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The Power of Partnership

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Fostering Strategic Collaborations with the University of California

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The Power of

INSTITUTIONS that conduct similar or complementary research often excel through collaboration. Indeed, much of Lawrence Livermore's research involves collaboration with other institutions, including universities, other national laboratories, government agencies, and private industry. In particular, Livermore's strategic collaborations with other University of California (UC) campuses have proven exceptionally successful in combining basic science and applied multidisciplinary research. In joint projects, the collaborating institutions benefit from sharing expertise and resources as they work toward their distinctive missions in education, research, and public service.

As Laboratory scientists and engineers identify resources needed to conduct their work, they often turn to university researchers with complementary expertise. Successful projects can expand in scope to include additional scientists and engineers both from the Laboratory and from UC, and these projects may become an important element of the research portfolios of the cognizant Livermore directorate and the university department. Additional funding may be provided to broaden or deepen a research project or perhaps develop it for transfer to the private sector for commercial release.

Occasionally, joint projects evolve into a strategic collaboration at the institutional level, attracting the attention of the Laboratory director and the UC chancellor. Government agencies or private industries may contribute funding in recognition of the potential payoff of the joint research, and a center may be established at one of the UC campuses. Livermore scientists and engineers and UC faculty are recruited to these centers to focus on a particular area and achieve goals through interdisciplinary research. Some of these researchers hold multilocation appointments, allowing them to work at Livermore and another UC campus. Such centers also attract postdoctoral researchers and graduate students pursuing careers in the centers' specialized areas of science.

Partnership

foster university collaboration is through the Laboratory's institutes, which have been established to focus university outreach efforts in fields of scientific importance to Livermore's programs and missions. Some of these joint projects may grow to the level of a strategic collaboration. Others may assist in Livermore's national security mission; provide a recruiting pipeline from universities to the Laboratory; or enhance university interactions and the vitality of Livermore's science and technology environment through seminars, workshops, and visitor programs.

Supporting Collaborative Growth

In 1995, Livermore formed its University Relations Program (URP) to facilitate the growing number of collaborations between the Laboratory's researchers and UC faculty. Working with the UC Office of the President (UCOP), URP supports a broad range of programs that improve access to Livermore, contribute to science education (see the box on p. 4), strengthen existing Laboratory programs, and develop new initiatives to facilitate the exchange of expertise among Livermore researchers and university faculty. URP is also assisting in program development for UC's newest campus, UC Merced. (See the box on p. 9.)

Program director Laura Gilliom says, "URP's role, in partnership with the Laboratory's directorates, is to broaden and deepen our levels of interaction with universities. Our strategic-level collaborations with other UC campuses have brought enormous benefits to the Laboratory and to UC. We're also working to enable strategic collaborations with other universities."

URP oversees the six Livermore institutes that have been established in specific fields. Much of the work performed by the institutes is inspired by work originally developed to fulfill the Laboratory's national security missions. And even as joint research advances are

Edward Teller's Education Vision

Livermore's University Relations Program (URP) manages educational programs for kindergarten through graduate school. The programs continue the vision established by Edward Teller, who began his 60-year teaching career in 1934. When asked what scientists could do to help the public overcome their suspicions about new technology and science, Teller responded, "It is not up to the scientists. It is up to teachers."

Teller had a vision to create an educational department at Livermore that would operate as part of the College of Engineering at the University of California (UC) at Davis. In 1963, the Department of Applied Science (DAS) was established. Professors from the university and scientists from the Laboratory have since provided classroom instruction and hands-on experience with Laboratory projects to more than 1,400 M.S. and Ph.D. students.

Livermore expanded its education efforts with the Science and Technology Education Program (STEP), which provides professional development instruction for science teachers and enrichment programs for students. STEP events are aligned with science content standards for California public schools and the California standards for teaching. Livermore scientists identify Laboratory areas that best align with the instructional content of the programs. STEP disseminates the programs through the Edward Teller Education Center, a UC-sponsored professional development center for science teachers.

The Critical Skills Internship Program facilitates undergraduate research interactions with the Laboratory by matching college students with internships within Livermore's Stockpile Stewardship Program. Most of these internships are funded directly by the National Nuclear Security Administration.

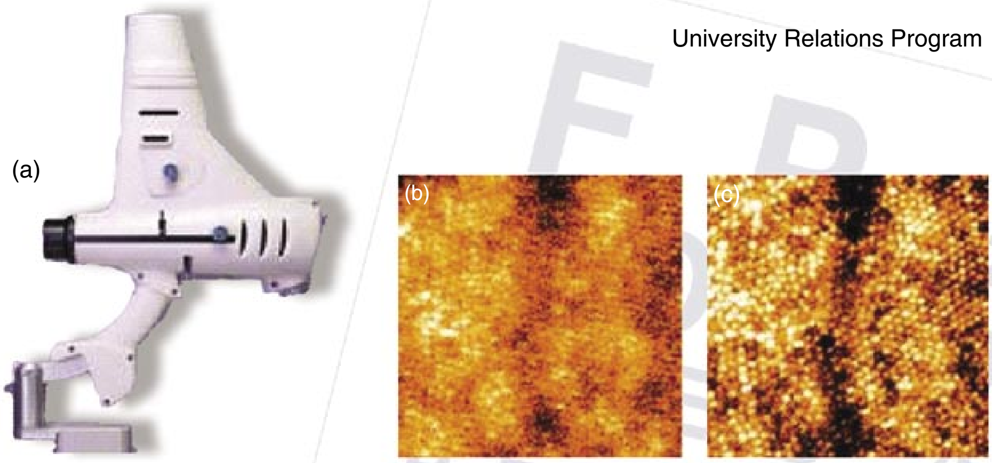
Livermore also has a few programs designed to help train and recruit college graduates. The Research Collaborations Program (RCP) links Laboratory scientists with professors, postdoctoral researchers, and students at historically black colleges and universities and minority institutions. RCP has developed 24 technical collaborations connecting the Laboratory with 15 minority universities. The Student Employee Graduate Research Fellowship (SEGRF) Program grants fellowships to Ph.D. candidates from UC. There are currently 60 SEGRF students at Livermore.

Finally, the Lawrence Livermore Postdoctoral Fellowship Program, known informally as the Lawrence Fellowship, is a tribute to Nobel laureate and Laboratory cofounder Ernest O. Lawrence. Researchers are hired by the Director's Office in cooperation with URP. The criteria for acceptance are rigorous. In the first four years of the program, only 15 of 1,849 applicants were accepted as Lawrence fellows. (See *S&TR*, November 2002, pp. 12–18.)

In a survey conducted by *Science* magazine early this year, postdoctoral researchers ranked Livermore the seventh best place for postdoctoral researchers to work, from a pool of 61 U.S. institutions. URP director Laura Gilliom says, "The postdoctoral researchers who come here know they will be able to do cutting-edge research using the world's most advanced lasers, accelerator mass spectroscopy, and nuclear magnetic resonance spectroscopy tools, and couple experimental and computational science."

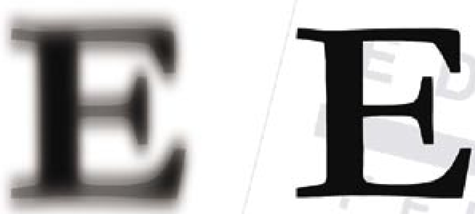
Livermore scientist Robert Tebbs (far left) and Michele Bennett (second from right, now at the National Institutes of Health) mentor faculty interns from Merced College. The interns worked with the Laboratory to update their knowledge of biotechnology for classroom instruction.

(a)



(b) (c)

(d) (e)



(a) An adaptive optics phoropter can be used to correct eyesight aberrations and will allow ophthalmologists to view certain types of individual retinal cells for the first time. The effects of adaptive optics correction are shown on single cells in the human retina and the E from a standard eye chart: (b, d) before correction and (c, e) after correction.

applied to human health, the environment, and other areas of importance, the technologies continue to support the nation's security.

Adapting Adaptive Optics

Livermore's first institute, the Institute of Geophysics and Planetary Physics (IGPP), was founded in 1982, with Livermore astrophysicist Claire Max serving as the first IGPP director. The Laboratory's branch of IGPP is linked to units on several campuses and is known as one of the leading geoscience and astrophysical research centers in the world.

IGPP's astrophysics efforts first received wide recognition through the MACHO (Massively Compact Halo Objects) project. Originally funded by Livermore's Laboratory Directed Research and Development (LDRD) Program, that project was a digital imaging study in search of cosmic dark matter. (See *E&TR*, April 1994, pp. 7–17; *S&TR*, April 1996, pp. 6–11.) Later, IGPP received LDRD funding to develop adaptive optics for ground-based telescopes. Adaptive optics systems measure the distortion of light from a star and then remove the distortion by reflecting the light off a deformable mirror that adjusts several hundred times per second to sharpen the image.

In 1995, Livermore installed a laser guide star—an artificial guide star system with adaptive optics—on the Shane Telescope at UC's Lick Observatory on Mount Hamilton in California. (See *S&TR*, July/August 1999, pp. 12–19; June 2002, pp. 12–19.) Shane was the first major astronomical telescope to use this system. In 2001, a similar system was installed on the Keck II Telescope in Hawaii, which is operated jointly by UC, the California Institute of Technology (Caltech), and the National Aeronautics and Space Administration (NASA).

In 2001, UC also opened the Center for Adaptive Optics at UC Santa Cruz. Funded by the National Science Foundation (NSF), the center's 27 partnering institutions include several UC campuses, Caltech, the University of Chicago, the University of Rochester, four laboratories, and 15 other partners. The center coordinates the efforts of researchers across the country involved in adaptive optics for astronomical and vision science. Max, who is deputy director of the center, says, "The Center for Adaptive Optics allowed Livermore to branch out from astronomy and lasers and apply adaptive optics to vision science, homeland security, and other developing applications."

In one LDRD-funded project, adaptive optics systems are being developed to correct for eye aberrations, detect the onset of eye diseases, and increase vision beyond 20/20. Livermore optical physicist Scot Olivier, who is an associate director of the center, leads a team that is partnering with the UC Davis Medical Center and the University of Rochester to apply this technology to three types of imaging systems. The instruments, which will increase resolution over existing instruments by a factor of three, are being designed to allow ophthalmologists to view certain types of individual retinal cells for the first time. In 2003, one of the instruments, the microelectromechanical systems– (MEMS-) based adaptive optics phoropter, received an R&D 100 Award. (See *S&TR*, October 2003, pp. 12–13.)

Glasses and contacts can correct for two eyesight aberrations: focus, which causes farsightedness or nearsightedness, and astigmatism. Adding adaptive optics to diagnostic instruments will allow optometrists to correct other types of aberrations. This capability will help specialists in prescribing new vision correction procedures such as custom laser refractive surgery. Ophthalmologists can use it to resolve eye cells as small as 2 to 3 micrometers, allowing them to detect diseases such as macular degeneration and glaucoma at an early stage. Physicians will also be able to monitor the effectiveness of drug treatments more closely.

Olivier believes that with adaptive optics, most people can achieve 20/10 or even 20/8 vision. "20/20 is just the average vision that can be corrected by glasses," he says. "Perfect vision would be limited only by the size of the pupil, or diffraction of light, and the ability of the retina and the brain to process the signals." The Department of Energy

(DOE) and the National Institutes of Health (NIH) are funding construction of the adaptive optics imaging systems on diagnostic instruments at the UC Davis Medical Center in Sacramento.

Detecting Faint Planets

The Center for Adaptive Optics continues to be active in astronomy applications, and a recent concept being pursued with LDRD funding is extreme adaptive optics. A team led by IGPP astrophysicist Bruce Macintosh and UC Berkeley professor James Graham is developing an extreme adaptive optics planet imager, which, for the first time, will allow astronomers to make direct images of planets orbiting stars. (See the figure below.)

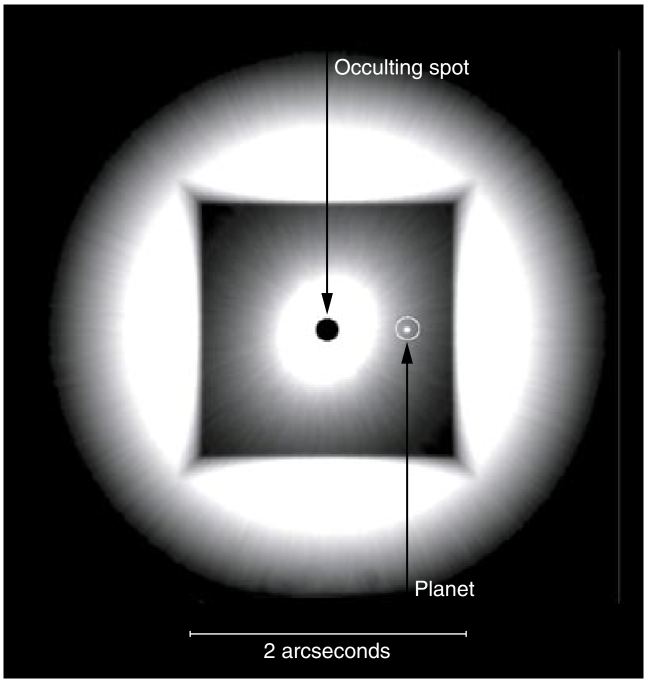
Currently, astrophysicists infer the presence of a planet by the wobble a star makes, which is caused by the tug of gravity from a planet orbiting the star. The scientists then measure the Doppler shift that occurs as the planet makes a complete orbit around the star, a process that can take a decade or more. The challenge in detecting planets and imaging them directly has been that the light from a star is a billion times brighter than the planet orbiting it, making the planet nearly impossible to see. The planets are also 10 million to 1 billion times smaller than their stars. “Existing systems were designed to detect faint objects such as galaxies, and a laser guide star was needed for that,” Macintosh says. “Our goal is to image planets next to the bright, scattered light surrounding a natural star.”

To discern the faint planets, the team is using MEMS technology to reduce the size of the actuators so that 4,096 actuators can fit on a deformable mirror. By contrast, Lick’s system has 127 actuators, and Keck II has 349. With this extreme adaptive optics system, astronomers will no longer need to wait until a planet completes an orbit. Instead, they will be able to see planets far from the star and take measurements of the planets directly.

Livermore and UC Santa Cruz will build an extreme adaptive optics system, and UC Los Angeles is building the spectrometer. NASA’s Jet Propulsion Laboratory is providing its expertise in calibrating precision optics. The system could be installed on a telescope by 2008.

Macintosh says the data from this system will be important because scientists still do not understand how a solar system forms. “We think planets are formed in the outer regions of the solar system and move inward,” he says, “but being able to study them directly will provide us with more complete answers.”

Max adds that applications of adaptive optics extend beyond astronomy and vision science. “The amazing thing is that, as a result of our work in adaptive optics to help astronomy, Livermore is also doing adaptive optics work for homeland security, surveillance, and projects for DARPA” (the Defense Advanced Research Projects Agency).



In this simulation of an extreme adaptive optics system, scattered light from a bright star spills out from behind the dark occulting spot. The adaptive optics system clarifies a dark-hole region, showing a planet (circled) four times the mass of Jupiter.

Analyzing Tiny Samples Fast

Many UC projects take advantage of Livermore’s tools to advance their work. One frequently used technology is accelerator mass spectrometry (AMS). AMS is an ultrasensitive technique that measures the concentrations of specific isotopes in samples weighing less than 1 milligram. The process is fast, producing results in days compared with other techniques that can take months.

In 1989, Livermore established its Center for Accelerator Mass Spectrometry (CAMS) to diagnose fission products from nuclear tests and study climate and geologic records. At the time, UC did not have AMS capability. Livermore physicist Jay Davis worked with UCOP for initial funding to help support CAMS. In exchange, UC researchers were allotted a percentage of time with the center’s spectrometer. The success of CAMS led to the center becoming a joint UC–Livermore facility, and it is now an established institute.

During the past decade, CAMS scientists have worked with university collaborators to develop analytic approaches that will define environmental and biochemical processes. They have

Scientists at the Center for Accelerator Mass Spectrometry have worked with hundreds of university collaborators in such research areas as materials analysis, global carbon cycles, geophysics, toxicology, and national security.

applied this expertise to research ranging from national security to global climate cycles to biomedicine. The facility has become an important resource to researchers at the UC Davis Cancer Center, which combines Livermore's science, medical technology, and engineering expertise with UC Davis's expertise in cancer research and clinical medicine.

Vitamin Activity in Humans

Early on, CAMS scientists worked with UC collaborators to create an entirely new application of AMS—following isotopically labeled compounds at trace doses through cells from human subjects. Livermore physicist John Vogel received funding from UC and LDRD for his pioneering work in nutrition research, which was instrumental in establishing CAMS for biomedical applications. In 1999, NIH designated CAMS as its only National Research Resource for biological AMS. Worldwide, CAMS is one of the few AMS facilities working on biomedical and pharmaceutical applications. (See *S&TR*, November 1997, pp. 4–11; July/August 2000, pp. 12–19.)

Vogel, who is also an adjunct professor of nutrition at UC Davis, is collaborating with Andrew Clifford, a UC Davis professor of nutrition, to determine whether the recommended dietary allowance (RDA) for vitamins is appropriate for all people. RDAs are currently set by epidemiological studies, which involve determining the cause of a disease once it has occurred. AMS allows researchers to examine vitamins' physiological activity in the body—that is, how vitamins are interacting in the body in real time.

Vogel and Clifford first studied folate, a vitamin that is important for heart health and preventing birth defects. They tracked 13 people with a median age of 24 years—the first folate study to focus on this age population. Tracking this age group has been difficult in the past. Although stable isotopes can be used to track folate, high doses must be given, preventing an accurate picture of the vitamin's activity. Radioisotopes can also be used to track a vitamin, but they give off radiation. Early tests using radioisotopes such as carbon-14 were done on elderly cancer patients, which is not the ideal group for studying dietary requirement levels to prevent birth defects.

The biggest surprise from the team's results, which will appear soon in the *American Journal of Clinical Nutrition*, was that a large amount of folate is recycled in the body and still present seven months after ingestion. The team will next study other populations to compare results.

Another study focused on vitamin A metabolism in six women in their twenties. The team's goal was to determine if a sufficient amount of the vitamin stored in the body modifies the need for beta-carotene, which converts to vitamin A. Results showed that even with sufficient vitamin A stores, adding beta-carotene allowed better absorption and less excretion of beta-carotene. The team's hypothesis is that vitamin A improved the health of the intestines, so absorption of both vitamin A and beta-carotene improved.

Vogel says, "An epidemiological study might conclude that if people have enough vitamin A, they don't need more beta-carotene. But a physiological study, which can be done using AMS, shows

Micrographs of fluorescent plastic balls, each 50 nanometers in diameter, show the improved resolution that researchers hope to achieve with living cells: (a) conventional microscopy, (b) linear structured illumination microscopy, and (c) saturated structured illumination microscopy.

that vitamin A allows beta-carotene to be processed more efficiently, and we see a cascade of events going on in the body. The added beta-carotene also improves antioxidant stores even if it is not needed to make vitamin A. What's more, AMS's sensitivity means researchers don't have to worry about radiation exposures."

Clues to Gulf War Illness

Some of Vogel's early toxicology work using AMS is also bringing more understanding to another health issue of national concern. Results from his collaborative studies with UC Davis and UC Riverside on the effects of low-dose exposures of pesticides are helping physicians better understand Gulf War Syndrome.

Two of the most common types of pesticides are organophosphates and pyrethroids. Organophosphates are also related to the nerve gases sarin and VX. Using a carbon-14 tracer, Vogel's team measured the amount of toxin present in mouse brains after low-dose exposure to one pesticide and to two different pesticides together. Tests were also performed with and without the pharmaceutical pyridostigmine bromide (PYB), which was given to U.S. soldiers to protect them from possible exposure to nerve gas.

Although PYB did have an overall protective effect, the exposure to two pesticides increased the amount of toxin in the brain by 25 to 30 percent, compared with exposure to just one pesticide. For U.S. soldiers, low-dose exposure to nerve gas and subsequent exposure to a pesticide that, for example, controls sand fleas might increase the amount of toxin reaching the brain, even with the ingestion of PYB. In 2003, Vogel presented these findings at a Department of Veterans Affairs research meeting addressing illnesses related to the 1991 Gulf War.

Manipulating Cells with Light

Advances in adaptive optics and AMS are allowing an unprecedented view of living cells. Another emerging area, called biophotonics, uses light and other forms of radiant energy to detect, image, and manipulate biological organisms at the cellular level. Applications of biophotonics include using light to image or selectively treat tumors, sequence DNA, and identify single biomolecules within cells.

The Center for Biophotonics Science and Technology (CBST), which was established at UC Davis in 2002, is the only NSF-funded center in the U.S. devoted to the study of light and radiant energy in biology and medicine. This collaboration brings together about 100 researchers, including physical scientists, life scientists, physicians, and engineers from Livermore; UC Davis, Berkeley, and San Francisco; Stanford University; and other universities.

Livermore physicist and UC Davis professor Dennis Matthews leads CBST along with UC Davis neurosurgeon Jim Boggan. Matthews says, "If we want to see how a single molecule interacts with other molecules inside a cell under different conditions, we don't have the technology to do that right now. Biophotonics, combined with other technologies we are developing, will allow us to see changes in the living cell."

UC San Francisco is leading a CBST project to develop structured illumination microscopy, an ultrahigh-resolution method to study the inner workings of cells. The method illuminates a sample with a light pattern that mixes with high-resolution sample features to produce resolvable low-resolution moiré fringes. (Moiré fringes are interference effects from overlaying two similar patterns, seen for instance when looking through two screen windows or two layers of mesh fabric.) By observing the fringes, the system can computationally reconstruct the original high-resolution information. This effect is pronounced when the illumination pattern is tight. By using tighter patterns, scientists can achieve better resolution than they can by direct illumination. This method, called saturated structured illumination, has produced some of the highest resolution images ever obtained with far-field visible light. (See the figure above.)

Tech Transfer Fills Many Needs

DOE is interested in structured illumination microscopy technology for the Genomics:GTL project, the follow-on to the Human Genome Project. Advanced microscopy, such as structured

The Birth of a University

The University of California (UC) and Lawrence Livermore have entered a new form of strategic collaboration to help establish the newest UC campus, which will be located in the San Joaquin Valley—the most populous region of the state without a UC campus. In 1995, UC chose Merced as the site for the nation's first public research university to be built in the 21st century. When fully developed, the campus will be home to 25,000 students and 6,600 faculty and staff.

The Laboratory's University Relations Program (URP) is helping UC Merced to become an important research university within the UC family, and areas of cooperation were defined in a memorandum of understanding signed on October 6, 2000.

URP's Paul Dickinson coordinates many areas of the collaboration. "Livermore is playing a critical role in recruiting science faculty for Merced," he says. "Faculty candidates visit the Laboratory to meet with potential colleagues, tour facilities, and gain an understanding of how partnering with the Laboratory can help facilitate their professorship at Merced."

As with other UC campuses, some members of the Merced faculty are expected to have multilocation appointments at Livermore. Laboratory researchers are also being encouraged to have multilocation appointments or become adjunct faculty at Merced.

So far, Merced has hired 27 faculty members, in addition to Maria Pallavicini, the dean of Natural Sciences; Jeff Wright, the dean of Engineering; Kenji Hakuta, the dean of Social Sciences, Humanities, and Arts; and Keith Alley, provost and vice chancellor of Research and dean of Graduate Studies. By August 2005, UC Merced is expected to have 60 faculty members and several adjunct members.

Because Merced is expected to become a valuable source of postdoctoral researchers and employees for the Laboratory, Livermore will offer graduate student internships. The Laboratory is also helping to plan a Central Valley institute that will help increase the number of students eligible to enter the university. Wright says, "Our collaboration with Livermore has been invaluable for building our academic programs, recruiting faculty, and providing future faculty the opportunity to see potential areas of research partnership with the Laboratory."

illumination, will allow researchers to study the function and structure of proteins in microbes. DOE is also funding a project to determine whether microbes can be used to synthesize cells for such applications as creating hydrocarbons for fuel, eliminating diseases in plants, purifying water, and scavenging for radioactive particles.

Another CBST project is using Livermore-developed optical probes with Raman spectroscopy to characterize cell function at the nanometer scale. (See *S&TR*, May 2004, pp. 4–11.) Raman scattering can identify a molecule by recording its distinct vibrational fingerprints as the molecule scatters laser light. Livermore physicist Tom Huser leads an LDRD-funded team that developed a method called surface-enhanced Raman spectroscopy, in which nanometer-size gold crystals are attached to molecules or cells. This method increases the signal by a factor of a quadrillion (10^{15}).

The gold nanoparticles, which are about 50 nanometers in diameter, serve as detectors that provide detail about the environment. The particles are covered with molecules of mercaptobenzoic acid, whose Raman spectrum changes with pH. As a cell reacts to external stimuli, its pH usually changes in response. One possible application of this technique is studying the pH of cancer cells while trying to develop better chemotherapeutics.

Matthews has also set up a program within CBST to develop optical-based medical devices in collaboration with industrial partners and UC campuses. Several technologies have already been transferred to industry for commercial development, including a device for treating ischemic stroke; micropower impulse radar for medical diagnostics; an implantable, continuous glucose monitor; and ultrashort-pulse laser microsurgery devices.

The Benefits of Collaboration

Members of the UC faculty have long cited the successful outcomes of their collaborations with Livermore researchers as an important reason to continue institution-to-institution research. Project results often establish a continuum of ideas for faculty to jump-start new research.

UC has two programs that provide grants to support emerging research activities until they become fully funded projects. The Campus–Laboratory Collaborations (CLC) Program funds three-year projects on issues that will affect the state of California. The Campus–Laboratory Exchange Program supports the exchange of people between campuses and the Laboratory. For example, Livermore geochemist Tom Guilderson leads a CLC-funded project with UC Santa Cruz researchers to define the fate of organic compounds in oceans. Understanding the global carbon cycle is an important research area because oceans serve as major reservoirs for carbon.

These programs not only support emerging technology, says Gilliom, but they also help university researchers gain experience in managing multidisciplinary programs. “Academics traditionally follow a focused career path, and gaining tenure doesn’t always require experience as project managers. The interdisciplinary research experience that our scientists and engineers bring helps universities deliver their technologies where they are needed.”

Livermore, in turn, greatly benefits from working with the great minds of academia. UC faculty members have won 32 Nobel prizes, and the current UC faculty includes 18 Nobel laureates.

Fostering Innovation

Postdoctoral researchers also provide the Laboratory many benefits. In general, students are up to date in training for their respective fields, know the latest techniques being used, and have fresh ideas on how to couple different technologies. Postdoctoral researcher Adam Love says,


Lawrence Livermore National Laboratory

"Postdocs at Livermore want to carve a unique path for themselves. We want to create novel ways to solve problems, which means we fail most of the time. But when we succeed, it's a big deal because it usually results in a breakthrough for an area of science."

Postdoctoral researchers benefit from having access to Livermore's researchers and facilities. "Virtually any instrument we want," says Love, "can be found here at the Laboratory." Love, who earned a Ph.D. in environmental engineering at UC Berkeley, specializes in contaminant transport processes in environmental systems. He received a three-year minigrant for his dissertation on reconstructing environmental levels of tritium by analyzing tree rings, and access to CAMS was key for his research.

Using AMS, Love measured carbon-14 and tritium levels throughout 150-millimeter cores taken from trees at Lawrence Berkeley National Laboratory. Until recently, Lawrence Berkeley used tritium to synthesize the tritium-labeled biological molecules used in tracing experiments. With his AMS results, Love established dates for the core section used in the tritium analysis by matching carbon-14 levels in the wood with known atmospheric levels. The AMS-measured tritium levels matched the levels reported by Lawrence Berkeley for the corresponding years over the last 30 years. Thus, he demonstrated an effective new application of AMS for retrospective environmental studies and for its use as a verification tool.

Love says that coming up with measurement-based techniques to reconstruct historical contaminant exposure levels is a fairly novel concept. Having access to CAMS was critical because AMS is the only technique that has both the sensitivity and throughput for running the numerous samples required for high resolution in many reconstruction scenarios. "In retrospective environmental studies," he says, "these capabilities are crucial, especially if we want to do a study going back many decades."

Forging Future Collaborations

Livermore's strategic collaborations to date have been with UC, but URP is also collaborating with other institutions. This year, Laboratory director Michael Anastasio signed a memorandum of understanding to establish a strategic collaboration with the Naval Postgraduate School (NPS). Livermore–NPS collaborations will focus on joint program development for the Department of Defense.

As the Laboratory increases its number of strategic collaborations with other institutions, UC and Livermore will continue to nourish the relationship they have formed from working together for more than 50 years. "Livermore has powerful, deep, and historic connections with UC," says Anastasio. "Our strategic collaborations have enhanced the quality of the Laboratory's research programs and helped us recruit the best people. These collaborations are good for the Laboratory, good for UC, and good for the nation."

—Gabriele Rennie

Key Words: accelerator mass spectrometry (AMS), adaptive optics, biophotonics, Center for Accelerator Mass Spectrometry (CAMS), Center for Adaptive Optics, Center for Biophotonics Science and Technology (CBST), Institute of Geophysics and Planetary Physics (IGPP), University of California (UC), UC Office of the President (UCOP), University Relations Program (URP).

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