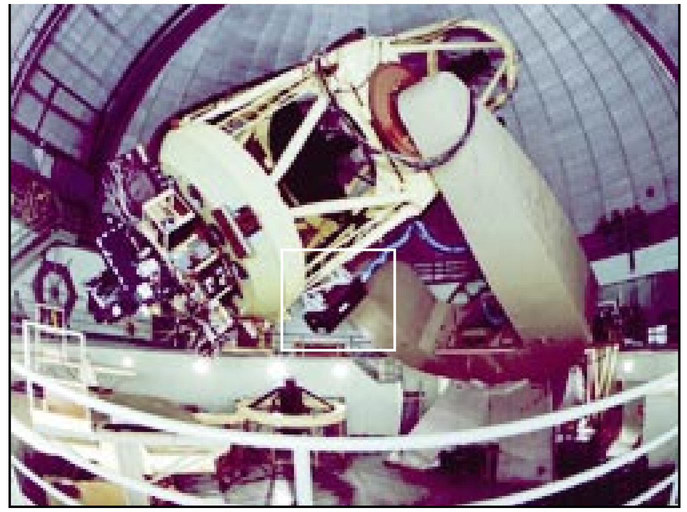
Crucial Steps Taken in Laser Guide Star System



EARTH-BOUND astronomers have long sought to diminish the effects of the atmosphere on their observations. Stars that appear as sharp pinpricks to the eye become smeared "blobs" by the time they are imaged by large ground-based telescopes.

At the University of California's Lick Observatory on Mount Hamilton near San Jose, California, Laboratory researchers and their UC colleagues are installing a system on the 3-m Shane telescope that will correct these troublesome distortions. The system includes a dye laser that will create a "guide star" in the upper atmosphere and very sensitive adaptive optics that will measure and correct for atmospheric distortions. According to Scot Olivier, project scientist for the adaptive optics subsystem, the Shane is the first major astronomical telescope with such a laser system.

Other groups have been using adaptive optics systems with natural guide stars. However, it turns out that not just any star will do. It must be bright enough, that is, generate enough light to serve as a reference. When observing at visible wavelengths, astronomers using adaptive optics require a fifth-magnitude star, one that is just bright enough to be seen unaided. For near-infrared observations, only a tenth-magnitude star is needed, which is 100 times fainter.

The problem, Olivier noted, is that even though there may be hundreds of thousands or even a million stars bright enough to be guide stars, they only cover a small fraction of the sky. "Many times, there just isn't a natural guide star in the area you want to observe," he said. "This is the kind of situation where a telescope equipped with a laser guide star comes out ahead." (See box.)

The guide star is created by a dye laser system, which is a small, closely related version of the system used by the Laboratory's Atomic Vapor Laser Isotope System (AVLIS) program. At Lick, green light from solid state lasers beneath the main floor of the telescope travels through fiber optics to a compact dye laser mounted on the side of the Shane telescope. A beam projector then directs the yellow dye laser light up through the atmosphere. At about 100 km, the laser beam hits a layer of sodium atoms created by micrometeorites, which vaporize as they enter the upper atmosphere. The yellow laser light, tuned to 0.589 micrometers, excites the sodium atoms, which then emit this yellow light in all directions, creating a glowing guide star in the upper atmosphere wherever the astronomer needs it.

Some of the light from this artificially created star travels back through the atmosphere into the Shane telescope. There, an adaptive optics system measures and corrects the guide star image for atmospheric distortions caused by air turbulence and temperature changes. Small sensors continuously monitor changes in the direction of light waves from the guide star. The sensors send this information to a computer, which in turn controls the movements of hundreds of tiny actuators attached to the back of a flexible mirror. Moving hundreds of times a second, the actuators deform the surface of the mirror to "smooth out" the image of the guide star.

When the telescope is viewing a celestial object, light from the guide star and the object travel through the same turbulence and receive the same corrections from the deformable mirror. The result is a clearer image of the object as well.

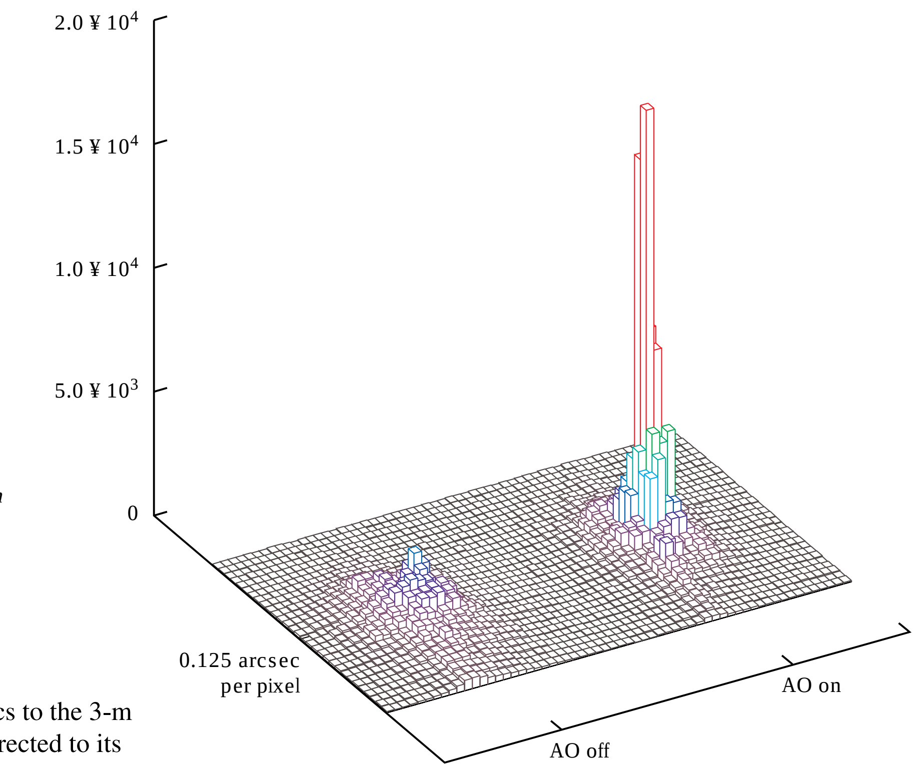
Last year, Livermore scientists, operating the adaptive optics system on Lick's 1-m telescope, observed objects at visible wavelengths. Using natural stars as guides, they corrected images to the diffraction limit of the telescope. At the end of last year, they moved the adaptive optics to the 3-m telescope and, again using natural guide stars, corrected to its diffraction limit in the near-infrared. The last step was to install the laser under the guidance of Herb Friedman, project scientist for the laser subsystem.

According to Olivier, the adaptive optics on the 3-m telescope allow astronomers to resolve objects more than 10 times smaller than before, when viewing in the near-infrared. With the addition of the laser guide star, astronomers are now able to perform these high-resolution observations over a large fraction of the sky. "This combination," notes Olivier, "makes this system arguably the world's most powerful tool for high-resolution, near-infrared astronomy."

Now that the Lick system is up and running, the Livermore team and other UC astronomers are beginning high-resolution, near-infrared observations of star-forming regions, quasars, and other interesting astronomical objects. Preliminary results from this research will be available later this fall.

In addition, based largely upon experience gained in building the Lick system, the Livermore team was recently awarded a contract to build the major components of a laser guide star adaptive optics system for the largest telescope in the world, the 10-m Keck telescope in Hawaii, owned by UC and the California Institute of Technology. This system, scheduled for completion in 1997, will become the world's most powerful tool for high-resolution near-infrared astronomy as we enter the 21st century.

(Top left) The black box, highlighted in white, holds the laser package that Livermore researchers developed for the 3-m Shane telescope at Lick Observatory. (Bottom left) Outdoors, the laser beam can be seen for miles.



(Right) The graph shows the data taken on the Shane telescope in the near infrared (2.1 micrometers) for Lambda Bootis, a nearby star in the same constellation as Arcturus. The vertical axis shows the intensity of light in one pixel, which corresponds to the telescope's diffraction limit. The smaller bump shows the data gathered with the adaptive optics (AO) system turned off. The second image, taken with the adaptive optics system turned on, shows most of the light concentrated in one pixel. If the image were taken in space, away from the atmosphere, that peak would be about four times higher than it appears here.

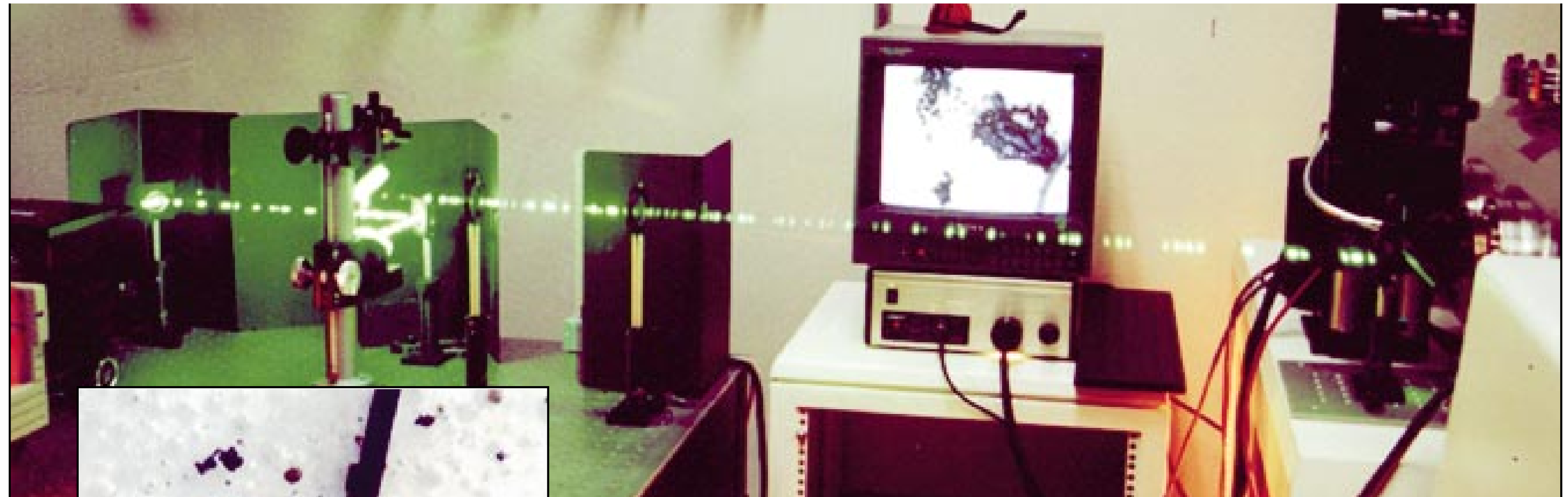
For further information contact Scot Olivier (510) 423-6483 (olivier1@llnl.gov).

Creating a Guide Star

Laser guide star efforts have generally focused on two methods of creating artificial stars. The first method uses visible or ultraviolet light to reflect off air molecules in the lower atmosphere from fluctuations (Rayleigh scattering), creating a star at an altitude of about 10 km. The other method uses yellow laser light to excite sodium atoms at about 90 km. The sodium-layer laser guide star turns out to be crucial for astronomy, because astronomers need large telescopes to see objects that are very far away and therefore very dim. These large telescopes require the laser guide star to be as high as possible so that the light from the laser star and the observed object pass through the same part of the atmosphere. With a guide star at the lower elevation, the system senses and corrects for only about half of the atmosphere affecting the light from a distant object.

The Laboratory's key contribution to this field has been the introduction of the sodium-layer laser guide star based on AVLIS dye laser technology. Claire Max, the project's principal investigator and the current Director of University Relations at LLNL, was a co-inventor of the idea of using a laser guide star in the sodium layer of the atmosphere for astonomical telescopes.

Forensic Science Center Update



The photo above shows the imaging laser-ablation mass spectrometer system in action. From the left, the 2.5-gigawatt-per-cm^2 Nd:YAG (neodymium yittrium-aluminum-garnet) laser beam is passing through steering and alignment optics in the imaging system and into the mass spectrometer. A display of the target material is visible on the videoscreen. To the left is a magnified human hair after bombardment by the laser beam.

FOR most people, "forensic science" means cops and fingerprints and DNA analysis. All of that is still true, but these days forensic science encompasses much more. Some "whodunits" are more complicated and can involve an international cast of characters. Forensic science now also is used to verify and monitor compliance with such international agreements as the Nuclear Non-Proliferation Treaty and the Chemical Weapons Convention, and to learn whether a country is developing a clandestine nuclear weapons program.

The Laboratory's Forensic Science Center was established in 1991, and in its short life has become a leader in law enforcement, national security, defense, and intelligence applications. Using sophisticated analytical equipment, experts in organic, inorganic, and biological chemistry can determine the composition and often the source of the most minute samples of material. Lasers are also being used to "interrogate," or examine, a variety of materials.

The March 1994 issue of *Energy & Technology Review* described in detail the workings of the Forensic Science Center. It reported on the Center's excellent performance in a "round-robin" series of exercises with analytical chemistry facilities from around the world. The Center has done so well in these exercises over the years that it is no longer just a participant. Its staff also prepares samples for other laboratories to analyze. Following is an update on activities at the Forensic Science Center since early 1994.

What You See Is What You Get

By combining three technologies into a single system—an ion trap mass spectrometer for analysis, a high-powered microscope for viewing, and a laser for ionizing samples—the Center has created something entirely new for forensic analysis: imaging laser-ablation mass spectroscopy. Conceived in 1994 and still being refined, this new process allows considerably more accuracy in analyzing samples than standard mass spectroscopy.

Sampling material is placed on the tip of a probe that is inserted into the source region of an ion trap mass spectrometer. With a microscope outside the vacuum chamber, the sampling material is viewed from above at 250 × magnification. A laser beam is then directed at precisely the 10- to 50-micrometer spot on the probe tip from which the sample's mass spectral data is desired. The intensity of the laser beam can be adjusted to instantaneously vaporize more or less sampling material, depending on the size of the sample. The laser ionizes the material, and the mass spectrometer sorts these fragments according to their molecular weights. Once sorted, each chemical component produces a characteristic mass spectral fragmentation pattern that is used by the operator to identify the entire sample.

There are several benefits of this method. The new imaging capability allows for a more accurate focus of the laser beam, which means more accuracy in sampling and more accuracy in analysis. By having the sampling material inside the mass spectrometer vacuum chamber before it is hit with the laser beam, sample losses are far less than when the sample is bombarded outside the ion source and then transferred to the mass spectrometer. We can also analyze smaller particles and fibers with this system than we can with a standard bench-top ion trap.

This new system has numerous applications. One possible use is to provide a chronological record of chemical exposures by analyzing hair, vegetation, and other materials. For example, ingestion of or exposure to certain chemicals, including illegal drugs, can be identified in human hair. Since human hair generally grows at about one-half inch per month, analysis of a person's hair along its length can provide a chronology of drug use over time (see photos above). Or the hair of a dog known to have been kept as a pet at a suspected drug manufacturing facility can be analyzed to determine chemicals associated with chemical spills and exposures at the drug lab. Positive identification of chemicals in the dog's hair, indicative of the lab's operations, could serve as criminal evidence in a trial.

Although this technique is still in its infancy, its potential could be enormous. As lasers become easier to use, smaller and smaller particles and fibers will be sampled and characterized in forensic investigations.

Miniaturizing the GC/MS

The Forensic Science Center is also at the forefront in developing new, portable systems capable of real-time analysis in the field. These units have numerous applications, from identifying materials to support verification of the Chemical Weapons Convention to investigating criminal activities.

All of the traveling components of LLNL's miniaturized gas chromatograph/mass spectrometer can fit into a metal travel case. Included are (on table) the GC/MS and laptop computer and (on floor) the pumping unit and generator.

Almost five years ago, the Center developed a suitcase-size gas chromatograph/mass spectrometer (GC/MS) for on-site identification of ultratrace (microgram or less) quantities of certain compounds in complex mixtures. The system weighed 68 kg (150 lb), which made it portable, but only barely. Three years later, the system's weight had been cut by more than half to 32 kg (70 lb), still a hefty load. Today, at 20 kg (44 lb), with an accompanying laptop computer, this system can realistically be considered portable. This rugged, all-metal vacuum vessel can be carried on board an airplane and put into the overhead compartment, while its accompanying generator and off-line vacuum reconditioning pumping unit travel in the baggage compartment.

Reduction in size does not mean a reduction in performance. The latest complete GC/MS unit is able to achieve the almost-perfect vacuum required for accurate analysis. It can run for 12 hours in the field, and, like a 500-lb bench-top model, can perform up to 200 operator-assisted analyses per day. While the operator sleeps, the turbomolecular pumping station refreshes the vacuum and other systems in the unit for another 12 hours of operation.

And how have they made this unit so small? When LLNL first took on the job of making a portable GC/MS system, very few off-the-shelf parts were available that, when assembled, would fit into anything the size of a suitcase. Almost all of the pieces that went into the first 68-kg unit were therefore designed and manufactured at LLNL. Meanwhile, miniaturization began to catch on in the GC/MS industry, so many of the components of the 32-kg version could be purchased from outside sources. While a few components of the latest 20-kg model had to be produced here, most have been purchased commercially, modified as necessary, and fitted together.

The unit's hydrogen supply for the portable gas chromatograph is typical of the shrinking components. The hydrogen supply in the 68-kg model weighed 14 kg. Today it weighs just 0.4 kg and still operates at 250 psi, just like its bigger bench-top brother.

The Center also has produced another unit whose parts can be replaced in the field. Parts are fitted together with O-rings, which facilitates repair, but more pumping capacity is needed to hold the desired vacuum. So there is still much work to do.

Counter-Forensic Inspection

In the summer of 1994, DOE asked the Forensic Science Center to perform a preliminary "counter-forensic" analysis to help the government investigate vulnerabilities of two gaseous-diffusion, uranium-enrichment plants that will be subject to international inspections. Although inspections of the plants are expected to be visual only, DOE wanted to know whether a hypothetical inspector with a different agenda, while walking through one of its plants, could surreptitiously collect samples of material, take them home, examine them, and replicate the enrichment process. The Center's mission was to examine the similar samples and learn critical details of the enrichment process.

In the gaseous diffusion enrichment process, uranium hexafluoride passes through a series of semipermeable barriers, the number of barriers being determined by the enrichment required. Uranium used in power reactors requires less enrichment than weapons-grade uranium, which is highly enriched.

The Center used for its analysis a variety of materials collected from different areas in the plant. With minute quantities of these materials and state-of-the-art analytical equipment, our chemists, engineers, and metallurgists were able to determine whether or not various aspects of the enrichment process are vulnerable to surreptitious collections. We expect these results to be useful in determining future inspection protocols.

For further information contact Brian Andresen (510) 422-0903 (andresen1@llnl.gov).

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Raymond P. Mariella, Jr. **Gregory A. Cooper**	Infrared-Sensitive Photocathode U.S. Patent 5,404,026 April 4, 1995	A single-crystal, multilayer device incorporating an IR absorbing layer that is compositionally different from the $Ga_xAl_{1-x}Sb$ layer, which acts as the electron emitter. Different IR absorbing layers can be used, limited only by the ability to grow quality material on a chosen substrate.
Arnold C. Lange	Base Drive Circuit U.S. Patent 5,404,052 April 4, 1995	Electronic circuitry for controlling bistable switching circuits, particularly high-power circuits for an electron-beam gun or electric motor. The switching control circuit ensures that bipolar power sources are not shorted together. A pair of solid-state output devices are connected to a level shifter through a pair of nonlinear delays.
Blake Myers	Ceramic Tile Expansion Engine Housing U.S. Patent 5,404,793 April 11, 1995	A high-temperature engine housing, including interlocking ceramic tiles that form an expandable ceramic housing; a pressurizable external metal housing that provides a support for the ceramic tiles; and means for thermally insulating the metal housing from the ceramic housing.
Stanley W. Thomas	Image Intensifier Gain Uniformity Improvements in Sealed Tubes by Selective Scrubbing U.S. Patent 5,408,087 April 18, 1995	A microchannel-plate image intensifier having a photocathode that is damaged to reduce high-gain areas. The high-gain sections are selectively scrubbed with a controlled bright light source.
Ronald E. English, Jr. **John J. Christensen**	Optical Power Splitter for Splitting High Power Light U.S. Patent 5,408,553 April 18, 1995	A prism segmenter having a plurality of prisms arranged about a central axis for forming a plurality of divided beams of light from a single beam of light without using complex optical pathways or sensitive components.
Thomas M. Tillotson **John F. Poco** **Lawrence W. Hrubesh** **Ian M. Thomas**	Method for Producing Metal Oxide Aerogels U.S. Patent 5,409,683 April 25, 1995	A two-step hydrolysis-condensation method to form metal-oxide aerogels of any density, including densities of less than $0.003 g/cm^3$ and greater than $0.27 g/cm^3$. A condensed metal intermediate is formed and can be stored for future use.
John S. Toeppen	Method and Apparatus for Holographic Wavefront Diagnostics U.S. Patent 5,410,397 April 25, 1995	A wavefront diagnostic apparatus and method for determining the parallelism of the rays of light within a beam of light by comparing projected and reference holographic images. Other geometric parameters can be measured using these diffractive optical elements.
Mark A. Rhodes	Magnetron Cathodes in Plasma Electrode Pockels Cells U.S. Patent 5,410,425 April 25, 1995	An electro-optic switch using magnetron cathodes as plasma electrodes. A low-pressure ionized gas is formed on both sides of the crystal. A magnetic field is produced by permanent magnets or electromagnets near the surface of the cathode.

Awards

The 1995 R&D Awards were given to five Laboratory groups for 1995 achievements in scientific and technological breakthroughs. Given by the Chicago-based R&D Magazine, *100 of these prestigious awards are presented each year. Following are the technologies and LLNL personnel involved.*

- Sealed Tube Electron Beam Guns for Material Processing: **Booth Myers**, **Hao-Lin Chen**, **James Davin**, and **Glenn Meyer**, and **George Wakalopulos** and **Peter Bond**, American International Technologies, Inc.

- Miniature Ion Cyclotron Resonance Mass Spectrometer: **Daniel Dietrich** and **Robert Keville**.

- All-Solid-State Laser with Diode Irradiance Conditioning: **Raymond Beach**, **Christopher Marshall**, **Mark Emanuel**, **Stephen Payne**, **William Benett**, **Barry Freitas**, **Steven Mills**, **Scott Mitchell**, **Charles Petty**, **John Lang**, and **Larry Smith**.

- High Average Power Solid-State Laser with High Pulse Energy and Low Beam Divergence: **Clifford Dany**, **Lloyd Hackel**, and **Mary Norton**.

- Aerogel Process Technology: A shared award for two different processes (1) Injection Molding Process for Rapid Production of Net-Shaped Aerogels: **Lawrence Hrubesh**, **Paul Coronado**, and **John Poco**. (2) Capacitive Deionization with Carbon Aerogel Electrodes: **Joseph Farmer**, **Richard Pekala**, **David Fix**, **Gregory Mack**, **John Poco**, **William Grant**, and **Charles Pomernacki**.

The Laboratory received a 1995 National DOE Pollution Prevention Award for achievement in recycling hazardous materials. Specifically recognized were eight employees in Plant Operations that received the National Award for Radioactive/Hazardous Waste Recycling. They are **Keith Gilbert**, **Mike Hayes**, **Rod Hollister**, **Charlie Patterson**, **Linda Souza**, and **Robert Wiebers**. The Laboratory's Hazardous Waste Management's CHemical Exchange Warehouse (CHEW) received a special mention, as did its developers **Marjorie Gonzalez** and **Mike DeMicco**.