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2006 Physics and Advanced Technologies In the News

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2006
Physics and Advanced Technologies
In the News

Lawrence Livermore National Laboratory

About the Cover

Top left: Hope Ishii (standing) and John Bradley from the Institute of Geophysics and Planetary Science placing a sample under a microscope in a clean room at Livermore. The sample contains cometary particles that were collected and returned to Earth by NASA's Stardust spacecraft. Livermore researchers are using the Laboratory's unique analytical tools to determine the mineralogy, and the chemical, and isotopic composition of these particles (see p. 2). Bottom right: Physicist Lee Bernstein examining a component of the Livermore-developed Silicon Telescope Array for Reactions Studies (STARS) detector installed at the Lawrence Berkeley National Laboratory (LBNL). Livermore and LBNL researchers are using STARS to study low energy nuclear reactions for stockpile stewardship, homeland security, and fundamental nuclear physics (see p. 6). Bottom left: Part of the Multiprogrammatic Capability Resource (MCR) computer system, which is a large, commodity-chip based Linux cluster capable of peak computing speeds of 11 teraflops. Top right: Rendition of the surface layer of a red giant star that shows bubbles of material floating to the surface due to deep turbulent mixing. The evolution of the star was simulated with the Livermore-developed three-dimensional hydrodynamic code Djehuty running on MCR (see p. 14).

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About this Report

Several outstanding research activities in the Physics and Advanced Technologies Directorate in 2006 were featured in Science and Technology Review, the monthly publication of Lawrence Livermore National Laboratory. Reprints of those articles accompany this report. Here we summarize other science and technology highlights, as well as the awards and recognition received by members of the Directorate in 2006.

About Physics and Advanced Technologies

The mission of the Physics and Advanced Technologies Directorate is to be a leader in frontier physics and technology for 21st-century national security missions: stockpile stewardship, homeland security, global stability, and scientific preeminence. Our research program is highly integrated and multidisciplinary, with substantive collaborations with the rest of LawrenceLivermore National Laboratory and with other national laboratories, universities, and industries. The Directorate has a budget of approximately $150 million and a staff of approximately 355 employees. Our staff continues to be recognized for their scientific and technological accomplishments, programmatic impact, and leadership in their respective fields

Find Out More About Us

Visit our Web site at http://www-pat.llnl.gov/ for more information on Physics and Advanced Technologies research, facilities, publications, staff, organization, events, and awards.

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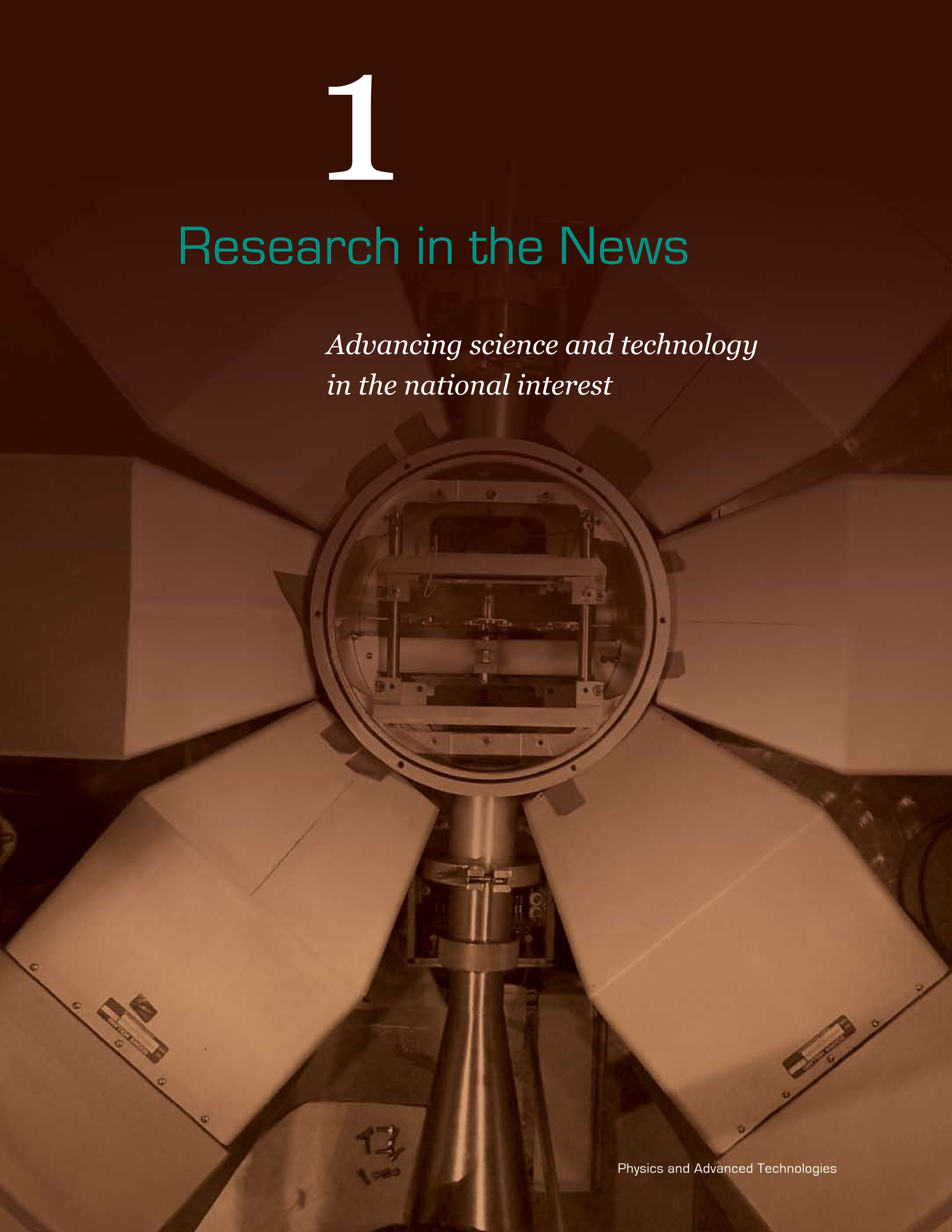
Research in the News

Advancing science and technology in the national interest



Cosmic dust could help uncover the origins of life

The National Aeronautics and Space Administration's (NASA's) Stardust spacecraft returned from a 7-year mission on January 15, 2006, bringing back cometary and interplanetary dust particles that may be able to tell the story of our solar system's beginnings and, possibly, the origins of life. By tailing a comet called Wild 2 that was shooting material into space at 6.1 kilometers per second, the spacecraft captured dust particles in a collector made up of silica aerogel—a material that is 99.8 percent air.

After landing, the capsule was flown to NASA's Johnson Space Center (JSC) in Houston and opened. Researchers from Livermore's Institute of Geophysics and Planetary Physics (IGPP) performed some of the first extractions at JSC using ultrasonic diamond-microblade technology, which was developed at Livermore by postdoctoral researcher Hope Ishii. The first few days were devoted to optical scanning of the aerogel tiles. Extractions of particles from aerogel cells began the following week, after which samples were distributed to Livermore and other research laboratories around the world. Since then, Livermore researchers have used the Laboratory's transmission electron microscope—the world's most powerful electron microscope—and the nanoscale secondary ion mass spectrometer to analyze the mineralogical, chemical, and isotopic composition of the dust particles.

The Stardust collaboration reported their preliminary results in a series of articles in the December 15, 2006, issue of ***Science***. For example, measurements of the elemental compositions of the Wild 2 particles showed that the mean composition of this cometary material is consistent with that found in CI-type meteorites, which is thought to represent the bulk composition of the solar system for nonvolatile elements. The collaboration has also found that the hydrogen, carbon, nitrogen, and oxygen isotopic compositions are heterogeneous among comet particles. Extreme isotopic anomalies are rare, indicating that the comet is not a pristine aggregate of presolar materials. Nonterrestrial nitrogen and neon isotope ratios suggest that indigenous organic matter and highly volatile materials were successfully collected. One grain was found to be enriched in ^{16}O, suggesting that Wild 2 contains material formed at high temperature in the inner solar system and transported to the outer regions before accreting to the comet.

Stardust is part of NASA's series of Discovery missions and is managed by the Jet Propulsion Laboratory. Other collaborators in the project include the University of Washington, Lockheed Martin Space Systems, the Boeing Company, the Max Planck Institute for Extraterrestrial Physics, NASA Ames Research Center, and the University of Chicago.

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Astronomers discover distant, Earth-like planet

Using a network of telescopes scattered across the globe, an international team of astronomers has discovered an extrasolar planet that is more Earth-like than any other planet found so far. The new planet—designated OGLE-2005-BLG-290 Lb—orbits a red dwarf star five times less massive than the Sun every 10 years. The discovery opens a new chapter in the search for planets that support life. The team's research appeared in the January 26, 2006, edition of ***Nature***.

In most cases, new planets have been found by measuring the Doppler shift in light from the orbiting star. However, most of these planets have been giant gas planets. The team found the new rocky planet using a technique called microlensing. The planet is not directly "seen," nor is the star that it's orbiting, but its presence can be deduced from the effect of the planet's gravity on light from more distant stars. "There's a deviation of light when a planet is in the way," says Kem Cook, an astronomer at Lawrence Livermore who is also a member of PLANET (Probing Lensing Anomalies NETwork), a part of the group that made the discovery. "In this instance, there was a half-day brightening that was indicative of a planet."

Microlensing can show just how common planets are in distant parts of the galaxy and probe details of planetary formation that other techniques cannot. The discovery of the Earth-like planet is the joint effort of three independent microlensing campaigns: PLANET/RoboNet, the Optical Gravitational Lensing Experiment, and Microlensing Observations in Astrophysics. The effort involves 73 collaborators affiliated with 32 institutions in 12 countries.

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Reprinted from April 2006 issue of Science & Technology Review of the Lawrence Livermore National Laboratory

A quantum leap in materials modeling

A Livermore team has determined the solid–liquid and solid–solid phase boundaries of carbon for pressures up to 20 million atmospheres and more than 10,000 kelvins. "Results of computer simulations show a consistent description of elemental carbon in a broad range of temperatures and pressures," says Alfredo Correa, a University of California (UC) at Berkeley student who works in Livermore's Physics and Advanced Technologies Directorate under the Student Employee Graduate Research Fellowship Program. The physical properties of carbon are of great importance for devising models of Neptune, Uranus, white dwarf stars, and extrasolar planets that are carbon-rich.

In its elemental form, carbon is found in materials such as coal, graphite, diamond, bucky balls, and nanotubes. These materials have very different properties, but, at the microscopic level, they differ only in their carbon atoms' geometric arrangements. Experimental data on the phase boundaries and melting properties of elemental carbon are scarce because of difficulties in reaching megabar (one million atmospheres) pressures and temperature regimes of thousands of kelvins in the laboratory.

"Our simulation results call for a partial revision of current planetary models, especially for the description of their core regions," Correa said. "Our computational work also may help us interpret future experimental work." Correa is the lead author of a report published in the January 31, 2006, online edition of the ***Proceedings of the National Academy of Sciences***. The research team is composed of Correa, Stanimir Bonev, and Giulia Galli, all of whom were at Livermore at the time the work began. Galli is now a professor at UC Davis, and Bonev is an assistant professor at Dalhousie University in Canada.

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Reprinted from April 2006 issue of Science & Technology Review of the Lawrence Livermore National Laboratory

Shedding light on neutrinos

An international team of scientists, including Livermore physicists Peter Barnes, Doug Wright, and Ed Hartouni, announced that it has recorded the transformation of neutrinos from one type to another.

Neutrinos are particles with negligible mass and no electric charge yet are fundamental to the structure of the universe. Sometimes termed "ghost particles," neutrinos are extremely difficult to detect because they rarely interact with anything. They come in three "flavors": electron, muon, and tau.

Each is related to a charged particle, which gives the corresponding neutrino its name.

The physicists have been working on the Main Injector Neutrino Oscillation Search (MINOS) Project, which was launched in 2005 to solve a 50-year-old mystery: how do neutrinos change flavors? MINOS uses two detectors, one located at the source of the neutrinos, at the Department of Energy's Fermi National Accelerator Laboratory (Fermilab), in Batavia, Illinois, and the other located 725 kilometers away, at Soudan Underground Mine State Park in northern Minnesota.

A high-intensity beam of muon neutrinos generated at Fermilab traveled through Earth to the Soudan detector. Scientists observed that a significant fraction of these neutrinos disappeared, which indicates the muon neutrinos have changed to another kind—an effect known as neutrino oscillation. If neutrinos had no mass, the particles would not oscillate as they traverse Earth, and the MINOS detector in Soudan would have recorded many more muon neutrinos.

The findings, announced March 30, 2006, at Fermilab and published in the November 10, 2006, issue of ***Physical Review Letters***, will help scientists better understand how particles acquire mass, as well as neutrinos' role in the formation of the universe and their relationship to dark matter.

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Reprinted from July/August 2006 issue of Science & Technology Review of the Lawrence Livermore National Laboratory

Nuclear reaction rates for testing solar models

A group of researchers led by Livermore physicist Petr Navratil has calculated from first principles (*ab initio*) the rate of a nuclear reaction that is critical for testing the predictions of models of the Sun. In a paper published in the March 9, 2006, issue of ***Physics Letters B***, the scientists reported the results of calculations for the reaction of protons with the beryllium isotope ^{7}Be to form the boron isotope ^{8}B. The weak decay of ^{8}B produces neutrinos — an elementary particle with negligible mass and no charge that is fundamental in understanding the formation of the universe. The production rate of solar neutrinos from ^{8}B is important for testing solar models and for limiting the value of the mixing parameters that characterize the transformations of one type of neutrino to another. The construction of reliable solar models and the prediction of the solar neutrino formation rate, however, require accurate rates for several nuclear reactions, the most uncertain of which is the ^{7}Be(p,γ)^{8}B rate.

In the present work, the researchers calculated *ab initio* the ground states of ^{7}Be and ^{8}B within the no-core-shell-model framework using a nucleon–nucleon interaction that fits nucleon–nucleon scattering data to a high precision. They determined the so-called S-factor characterizing the ^{7}Be(p,γ)^{8}B reaction in two different ways. The resulting S-factors are in good agreement with each other, and also with recent measurements at the Nuclear Physics Center of Excellence at the University of Washington.

This research, which represents the first *ab initio* treatment of a nuclear reaction for a nucleus heavier than ^{4}He, was highlighted as a noteworthy 2006 accomplishment in the DOE Office of Science 2008 budget submission to Congress.

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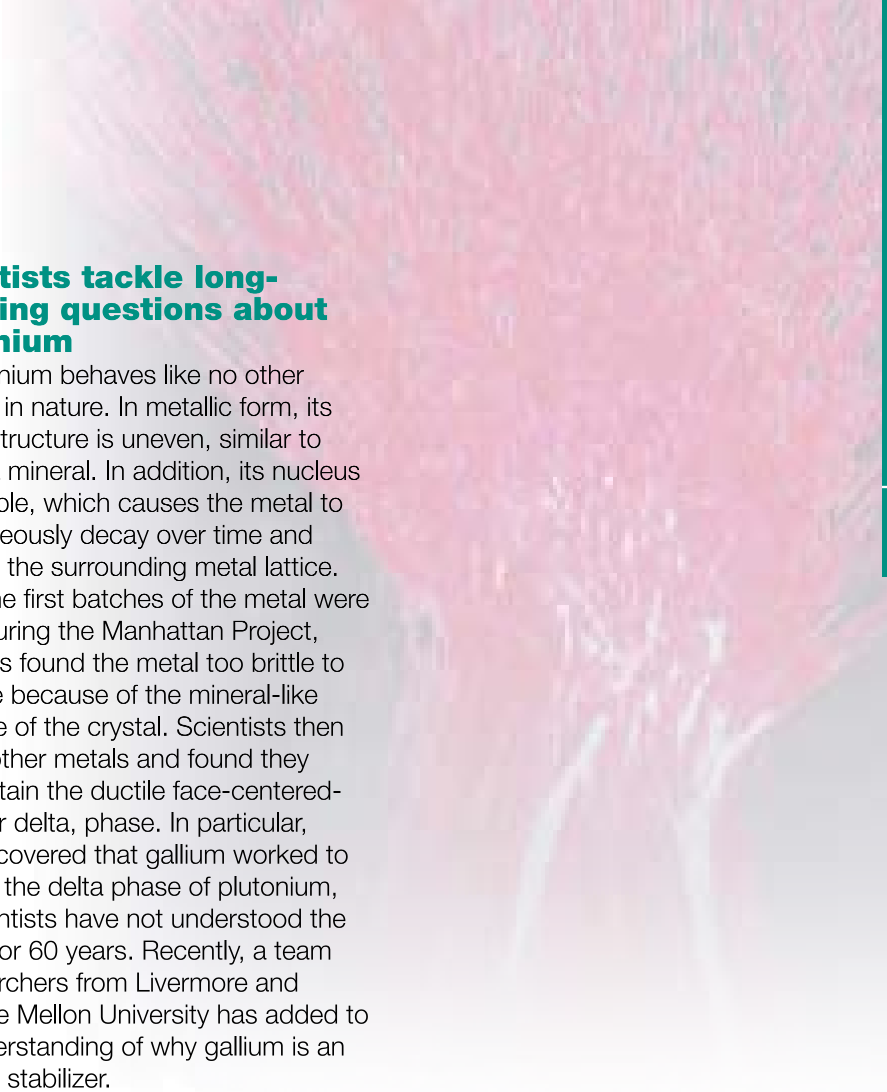
Scientists develop hot radiation environments

Future experiments on the National Ignition Facility at Livermore will include investigations of material properties under extreme conditions. Livermore scientists are developing the techniques for creating the hot radiation environments required for such



experiments. The research involves both carefully diagnosed experiments at existing high-energy lasers and detailed radiation hydrodynamic simulations of the laser–target interactions.

In experiments conducted at the Omega laser at the University of Rochester, the researchers studied the radiation environment produced by depositing all the available laser energy into small cylindrical gold cans. For cans with diameters of 400 micrometers, nearly doubling the laser energy resulted in only an incremental increase in the x-radiation flux, and almost no increase in the maximum achieved radiation temperature. This is a direct consequence of laser–plasma interactions outside of the target, which prevent the deposition of laser energy inside the target late during the laser pulse.

Radiation hydrodynamic simulations show significant plasma formation outside of such small cans. A laser beam propagating through this plasma creates density depressions, which, in turn, self-focus and filament the hot spots in the laser beam. As a result, a beam impinging on the target at high angles relative to the axis of the cylindrical target may never deposit its energy inside the can. This problem is further exacerbated by crossed-beam energy transfer, when pairs of beams propagating at different angles into the can overlap near the entrance hole. Accounting for these processes in the modeling of the laser–target interactions yielded results in quantitative agreement, for the first time, with experiments using very small cans.

These findings, which appeared in an article featured on the cover of the May 19, 2006, issue of ***Physical Review Letters***, have provided the scientific foundation for modifying the target geometry to mitigate the effects of laser–plasma interactions and to achieve higher radiation temperatures.

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Scientists tackle long-standing questions about plutonium

Plutonium behaves like no other element in nature. In metallic form, its crystal structure is uneven, similar to that of a mineral. In addition, its nucleus is unstable, which causes the metal to spontaneously decay over time and damage the surrounding metal lattice. When the first batches of the metal were made during the Manhattan Project, scientists found the metal too brittle to machine because of the mineral-like structure of the crystal. Scientists then added other metals and found they could retain the ductile face-centered-cubic, or delta, phase. In particular, they discovered that gallium worked to stabilize the delta phase of plutonium, but scientists have not understood the reason for 60 years. Recently, a team of researchers from Livermore and Carnegie Mellon University has added to the understanding of why gallium is an effective stabilizer.

According to lead researcher Kevin Moore in Livermore’s Chemistry, Materials, and Life Sciences Directorate, the metal has a high propensity to adopt a low-symmetry structure because the bonds between plutonium atoms are uneven. However, when a gallium atom is put in the plutonium lattice, the bonds become more uniform, leading to a highly symmetric cubic structure.

“Previous experiments tell us that the plutonium lattice exhibits very slight distortions, but there was no clear explanation as to why this happens,” says Moore. “Our calculations explain the observations. They show the distortions are the response of plutonium and its uneven bonds to defects produced in the crystal. The calculations strongly illuminate why gallium stabilizes the ductile cubic structure to room temperature.”

The work of Moore, Livermore colleagues Per Söderlind and Adam Schwartz, and David Laughlin of

Carnegie Mellon appeared in the May 26, 2006, edition of ***Physical Review Letters***.

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Reprinted from September 2006 issue of Science & Technology Review of the Lawrence Livermore National Laboratory

Unraveling the reactions of difficult nuclei

A collaboration led by Livermore physicists has been developing methods for determining the rates of neutron-induced reactions of nuclei that are difficult to produce and measure in laboratory experiments. In a paper published in the May 2006 issue of ***Physical Review C***, the team reported cross sections for the neutron-induced fission of the uranium isotope ^{237}U deduced using the surrogate reaction method.

The surrogate reaction technique is an indirect way to determine the cross section for a "desired" nuclear reaction that proceeds through a compound nucleus, which is a highly excited state in statistical equilibrium. The formation and decay of the compound nucleus are independent of each other. In many cases, the rates of formation can be adequately calculated using theoretical models. The decay rates are determined by measuring the cross sections for an alternative, surrogate reaction that produces the same compound nucleus as is formed in the desired, difficult-to-measure reaction. To eliminate the need to accurately measure the total number of reaction events, which is the largest source of uncertainty in surrogate reaction experiments, the cross section is actually measured relative to another that is independently known.

In the uranium experiments, the collaboration, comprising researchers from Livermore, Lawrence Berkeley National Laboratory (LBNL), Yale University, and the University of Richmond in Virginia, used alpha-particle scattering from ^{237}U as the surrogate reaction to produce the same compound nucleus as is formed in the neutron-induced ^{237}U fission reaction ^{237}U(n,f). They also measured the inelastic alpha-particle cross section for ^{237}U, serving as the surrogate reaction for ^{237}U(n,f). The fission cross section of ^{237}U is accurately known and, thus, was used to deduce the cross section for ^{237}U from the measured surrogate ratios.

The experiments, which took place at the 88-inch cyclotron at LBNL, used the Livermore-developed Silicon Telescope Array for Reactions Studies (STARS). This array, coupled with a germanium clover detector system called the Livermore-Berkeley Array for Collaborative Experiments (LIBERACE), is optimized to utilize particle-gamma-ray coincidences for low-energy nuclear cross section measurements. The installation and commissioning of STARS at LBNL was highlighted as a 2006 technical accomplishment in the DOE Office of Science 2008 budget submission to Congress.

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Shedding light on electrons in lanthanide metals

Livermore researchers, working with colleagues from the University of California at Davis, have elucidated the behavior of electrons in gadolinium (Gd) metal as a function of compression. Physicists have known for some time that a number of lanthanide and actinide metals exhibit phase transitions at high pressures characterized by unusually large changes in volume. They have theorized that such transitions are associated with the delocalization of f electrons due to the dramatic changes in properties, such as crystal structure, that occur in going from low to high pressures. Now, new experiments on compressed Gd metal have revealed prolonged and continuous delocalization of the 4f electrons with volume over the entire pressure range (from ambient to 113 gigapascals). This result suggests that the volume-collapse transition, which occurs at 59 gigapascals in Gd, is only part of the phenomenon affecting the behavior of electrons with increasing compression.

Using a 7-kiloelectronvolt x-ray beam at the Advanced Photon Source at Argonne National Laboratory, the scientists measured resonant inelastic x-ray scattering and x-ray emission spectra from Gd samples compressed to pressures up to 113 gigapascals. These techniques probe the electronic and magnetic properties of the metal as a function of pressure. The high pressures were achieved by loading Gd samples, together with mineral oil for the pressure medium and small ruby chips for pressure determination, into a Livermore-designed piston-cylinder diamond anvil cell.

The measured inelastic x-ray scattering spectrum provides information about the number of electrons occupying the 4f shell in Gd. At ambient pressure, in the strongly localized limit, this occupation number is seven. The changes in the spectrum with increasing pressure show that, under compression, the 4f occupation effectively increases due to electron transfer between the 4f and valence shells. Furthermore, this increase is continuous and occurs over the entire pressure range. At the highest compression reached in the experiment, approximately one sixth of the atoms, on average, have eight electrons in the 4f shell. Another interesting result comes from the x-ray emission spectrum, which shows essentially no variation of the spin magnetic moment of the 4f electrons with compression, even at the volume-collapse transition. This disagrees with the predictions of electronic structure calculations. These results appear in an article published in the June 2, 2006, issue of ***Physical Review Letters***.

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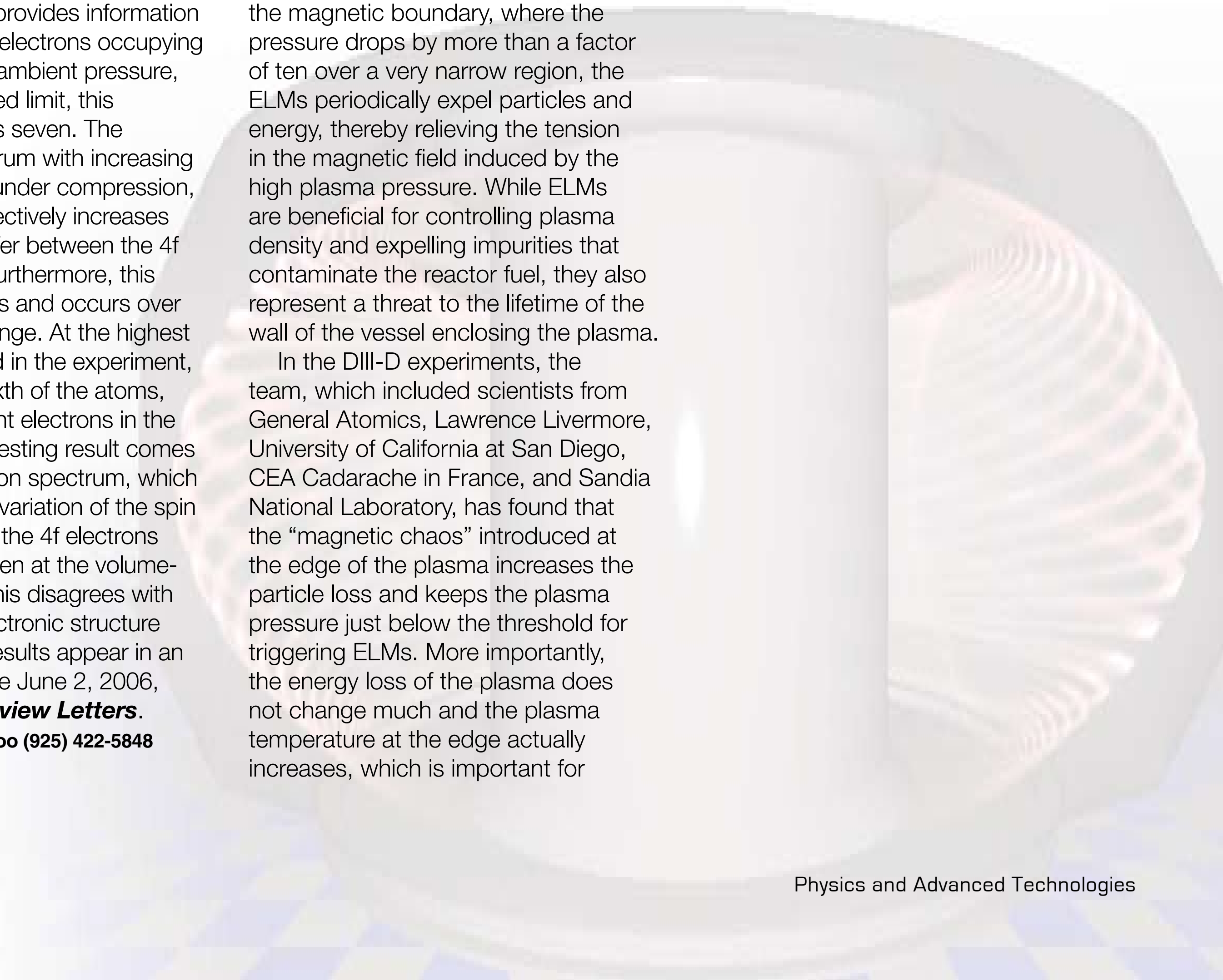
"Magnetic chaos" relieves tension at plasma boundary

A critical issue for fusion plasma research is the erosion of the first wall of the experimental device due to impulsive heating from repetitive magnetohydrodynamic instabilities known as edge localized modes (ELMs) that occur at the edge of the plasma in a tokamak. In a series of pioneering experiments done on the DIII-D tokamak at General Atomics in La Jolla, California, a team of researchers has discovered that ELMs can be reduced, in some cases eliminated, by introducing a small amount of magnetic chaos across the edge using simple magnetic perturbation coils.

As the performance of tokamak devices is pushed toward the higher temperatures and densities that are needed in future fusion reactors, the edge plasma pressure builds up to an extraordinarily large value. At the magnetic boundary, where the pressure drops by more than a factor of ten over a very narrow region, the ELMs periodically expel particles and energy, thereby relieving the tension in the magnetic field induced by the high plasma pressure. While ELMs are beneficial for controlling plasma density and expelling impurities that contaminate the reactor fuel, they also represent a threat to the lifetime of the wall of the vessel enclosing the plasma.

In the DIII-D experiments, the team, which included scientists from General Atomics, Lawrence Livermore, University of California at San Diego, CEA Cadarache in France, and Sandia National Laboratory, has found that the "magnetic chaos" introduced at the edge of the plasma increases the particle loss and keeps the plasma pressure just below the threshold for triggering ELMs. More importantly, the energy loss of the plasma does not change much and the plasma temperature at the edge actually increases, which is important for



improving the performance in fusion reactors. In addition, the increased particle loss improves the control of the plasma density and helps flush out impurities originating from the vacuum vessel walls. These results appeared in an article that was featured on the cover of the June 2006 issue of ***Nature Physics***.

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Shedding light on warm dense gold

Livermore researchers measured for the first time the dielectric function of gold heated by a femtosecond laser pulse to a nonequilibrium state with an energy density greater than 1 megajoule per kilogram. At these conditions, gold becomes warm dense matter, which refers to states of matter at the boundary between condensed matter and dense plasmas. Nonequilibrium states, which are produced as transient states in short-duration experiments, play a central role in phase transitions and relaxation processes. The dielectric function, a key parameter characterizing warm dense matter, is central to understanding electron transport and the optical properties.

The experiments, performed at Livermore's Jupiter laser facility, used two synchronized pulses from the Ti:sapphire Europa laser. A 150-femtosecond pulse (with a 400-nanometer wavelength) heated the gold sample, a freestanding foil 25–33 nanometers thick, mounted over a 600-micrometer-diameter aperture. Another pulse (180 femtoseconds long) illuminated a CaF_2 crystal generating the broadband light used to probe the optical properties of the warm gold sample. Calibrated diagnostics measured the intensities of the incident, reflected, and transmitted probe light. The range of ballistic electrons generated by the heating pulse is about 110 nanometers, which far exceeds the thickness of the target. Combined with the 150-femtosecond-pulse duration, this resulted in uniform heating of the gold foil at constant volume and solid density.

The experimental results, which were published in the June 30, 2006, issue of ***Physical Review Letters***, provide new information about the changes induced by ultra-fast laser excitation in the electronic states of solid gold and their dependence on the excitation energy density. The unexpected appearance of interband (d-to-p) transitions in the dielectric function suggests that the nonequilibrium state of gold reached in the experiment is characteristic of a superheated solid, in which the long range order of the atoms is preserved while the excitation energy is concentrated in the electrons. The processes that drive the temporal evolution of the d and p electronic states consist of photo-excitation of d electrons, electron-hole recombination, and electron–electron thermalization. The researchers also observed an enhancement of the d-to-p transitions in the dielectric function with increasing excitation energy density. This was another unexpected result, since previous work on the optical properties of equilibrium states of aluminum showed no such enhancement as the solid was heated to the melting point. The enhancement observed in the Livermore experiments is attributed to the nonequilibrium distribution of electronic states resulting from the ultra-fast excitation of the solid to high-energy densities.

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Academic researchers collaborate on Titan laser experiments

Livermore's Institute of Laser Science and Applications (ILSA) hosted a group of academic researchers who participated in a four-week-long experimental campaign at the Titan laser in August 2006. Titan is the only laser in the world that combines a high-power (petawatt), short-pulse (picosecond) beam with a high-energy (kilojoule), long-pulse (nanosecond) beam in the same target chamber. This unique capability, which was commissioned for experiments in July, is being used to explore a range of high-energy-density phenomena, including acceleration of charged particles, hydrodynamics, and radiation emission and absorption in dense plasmas.

The visiting scientists were researchers from the University of California at Davis and at San Diego, Massachusetts Institute of Technology, Ohio State University, University of Maryland, the Fusion Science Center (FSC) at the University of Rochester (http://fsc.lle.rochester.edu/), Osaka University in Japan, and General Atomics in La Jolla, California. The group included three graduate students sponsored by Livermore's University Education Partnership Program, and two postdoctoral fellows and four graduate students associated with the FSC in Extreme States of Matter funded by the Department of Energy Office of Science.

As part of the Academic Use of Titan program sponsored by ILSA, the academic researchers collaborated on experiments exploring electron transport for fast ignition, a concept for achieving inertial confinement fusion. One possible target design for fast ignition is a gold cone inserted radially into the fusion-fuel capsule, with tip of the cone penetrating almost to the center of the spherical capsule. Long-pulse (nanosecond) laser beams would compress the fuel capsule to a dense plasma core. A short-pulse (picosecond) petawatt beam, focused into the gold cone, would generate energetic electrons, which, in turn, would ignite the fuel's plasma core. Experiments at Titan can test the physics requirements for the cone target on a small scale and provide data needed to scale to the much higher energy densities that will become available at the National Ignition Facility.

In one experiment, the team examined electron transport in a 20-micrometer-diameter copper wire coated with titanium. The electrons in the wire were heated by a 100-joule, 1-picosecond laser pulse focused on a 10-micrometer spot at the end of the wire. The researchers measured the spatial distribution of the *K*-alpha x-ray emission produced by the hot electrons from both copper and titanium. The x-ray images showed the electrons' depth of penetration along the length of the wire in good agreement with simulations. Results from the Academic Use of Titan experiments appeared in an article featured on the cover of the January/February 2007 issue of ***Science & Technology Review*** (http://www.llnl.gov/str/JanFeb07/JanFeb07.html).

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Measuring the electron density in particle beams

A team of researchers from Lawrence Livermore and Lawrence Berkeley National Laboratory (LBNL) reported the first absolute measurement of the density of electrons in a positively charged particle beam. Such measurements, in combination with theory and simulations, are important for elucidating the effects of electron clouds in ion accelerators and storage rings. Stray ions and photons hitting the walls of the beam tube desorb gas and electrons. Under some conditions, the electrons multiply through ionization of the desorbed gas. The accumulated electron cloud has a deleterious effect on the beam quality and can drive instabilities degrading the performance of the accelerator.

The experiments were performed in the magnetic transport section of the High Current Experiment (HCX) at LBNL. HCX produces a pulsed beam of singly charged potassium ions. The researchers used a new method, which relies on retarding field analyzers (RFA), to measure the time-dependent electron cloud accumulation during the beam pulse. The RFA diagnostic measures the energies of the cold ions expelled by the space-charge potential of the beam in a direction transverse to the beam. These cold ions are produced from the background gas by the beam through the processes of ionization and charge exchange. As electrons accumulate during the beam pulse, the beam potential decreases and so does the energy of the expelled ions. The researchers extracted the electron density as a function of time from the measurement of the beam potential's decay, accounting for the transverse distribution of electrons and ions. To obtain the absolute electron density, the researchers supplemented the dynamic density with the static background density obtained from separate measurements.

To complement the experiments, the researchers performed self-consistent, three-dimensional simulations of the magnetic transport section of HCX using the Livermore-developed WARP code. The simulations predicted that, when the clearing electrodes are off, the electrons ejected from the end wall of the section drift upstream through the quadrupole magnets with a velocity of 0.66 meters per microsecond, which was in good agreement with the experiment. Under these conditions, the simulations also predicted that about 80 percent of the beam is neutralized by the time it reaches the last quadrupole magnet.

The results of this research appeared in an article published in the August 4, 2006, issue of ***Physical Review Letters***.

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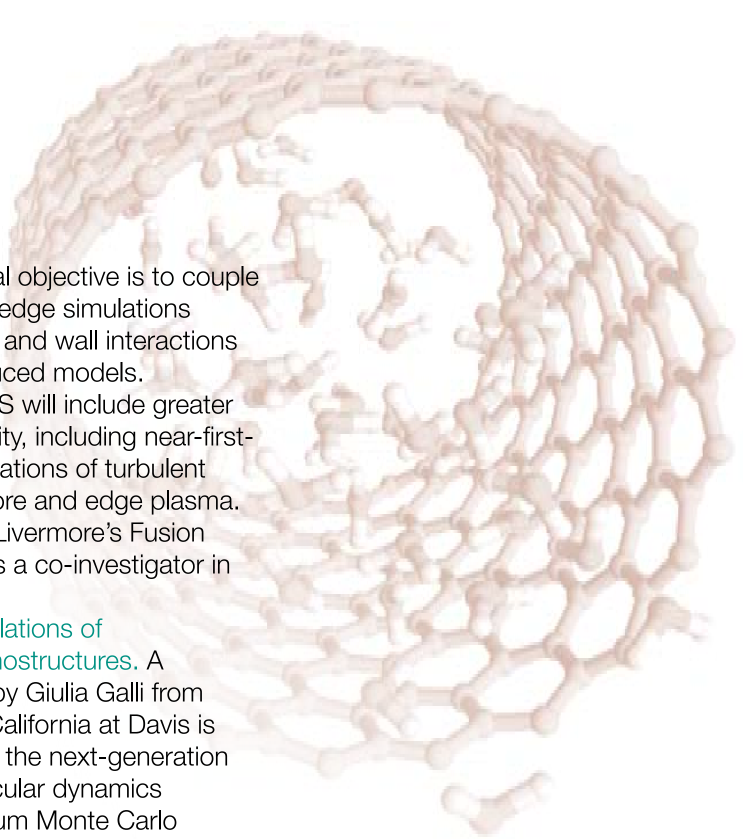
Scientific discovery through advanced computing

In September 2006, the U.S. Department of Energy's (DOE) Office of Science announced approximately $60 million in new awards annually for 30 computational science projects over the next three to five years. Sponsored by DOE's Scientific Discovery through Advanced Computing (SciDAC) program, these projects will bring together researchers at the national laboratories and U.S. universities to create the software and infrastructure needed to help scientists effectively utilize the next generation of supercomputers. The SciDAC-2 projects, selected from a total of 240 proposals, include seventeen science applications that will focus on problems ranging from quarks to nanostructures to astrophysics. Researchers from Physics and Advanced Technologies (PAT) at Livermore are co-investigators on five of these science applications.

Building a Universal Nuclear Energy Density Functional. A collaboration led by George Bertsch from the University of Washington is aiming to develop the optimal energy density functional (EDF) for use in calculating nuclear structure and reactions. EDF theory has been spectacularly successful in condensed matter physics and chemistry, and it is the only tractable theory that can be applied across the entire table of nuclides. The objectives of this high performance computing initiative in low energy nuclear physics are to find the optimal nuclear EDF using current knowledge of basic nuclear properties, validate the functional against all available nuclear structure data, and apply the validated theory to calculations of properties (e.g., reaction rates) that cannot be measured. Jutta



Escher, Petr Navratil, Erich Ormand, and Ian Thompson from N Division are contributing to this initiative.

When Good Stars Go Bang. The Computational Astrophysics Consortium, led by Stan Woosley from the University of California at Santa Cruz, will simulate the most violent explosions in the universe. The goal is to advance the understanding of stellar evolution, of nucleosynthesis, and of the mysterious dark energy that makes up the majority of the universe. Principal science topics include models for Type Ia supernovae; radiation transport, spectrum formation, and nucleosynthesis in model supernovae of all types; core collapse supernovae; and gamma-ray bursts. Models of these phenomena share a common need for nuclear reactions and radiation transport coupled to multi-dimensional fluid flow. The collaboration will also assess the observational implications of computational results for the Joint Dark Energy Mission, the Supernova/Acceleration Probe (SNAP), and the Large Synoptic Survey Telescope (LSST). Rob Hoffman, Louis Howell, and Jason Pruet from N Division are participating in this consortium.

Petaflops for Gigawatts. A team led by John Cary from Tech-X Corporation in Boulder, Colorado will develop the multi-physics, parallel framework application, FACETS. This code, running on the largest high-performance computers available, will enable full-scale reactor modeling for the U.S. fusion program and the International Thermonuclear Experimental Reactor (ITER), the next-generation fusion confinement device. FACETS will use modern computational methods, including component technology and object oriented design, to facilitate switching from one physics model to another for a specific part of the problem. The initial objective is to couple existing core and edge simulations with the transport and wall interactions described by reduced models. Ultimately, FACETS will include greater coupling complexity, including near-first-principles computations of turbulent transport in the core and edge plasma. Ron Cohen from Livermore's Fusion Energy Program is a co-investigator in this project.

Quantum Simulations of Materials and Nanostructures. A collaboration led by Giulia Galli from the University of California at Davis is aiming to develop the next-generation of quantum molecular dynamics (QMD) and quantum Monte Carlo (QMC) methods for predictive design of materials with specified properties. The computational science objectives include developing coupled QMD and QMC approaches capable of describing materials in the presence of external perturbations; enhancing the efficiency of the simulations by improving linear scaling algorithms and codes; and improving software performance and scalability by developing specialized linear algebra algorithms and codes for both next-generation high performance platforms and commodity clusters. Materials of interest include composite inorganic/organic nanomaterials for sensing applications, nanostructures in the presence of external fields for the simulation of realistic devices, fluids and solids under extreme conditions, the properties of water in biological environments, and materials relevant to energy storage and transformation. Eric Schwegler, Jean-Luc Fattebert, Tadashi Ogitsu, and Andrew Williamson from H Division are contributing to this project.

Cracking Under Stress. A collaboration led by Priya Vashishta from the University of Southern California is developing a petascale simulation framework for stress corrosion cracking. The goal is to develop modeling techniques, algorithms, analytical underpinnings, and release-quality software capable of petascale simulations with quantum-level accuracy; trillion-atom molecular dynamics simulations based on density functional theory; and coupled accelerated molecular dynamics and quasi-continuum simulations to reach macroscopic time scales relevant to stress corrosion cracking. The science applications will focus on the performance and lifetime of materials used in nuclear technology and in advanced power generation technologies such as turbines, combustors, and fuel cells, which operate in corrosive environments or extreme conditions of high pressure and temperature. A specific goal is to understand premature and catastrophic failure of materials resulting from chemically influenced corrosion. Randy Hood, John Moriarty, and Lin Yang from H Division are collaborating on this project.

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A new technique for actuating medical devices

Livermore researchers have been developing new medical micro devices based on a class of materials called shape memory polymers (SMPs). Such polymeric materials can be formed into a specific primary shape, reformed into a stable secondary shape, and then controllably induced to recover the primary shape. In thermally activated SMPs, raising the temperature of the polymer above its glass transition temperature will induce the change in shape. One of the key challenges in realizing SMP medical devices is the implementation of a safe and effective method of thermally actuating various device geometries *in vivo*. Recently, the researchers demonstrated a novel scheme for actuation, in which they apply a magnetic field to an SMP loaded with ferrromagnetic particles to induce heating.

In experiments published in the October 2006 issue of ***IEEE Transactions on Biomedical Engineering***, the researchers used nickel zinc ferrite ($Ni_{1-x}Zn_xFe_2O_4$) particles to dope the SMP. Nickel zinc ferrites have material properties that make them well suited for this application. They are ferromagnetic and able to generate heat via a hysteresis loss mechanism in an alternating magnetic field. The Curie temperature (T_C)—the temperature at which the material becomes paramagnetic—sets the maximum temperature achievable through inductive heating. In nickel zinc ferrites, T_C falls within safe medical limits and can be varied by changing the zinc substitution. This innate thermoregulation mechanism eliminates the danger of overheating and the need for monitoring the device's temperature.

The researchers used a 12.2-megahertz alternating magnetic field to induce heating of ferrite-doped SMP devices in air. Using calorimetry they measured the rate of heat generation as a function of particle size and volumetric loading of ferrite particles in the SMP. They also performed dynamic mechanical-thermal tests on neat and doped SMP samples to investigate the effects of ferrite particles on the mechanical properties of the SMP. Particle loading up to 10 percent volume content did not interfere with the shape recovery of the SMP. The experiments achieved uniform and rapid heating in complex geometries, demonstrating the feasibility of SMP actuation through inductive heating.

This approach to activating SMP-based micro devices offers several benefits for medical applications. It eliminates the power transmission lines leading to the SMP device that are required with laser or electro-resistive heating methods. Selective heating of specific device areas is possible by impregnating only the desired areas with magnetic particles. Remote actuation allows for the possibility of implantable devices that can later be actuated by an externally applied magnetic field. This opens the way for developing entirely new class of SMP devices.

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Rapid detection of airborne *Mycobacterium tuberculosis* particles

Livermore researchers are continuing to develop the bioaerosol mass spectrometer (BAMS) for the rapid detection of airborne particles containing pathogens or other biological materials. Recently, the team has demonstrated that BAMS is capable of detecting individual, airborne, micrometer-sized *Mycobacterium tuberculosis* H37Ra particles, comprising a single cell or a small number of clumped cells. This is the first time a potentially unique biomarker was measured in *M. tuberculosis* H37Ra on a single-cell level.

BAMS operates by drawing air through a nozzle and removing nearly all the particles that are too small to be of biological interest. A pulsed laser beam desorbs macromolecules from the remaining particles — each 0.5 to 10 micrometers in diameter — and then ionizes them. Time-of-flight mass spectrometry of the ionized fragments produces spectral signatures that are characteristic of the particles, which can be used to identify them. The researchers found that the mass spectral signatures produced by BAMS for aerosolized *M. tuberculosis* H37Ra particles were distinct from those for *M. smegmatis*, *Bacillus atrophaeus*, and *B. cereus* particles, using a specific biomarker. In a background-free environment, BAMS was able to sample and detect *M. tuberculosis* H37Ra at airborne concentrations greater than one particle per liter of air in 20 minutes, and concentrations greater 40 CFU per liter of air in 1 minute. These results provide the scientific foundation for the development of a rapid, stand-alone instrument capable of directly detecting *M. tuberculosis* bioaerosols generated by an infectious patient.

Tuberculosis, the disease caused by *M. tuberculosis*, is a worldwide epidemic. Over 8 million cases were reported and nearly 2 million people died of tuberculosis in 2000. Airborne *M. tuberculosis* particles ranging in size from 1 to 5 micrometer's are transmitted from the respiratory effluent of infected individuals and are prevalent in areas such as hospitals, prisons, homeless shelters, drug treatment centers, and other institutional settings. Real-time detection of airborne *M. tuberculosis* particles could help identify infected individuals and improve response and management to mitigate the spread of the disease.

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Very fast imaging with an x-ray laser

A team led by Livermore scientists demonstrated for the first time that, using an ultra-short and extremely bright coherent x-ray pulse, it is possible to record a single diffraction pattern from a large macromolecule, a virus, or a cell before the sample explodes and turns into a plasma. In addition to Livermore, the collaboration included researchers from Uppsala University in Sweden, University of California at Davis, Stanford Synchrotron Radiation Laboratory, Deutsches Elektronen-Synchrotron (DESY) in Hamburg, and Berlin Technical University in Germany. The experiments were conducted at the FLASH soft-x-ray free-electron laser (FEL) at DESY.

The scientists used an intense, 25-femtosecond-long pulse containing

10^{12} photons with a wavelength of 32 nanometers to produce a coherent diffraction pattern from a nanostructured, non-periodic object, before it vaporized at 60,000 kelvins. The sample used in the experiments was a 20-nanometer-thick membrane of silicon nitride, 20 by 20 micrometers in size. The membrane, which was partially transparent to the x-rays, had a non-periodic, micrometer-sized pattern cut into it (to full depth) with a focused ion beam. A Livermore-developed x-ray camera collected the photons diffracted from the object. The camera's novel design assured single-photon detection sensitivity by filtering out scattered x-rays and plasma radiation.

The reconstructed image of the object, obtained directly from the coherent diffraction pattern by a previously developed phase retrieval and inversion algorithm, shows no measurable damage and has diffraction-limited resolution. The experimental technique avoids the effects of the intense x-ray-induced sample damage on the recorded image by collecting diffraction data faster than the energy absorption and transport processes heat the sample. This is made possible by the brightness and ultra-short pulse duration of the FEL. These results appeared in an article that was featured on the cover of the December 2006 edition of ***Nature Physics***.

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Reconciling Big Bang and stellar nucleosynthesis

Livermore astrophysicists have resolved a long-standing puzzle about the cosmic abundance of the helium isotope ^{3}He. By modeling a red giant star with a fully three-dimensional (3D) hydrodynamic code and a complete nuclear reaction network, the scientists found unexpectedly strong and rapid mixing in the supposedly stable zone between the hydrogen-burning shell and the convective envelope of the star. This mixing moves material rich in ^{3}He to a region deeper in the star, where the ^{3}He is consumed through nuclear reaction.

For years, scientists have theorized that low-mass stars (about one to two times the size of the Sun) produce great amounts of ^{3}He, which is stored in the convective envelope. When low-mass stars exhaust the hydrogen in their cores to become red giants, most of their matter is ejected, substantially enriching the universe in this light isotope of helium. This process is so efficient that, up to now, it has been difficult to reconcile the observed low cosmic abundance of ^{3}He with the predictions of either stellar or Big Bang nucleosynthesis. But the results from the 3D simulations, published in the December 8, 2006, issue of ***Science***, identify a mechanism for the destruction of ^{3}He before it is ejected into the interstellar medium.

The Livermore researchers found that ^{3}He burning in a region just outside of the helium core, previously thought to be stable, creates hydrodynamic conditions that drive a turbulent mixing mechanism. Bubbles of material, slightly enriched in hydrogen and substantially depleted in ^{3}He, float to the surface of the star and are replaced by ^{3}He-rich material for additional burning. The mixing and removal of ^{3}He from the star's envelope is so deep and rapid that the mass of the ^{3}He destroyed is about 16 times larger than the mass through which the hydrogen-burning shell propagates.

These calculations, which were performed running the Livermore-developed Djehuty code on some of the world's fastest computers, clearly demonstrate the virtue of modeling stars in 3D, where the hydrodynamic motion evolved naturally and to a magnitude that was unexpected.

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People in the News

Valuing scientific excellence, leadership, and visibility

The scientific and technological accomplishments of the staff in the Physics and Advanced Technologies Directorate are recognized outside the Laboratory through prizes, awards, and front-page publicity. Highlights in 2006 include:

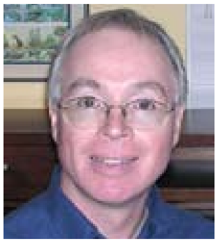
Max Tabak, the High Energy Density Physics Target Theory leader in the Fusion Energy Program, and **Scott Wilks**, a physicist in AP Division, received the 2006 **Award for Excellence in Plasma Physics Research** of the **American Physical Society**, along with two physicists from Japan and one from Great Britain. The recipients were cited "for developing the fast ignition inertial fusion concept and for demonstrating key aspects of it in a series of experiments that have catalyzed the worldwide effort on the concept." Tabak, a physicist in the Defense and Nuclear Technologies Directorate, is best known as the lead inventor of fast ignition, a technique that uses ultra-powerful, short pulse lasers to directly ignite precompressed fusion fuel. Tabak and Wilks, along with other researchers at Livermore and elsewhere, are exploring different target designs that will improve the efficiency of the entire fast ignition process, and thereby significantly reduce the energy requirements in laser-driven inertial confinement fusion.

Physicist **Karl van Bibber** was named **Fellow of the American Association for the Advancement of Science** (AAAS). He was recognized in the physics category for distinguished contributions to the field of astrophysics and particle accelerator physics, particularly for his efforts in the search for dark matter axions. Van Bibber is co-leader of Livermore's Axion Dark Matter Experiment, in which scientists are utilizing a microwave cavity in an intense magnetic field to detect the axion, an elusive particle that, if discovered, will help determine how much of dark matter is made up of these particle and how our galaxy came together. Since 2002, van Bibber has been the deputy director of the Laboratory Science and Technology Office for the Laboratory Directed Research and Development (LDRD) Program. The tradition of AAAS Fellows began in 1874. In 2006, 449 members of AAAS were honored as fellows in recognition of their scientifically or socially distinguished efforts to advance science or its applications.

Prior to joining the Laboratory in 1985, van Bibber was assistant professor of physics at Stanford University. In 2006, Stanford established two **Karl van Bibber Postdoctoral Fellowships** in physics, which were endowed anonymously by a former student of van Bibber, who became a very successful industrialist after graduation. The first fellowship was awarded to Peter Fierlinger, a young experimentalist working on the EXO project, a search for neutrinoless double beta decay. The second fellowship to a theorist will be awarded in 2007.

Gilbert (Rip) Collins, an experimental group leader in V Division, was elected **Fellow of the American Physical Society** (APS) in 2006. He was recognized by the APS plasma physics division for "seminal contributions to the field of high-energy-density physics related to the development and application of

novel laser-compression capabilities to measuring ultra-high-pressure material properties." Collins' current research focuses on developing new experimental techniques for measuring the thermodynamic, electronic, and optical properties of materials at ultra-high pressures. The APS Fellowship recognizes those members who have made significant advances in knowledge through original research or who have made significant, innovative contributions in the application of physics to science and technology. Each year, no more than one-half of one percent of the current APS membership is elected to the status of Fellow. Currently there are 43 APS Fellows in Physics and Advanced Technologies (PAT).



Two scientists in PAT were elected **Fellows of the Optical Society of America** (OSA) in 2006. **Henry Chapman** of AP Division was recognized for his "contributions to x-ray microscopy, coherent x-ray imaging, x-ray optics and EUV lithography." Chapman's research is in x-ray physics. Most recently, he has been working on new experimental methods for diffractive imaging of macromolecules using x-ray free-electron lasers (see p. 13). **James Dunn** of V Division was cited for his "important contributions to the development of soft x-ray lasers and optical diagnostics of dense plasmas." Dunn joined the Lab in 1992 to work on x-ray lasers and has developed tabletop, plasma-based soft x-ray laser sources using the Compact Multipulse Terawatt (COMET) laser at the Jupiter facility operated by PAT. The rank of OSA Fellow recognizes those members who have served with distinction in the advancement of optics. The number of Fellows is limited to 10 percent of the total OSA membership.

Seven teams of Livermore researchers won 2006 **R&D 100 Awards**, known as the "Oscars of Invention." Each year, R&D Magazine selects the 100 most technologically significant new products and processes, ones that are likely to produce the most benefits for the world at large. Three of the awards involved contributions by scientists in the PAT Directorate:

- *Ultra-High Resolution Gamma and Neutron Spectrometer* (UltraSPec) is a sensor based on superconducting materials that can detect even the minute thermal energy deposited by a single gamma ray or neutron with high precision. With this capability, the detector can identify differences in composition that help reveal a material's origin, processing history, and likely intended use. UltraSpec can be used to detect smuggled nuclear materials, protect material stored at nuclear power plants, and to evaluate weapon stockpiles. It can distinguish between radiation from clandestine nuclear materials and legitimate sources, such as medical isotopes. PAT members of the award-winning team were **Stephan Friedrich, Owen Drury, Simon Labov**, and **Thomas Niedermayr** in AP Division.
- *Externally Dispersed Interferometer* (EDI) is a compact, inexpensive instrument that achieves the high

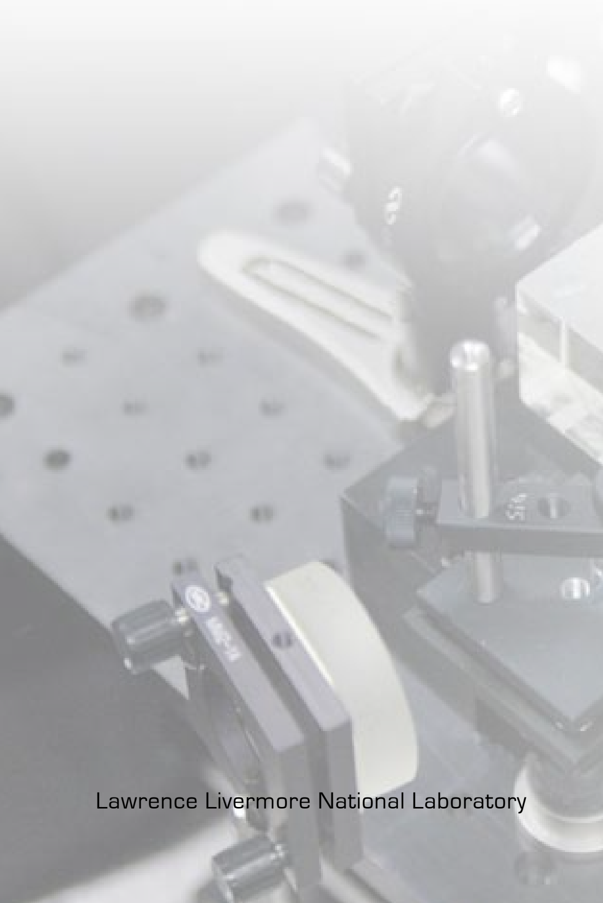
The UltraSpec development team (from left to right): Stephan Friedrich, Owen Drury, Jan Batteux, Simon Labov, and Thomas Niedermayr.

spectral resolution required for detecting extrasolar planets through the Doppler effect. The EDI accomplishes this feat by combining a commercially available low-resolution spectrograph with an interferometer that can measure small shifts in Doppler velocity through the interference fringes it produces. This new instrument will allow astronomers working at observatories that do not possess very large, multi-million-dollar spectrographs to join the search for new planets. Physicist **David Erskine** in V Division is the inventor of the EDI concept. He and astronomer Jerry Edelstein of the Space Sciences Laboratory at the University of California at Berkeley received the award for the development of the EDI prototype.

• *Sonoma Persistent Surveillance System* provides continuous, real-time video imagery of an area the size of a small city with a spatial resolution fine enough to track 8,000 moving objects in its field of view. A team of Livermore researchers, led by Deanna Pennington of the Nonproliferation, Homeland, and International Security Directorate, developed Sonoma for nonproliferation applications, such as observing the pattern of vehicle movements. **Gary Stone** from AP Division was a member of the award-winning team.

Four teams of Livermore researchers and two individuals received **DOE Weapons Awards of Excellence** from the National Nuclear Security Administration (NNSA). **Hyunchae Cynn, Neil Holmes, John Klepeis, Alison Kubota, Adam Schwartz, Robert Thoe, Wilhelm Wolfer,** and **Choong-shik Yoo** from H Division were members of the team that was recognized for a successful scientific and engineering program leading to the determination of plutonium pit lifetimes. This program integrated results from simulations, large- and small-scale experiments, manufacturing and surveillance records, and results from past nuclear tests. The team developed an experimentally validated model of plutonium aging and applied it to the determination of pit lifetimes. This improved understanding of plutonium is important to NNSA's Life Extension Program, future pit manufacturing, and the annual certification of the nation's nuclear weapons stockpile.

Physicist **Ron Soltz** from N Division was a member of the team that received a 2006 **Gordon Bell Prize – Special Achievement Award** for quantum chromodynamics (QCD) simulations conducted on Livermore's BlueGene/L — the world's fasted supercomputer. Named for one of the founding fathers of supercomputing, the prestigious Gordon Bell Prize is awarded to innovators who advance high-performance computing. The team, led by Pavlos Vranas from IBM, was recognized for the performance of lattice QCD calculations, which sustained computing speeds of over 70 teraflops and achieved linear scaling with the number of central processor units (CPUs) up to 131,072 CPU cores. Such simulations are important for cosmology, for the heavy ion experiments at Brookhaven National Laboratory, and for experiments planned at CERN in Geneva, Switzerland. Quantum chromodynamics is the theory of the strong nuclear force that binds the sub-nuclear constituents — quarks and gluons — together to form stable nuclei, which constitute more than 90 percent of the visible matter in the universe.



Plutonium Pit Lifetime Team

Scot Olivier was elected **Fellow of the International Society for Optical Engineering (SPIE)**. He was recognized for "extensive contributions to the development of adaptive optics and applications of adaptive optics to astronomy, vision science, high power lasers and remote sensing." Currently he is the Associate Division Leader for Optical Science and Technology in AP Division. SPIE Fellows are honored for significant scientific and technical contributions in the multidisciplinary fields of optics, photonics, and imaging, for their service to the general optics community.

Physicist **Jim Trebes** is one of two Livermore employees, who were members of a U.S. Army, U.S. Air Force, and Lockheed Martin team that has developed an around-the-clock surveillance technology for tracking terrorists and protecting U.S. military personnel serving in Iraq. The technology, which has been deployed in Iraq for over two years, won an award as one of the **U.S. Army's "Ten Greatest Inventions"** for 2005. These awards, announced in 2006, were given for their impact on Army capabilities, inventiveness, and potential use outside the Army. Trebes was the lead independent evaluator during systems integration and testing at Yuma Proving Grounds during the summer of 2004. Trebes' research primarily involves optical and x-ray imaging and detection. He is the Applied Physics and Biophysics (AP) division leader in PAT.

Hope Ishii, a postdoctoral researcher in PAT, is one of two Livermore scientists who have won **2006 Science Spectrum Trailblazer Awards** from Science Spectrum Magazine. The award recognizes outstanding Hispanic, Asian American, Native American, and Black professionals in the science arena whose leadership and innovative thinking on the job and in the community extend throughout and beyond their careers. Ishii works in the Institute of Geophysics and Planetary Physics. Her current research focuses on the handling and analysis of cometary dust particles collected in space, and then returned to Earth, by NASA's Stardust spacecraft (see p. 2).

A paper entitled "Bioaerosol Mass Spectrometry for Rapid Detection of Individual Airborne *Mycobacterium Tuberculosis* H37Ra Particles" received a **2006 Alice Hamilton Award** from the **National Institute for Occupational Safety and Health** (NIOSH). These annual awards recognize the scientific excellence of technical and instructional materials by NIOSH scientists and engineers in the areas of biological science, engineering and physical science, human studies, and education. The paper, which was published in the October 2005 issue of ***Applied and Environmental Microbiology***, won

Honorable Mention in the biological sciences category. **Matthias Frank** of AP Division was one of the Livermore authors. (See p. 13 for research results.)

Two teams of researchers received 2006 **LLNL Science and Technology Awards**. Established in 2000, these awards are given annually to recognize truly outstanding technical accomplishments across the Laboratory. A team, which included researchers from Physics and Advanced Technologies; Nonproliferation, Homeland, and International Security; Engineering; Chemistry, Materials, and Life Sciences; and Safety and Environmental Protection, was recognized for outstanding scientific and technical achievements in the development of an innovative new technique to detect Special Nuclear Materials in fully loaded cargo containers. PAT members of the team were **Dennis Slaughter** (principal investigator), **Jennifer Church, Jim Hall, Thomas Luu, Rick Norman**, and **Jason Pruet** from N Divison, **Steve Asztalos, Adam Bernstein**, and **Marie-Anne Descalle** from AP Division, and **David Petersen**, a graduate student sponsored by Livermore's Student Employee Graduate Research Fellowship Program. Another team, consisting of **Andrew Ng, Yuan Ping**, and **Gilbert Collins** from V Division, and **Tadashi Ogitsu** and **Eric Schwegler** from H Division, was recognized for outstanding scientific and technical achievements in making seminal contributions to the understanding of warm dense matter under extreme, non-equilibrium conditions. (See p. 8 for research results.)


Members of the warm dense matter team with Laboratory directors (from left to right): PAT Associate Director William Goldstein, Yuan Ping, Laboratory Deputy Director Cherry Murray, Andrew Ng, Eric Schwegler, Tadashi Ogitsu, Laboratory Director George Miller, and Gilbert Collins.

The **Postdoctoral Advisory Council** at the Laboratory honored three scientists in 2006 for their many contributions to the postdoctoral researchers' networking group, which has played an important role in ensuring a successful experience for postdoctoral scientists at Livermore. **Reed Patterson**, who works in H Division in PAT, was among those recognized. Patterson's research is in experimental high-pressure physics.


Members of the cargo container detection team with Laboratory directors.

The accomplishments of the staff in the Physics and Advanced Technologies (PAT) Directorate also receive special recognition through the **PAT Awards and Recognition Program**. The purpose of this Program is to provide timely recognition and reward for exceptional accomplishments by individuals or teams that contribute to the scientific, programmatic, administrative, or operational goals of the organization and the Laboratory. Two types of PAT awards are presented annually. **PATfest Awards** recognize noteworthy contributions and achievements that benefit the Directorate or the Laboratory. **Physical Data Research Program (PDRP) Awards** honor achievements and contributions toward the pursuit of excellence in stockpile stewardship at Livermore. Below are some of the individuals and teams, who received PAT awards in 2006. PAT Associate Director William Goldstein and PDRP Leader Paul Springer presented the awards at the annual PATfest.