computational Model, Method, and System for Kinetically-Tailoring Multi-Drug Chemotherapy for Individuals**
**Shea Nicole Gardner**
U.S. Patent 7,286,970 B2
October 23, 2007
This system tailors treatment regimens for patients whose diseased cells resist treatment. A mathematical model provides rates of population change for proliferating and quiescent diseased cells. The model uses cell kinetics and resistance evolution as well as pharmacokinetic and pharmacodynamic models. Cell kinetic parameters for a patient are applied to the model to determine the treatment options and the quantitative efficacy value for each. A treatment regimen can then be selected based on the efficacy value.

**Diagnostic System for Profiling Micro-Beams**
**John W. Elmer, Todd A. Palmer, Alan T. Teruya, Chris C. Walton**
U.S. Patent 7,288,772 B2
October 30, 2007
This apparatus for characterizing a microbeam is composed of a micro-modified Faraday cup assembly with four layers of material. The first layer—an electrical conducting material with at least one radial slit extending through the layer—is connected to an electrical ground. The second layer, which connects to the first layer, is an insulating material with at least one radial slit corresponding to the slit (or slits) in the first layer. The third layer, a conducting material connected to the second layer, has at least one radial slit corresponding to the slit in the second layer. The fourth layer, an electrical conducting material with no slits, connects to the third layer and to an electrical measuring device. This micro-modified Faraday cup assembly is positioned to be swept by the microbeam.

**Microfluidic Sieve Using Intertwined, Free-Standing Carbon Nanotube Mesh as Active Medium**
**Olgica Bakajin, Aleksandr Noy**
U.S. Patent 7,290,667 B1
November 6, 2007
This microfluidic sieve has a substrate with a microfluidic channel and mesh made from intertwined freestanding carbon nanotubes for separating, concentrating, or filtering molecules. The microfluidic sieve can be fabricated by growing the intertwined freestanding carbon nanotubes within the microfluidic channel of a substrate.

**Shape Memory Polymer Actuator and Catheter**
**Duncan J. Maitland, Abraham P. Lee, Daniel L. Schumann, Dennis L. Matthews, Derek E. Decker, Charles A. Jungreis**
U.S. Patent 7,291,154 B2
November 6, 2007
This actuator system acts on a material in a vessel. The system includes a shape-memory polymer connected to an optical fiber. The polymer adapts from one shape for moving through the vessel to a second shape for acting on the vessel material.

**Robotic CCD Microscope for Enhanced Crystal Recognition**
**Brent W. Segelke, Dominique Toppani**
U.S. Patent 7,292,263 B2
November 6, 2007
A robotic charge-coupled device (CCD) microscope designed to automate crystal recognition provides more accurate results than other recognition methods. The system reduces the number of false negatives and false positives and can detect smaller crystals than other recognition methods.

**Inspection Tester for Explosives**
**Jeffrey S. Haas, Randall L. Simpson, Joe H. Satcher**
U.S. Patent 7,294,306 B2
November 13, 2007
An inspection tester designed for use by nontechnical personnel serves as a primary screening tool to determine whether a surface contains explosives. The tester body has a sample pad connected to a heater. Two holders and dispensers attached to the tester deliver explosives-detecting reagents to the sample pad.

## Awards

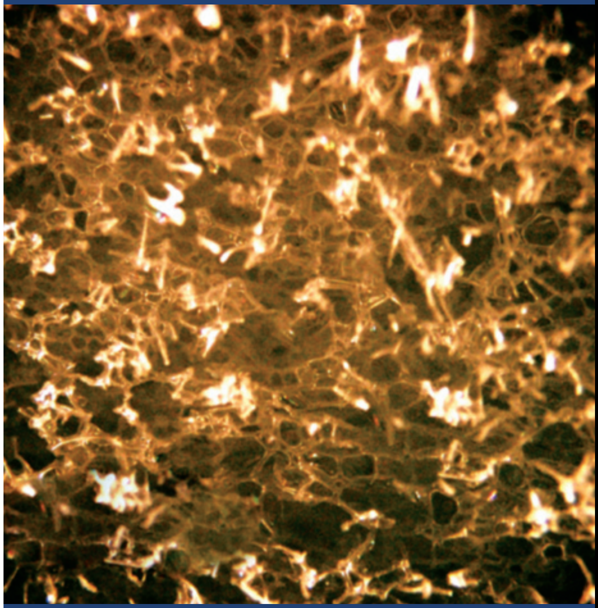
Retired Laboratory physicist **Ken Kulander** received the **2008 Will Allis Prize for the Study of Ionized Gases** from the **American Physical Society**. The award citation honored Kulander for developing “time-dependent methods and models that have advanced our understanding of strong field ionization processes in rapidly ionizing gases.” Kulander joined the Laboratory in 1978 and led the Theoretical Atomic and Molecular Physics Group from 1986 until he retired in 2001.

A team of scientists from Lawrence Livermore and IBM earned the **2007 Gordon Bell Prize** for their simulation of Kelvin–Helmholtz instability in molten metals. This large-scale molecular dynamics simulation run on the BlueGene/L supercomputer allowed the researchers to study, for the first time, how such instabilities develop from atomic-scale fluctuations into micrometer-scale vortices. Team members include **Jim Glosli**, **Kyle Caspersen**, **David Richards**, **Robert Rudd**, and **Fred Streitz**, all from Livermore’s Physical Sciences Directorate, and IBM scientist **John Gunnels**.

## Extending the Search for Extrasolar Planets

Lawrence Livermore scientists are leading an international collaboration developing the Gemini Planet Imager (GPI) to study extrasolar planets—those outside our solar system—that cannot be detected with current instrumentation. The imager will come on line at the Gemini South telescope in Chile in 2010. A spectrograph designed for GPI will give scientists the first-ever information about the atmospheres of extrasolar planets. With the new imager, astrophysicists can better study how planets and solar systems form and evolve. Extreme adaptive optics, developed at Livermore, will straighten the wavefronts of starlight so that images of stars and other celestial objects gain resolution and contrast. A deformable mirror will use a silicon microelectromechanical system device that is lithographically patterned and etched like a microchip.
***Contact: Bruce Macintosh (925) 423-8129 (macintosh1@llnl.gov).***

# Livermore's "Smart" Foam Technology



Livermore scientists are developing expandable foam devices to treat life-threatening aneurysms.

*Also in May/June*

- *Using three-dimensional stellar models, Laboratory researchers have solved a long-standing astrophysical puzzle of stellar evolution.*

- *Livermore personnel in Washington, DC, support federal sponsors and become valuable assets to Laboratory programs.*

Coming Next Issue

U.S. Government Printing Office: 2008/770-075-71004

Science & Technology Review
Lawrence Livermore National Laboratory
P.O. Box 808, L-664
Livermore, California 94551

PRSRT STD
U.S. POSTAGE
PAID
LIVERMORE, CA
PERMIT NO. 154

Printed on recycled paper.