SPECTRUM OF DISCOVERY

by Neil Calder

Subatomic scale

Theory
Theoretical models and analysis provide a frame-work for understanding experimental results.

BaBar
The *B*-factory detects the properties of *B* mesons and other subatomic particles after electrons and positrons collide.

Advanced Accelerators
"Next-next generation" technologies will dramatically increase acceleration strength in future experiments.

International Linear Collider
SLAC physicists form part of an international collaboration working toward plans for a next generation linear collider.

Life scale

SSRL
The Stanford Synchrotron Radiation Laboratory analyzes biological and material structures using high intensity x-ray light.

LCLS
The Linac Coherent Light Source is a fourth generation x-ray light source that will create movies of molecular processes.

USC
The Ultrafast Science Center will analyze biological and material dynamics on the time-scale of molecular motion.

Cosmological scale

KIPAC
The Kavli Institute for Particle Astrophysics and Cosmology explores the fundamental physics behind astronomical and cosmological phenomena.

GLAST
The Gamma-ray Large Area Space Telescope will analyze active galactic nuclei, gamma ray bursts, and the early universe from space.

LSST
The proposed Large Synoptic Survey Telescope project would provide imaging of very faint astronomical objects, and help understand the nature of dark energy.

The future of Stanford Linear Accelerator Center involves a broadening from traditional particle physics experiments to research from subatomic to cosmological scales.

Stanford Linear Accelerator Center is changing. You only need to drive through the main gate to understand, as looming in front of you is the huge steel skeleton of the new building for the Kavli Institute for Particle Astrophysics and Cosmology (KIPAC). Keep driving to the linear accelerator itself and a diversion takes you around the construction of the injector system for the Linac Coherent Light Source (LCLS), the world's first x-ray free electron laser. Noise, dust, cranes, and hardhats–SLAC is building new facilities, building for the future.

SLAC's future research programs cover a wide spectrum of discovery potential. Photon science research will examine the world of the ultra-small and ultrafast, where molecules and atoms hum, vibrate, and change states and locations in quadrillionths of a second. Particle physics and particle astrophysics research takes on the fundamental constituents and forces that define the evolution of our boundless and very dark universe. The distance spectrum SLAC will study starts at the subatomic particle scale of millionths of a billionth of a meter and stretches out to the boundaries of the universe. The time spectrum will range from the quadrillionth-of-a-second length of an LCLS pulse to the 14 billion years of the universe's existence.

New Structure

"One thing that is recurrent in world-class scientific research is change," says SLAC director Jonathan Dorfan. "Recognizing new science goals and discovery opportunities and adapting rapidly to exploit them efficiently, cost effectively and safely is the mark of a great laboratory. Thanks to the support of the Department of Energy's Office of Science and Stanford University, SLAC is ideally placed to make important breakthroughs over a wide spectrum of discovery in photon science, particle physics and particle astrophysics.

"These fields are evolving rapidly and we have reorganized the management structure to mobilize SLAC's exceptional staff to better serve its large user community. The new structure is adapted to allow them to get on with what they do best–make major discoveries."

The new organizational structure is built around four new directorates: Photon Science, Particle & Particle Astrophysics, Linac Coherent Light Source Construction, and Operations. Two of the new directorates–Photon Science and Particle & Particle Astrophysics–encompass SLAC's major research directions.

As director of the Photon Science Directorate, Keith Hodgson has responsibility for the Stanford Synchrotron Radiation Laboratory, the science and instrument program for the LCLS, and the new Ultrafast Science Center.

Persis Drell, director of the Particle & Particle Astrophysics Directorate, oversees the *B*-factory, an international collaboration studying matter and antimatter, the Kavli Institute for Particle Astrophysics and Cosmology, the International Linear Collider effort, accelerator research, and non-accelerator particle physics programs.

John Galayda is director of the LCLS Construction Directorate. Construction of the $379 million LCLS has already started, and a significant part of the laboratory's resources and manpower are being devoted to the project. Commissioning will begin in 2008, and first science experiments are planned for 2009.

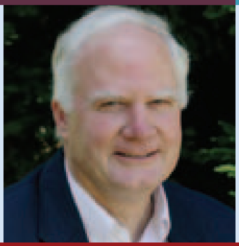
The new position of chief operating officer is filled by John Cornuelle. The fourth directorate, Operations, has broad responsibilities for operational support and R&D efforts that are central to the science directorates. Included in the Operations Directorate will be environmental safety and health, scientific computing and computing services, mechanical and electrical support departments, business services, central facilities, and maintenance.

"Our mission is to make discoveries in cutting-edge areas of research and to operate a safe laboratory that employs and trains the best and brightest," Dorfan says. "The new management structure adapts SLAC's outstanding resources to that mission and gives us renewed strength to complete it."

Light

To the world outside SLAC's gates, perhaps the least familiar branch of the laboratory's work is photon science research. The operation of the LCLS will change all that.

"Photon science is the most rapidly expanding element in the changing balance of scientific foci at SLAC," says Hodgson. "Three central and interconnected elements–synchrotron-based research using SPEAR3, SLAC's synchrotron radiation facility; x-ray free-electron laser development and research using the LCLS; and four interdisciplinary, science-based initiatives–create a coherent program that will produce outstanding photon science that cuts across many disciplines. The LCLS is a research tool with discovery potential that comes along perhaps once in a generation. By 2010, no other laboratory in the world will have an equal ability to investigate both the ultrafast and the ultra-small."

New management team for SLAC, assisting the director Jonathan Dorfan. Left to right: Keith Hodgson, SLAC Deputy Director and Director for Photon Science; Persis Drell, SLAC Deputy Director and Director of Particle & Particle Astrophysics; John Galayda, Director of LCLS Construction; and John Cornuelle, Director of Operations.
Photos: Diana Rogers, SLAC

Hodgson adds, "SLAC is deeply and naturally embedded in the fabric of Stanford University. Four joint initiatives, the Ultrafast Science Center, the X-ray Laboratory for Advanced Materials, the Structural Biology Initiative, and the Stanford Environmental Molecular Sciences Institute, couple the strengths of the laboratory and the university to exploit the tremendous science potential of SLAC's photon science programs."

Speed

"The LCLS is to be the world's first 'hard' x-ray laser," says Galayda. "It will pack enough x-rays to do a materials structure measurement into a time so short that it will freeze the motion of atoms in time; in effect, the LCLS will photograph atomic motion, much as a 'strobe' flash is used to photograph the motion of a bullet in flight."

LCLS will use the last kilometer of SLAC's linear accelerator. The upgraded linac (linear accelerator) will accelerate electrons packed into tiny bunches at nearly the speed of light. The electrons then ride a zigzagging path through an undulator magnet. Every time the electrons change direction, they release x-rays. LCLS x-rays will be emitted coherently and with identical wavelength—the essential properties of a laser. The short electron bunches translate into really short x-ray pulses, one thousandth of the duration of those from current synchrotron x-ray sources. For the first time, it will be possible to directly observe atoms as they change states of excitation; to observe molecules in the instants of time when new chemicals are formed; to snapshoot the interiors of dense plasmas or materials in extreme magnetic fields; and to observe single molecules essential to life processes, determining those structural features critical to their function. The LCLS will bring SLAC simultaneously to the discovery frontiers of atomic physics, chemistry, materials, fluids, plasmas, and molecular biology.

"It will be a completely new way of seeing," says Galayda. "A movie camera runs at 24 frames per second—LCLS will take shots billions of times per second. In that short a time, there is no blurring of the positions of atoms as a result of motion. I don't think anyone really knows what the most important science will be from LCLS. It is such a huge jump forward."

Observing

"This is an incredibly exciting time for the field of particle physics," says Drell. "There are two main experimental strategies to study the universe: observatories, both in space and underground, to study the relics of the big bang that remain with us today; and particle accelerators that create the particles that were present in the early universe, allowing us to study how they interact. These two strategies are crucially important in developing our understanding of the universe. SLAC's Particle and Particle Astrophysics programs are at the forefront in the development & operation of both."

SLAC is currently involved in space-based, ground-based, and underground observatories.

In space: SLAC's first venture into particle astrophysics, the Gamma-ray Large Area Space Telescope (GLAST), is a satellite, to be launched in 2007, which will explore how cosmic accelerators work and what they are accelerating, including the study of gamma-ray bursts and observations of jets emanating from active galactic nuclei and galactic black holes. In addition, GLAST will search for dark matter in our galaxy. Construction of GLAST's Large Area Telescope, a silicon-strip detector-based tracker and a cesium iodide calorimeter derived directly from particle physics experiments, is centered at SLAC. After the launch, SLAC will operate the Instrument Science and Operations Center for between five and ten years.

On the ground: SLAC is playing a leadership role in the Large Synoptic Space Telescope (LSST), a proposed telescope to measure the properties of dark energy and dark matter. SLAC would have specific responsibility for building the enormous CCD camera, paved with 3.5 billion high-sensitivity pixels, which will be central to the telescope's design.

Underground: Members of the SLAC and Stanford community are leading an R&D effort for the Enriched Xenon Observatory (EXO). By searching for a rare type of nuclear decay called "neutrinoless double beta decay," the research team hopes to discover whether neutrinos are their own antiparticles, and if so, measure their mass. The detector will be installed deep beneath the earth in the salt beds of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico.

KIPAC

The Kavli Institute for Particle Astrophysics and Cosmology has greatly increased SLAC's involvement in particle astrophysics. KIPAC, which was inaugurated in 2003, is an independent laboratory of Stanford University with buildings being constructed this year at SLAC and on the university campus.

"The quest to answer the most basic questions of the universe has reached a singular moment," says Roger Blandford, director of KIPAC. "We are in the dark as to what 95 percent of the universe is made of. The most efficient approach to gaining new knowledge is through the dual approach of astronomical observation and particle physics precision measurement. A new field is being created."

KIPAC, which has significant involvement in GLAST and LSST, has already drawn some of the most talented theorists, experimentalists and observers in the field to SLAC. The best and brightest of postdoctoral fellows and students are joining KIPAC in striking numbers.

"It is a bit more than half a year since I came here," says postdoctoral fellow Maruša Bradač, "but it doesn't feel that way. New exciting things happening every day make my time fly by without my noticing—new buildings, new people, fantastic science, all in one place. KIPAC is the place to be!"

Blandford adds, "Another exciting element at SLAC is that the combination of SLAC's theory group, the Institute for Theoretical Physics at Stanford and the KIPAC theory effort, which are seamlessly integrated together, gives SLAC and Stanford the world's most powerful and broadest theory effort aimed at our new but inadequate vision of the universe."

Accelerating

SLAC started as an accelerator laboratory, and the current and future programs will maintain its place as a center of excellence.

At present, SLAC's main accelerator-based program is the *B*-factory, which examines a cosmological mystery: the mechanism that created the crucial quark-antiquark asymmetry that led to the existence of the visible universe. The *B*-factory, constructed in the 1990s by a large-scale international collaboration, is well into a 10-year program of data taking. The scientific program sees a continuation of *B*-factory operation until the end of FY2008, with data analysis then extending well into the next decade.

Until 2008, the *B*-factory will go for broke, with the goal of substantially improving searches for new physics. The accelerator complex has already delivered integrated luminosities five times higher than expected in the original accelerator design. Through an ongoing program of accelerator upgrades, to be completed in 2006, the peak luminosity is expected to improve further by a factor of about 2.5. This will allow a quadrupling of the data sample logged by the detector by the end of the program.

"BaBar still has outstanding opportunities for new physics discoveries", says David MacFarlane, spokesman of the BaBar experiment, core of the *B*-factory. "For example, doubling our data sample by summer 2006 might turn the present 3 sigma hints for new physics in CP violation for penguin modes of *B* decays into a 5 sigma discovery [of conclusive statistical significance]; if realized this could herald the discovery of physics beyond the Standard Model, such as supersymmetry."

But what happens to accelerator based particle physics at SLAC after the closing of the *B*-factory? "The field has made a choice," says Drell. "Both nationally and internationally we have said the International Linear Collider is our future. We have to accept some consequences. The ILC will not be built at Stanford, but I'd much rather have the ILC somewhere than a collection of smaller machines—even one here at SLAC."

Director Dorfan says, "SLAC is committed to continuing its leadership in advocating and working on the design of the ILC machine and the detector. The laboratory has the strongest electron accelerator group in the United States, if not the world, and in collaboration with our international partners we will contribute to both the design and testing of major ILC subsystems as well as to the overall design."

The advanced accelerator research programs at SLAC are looking far into the future. They include experimental and theoretical research in laser acceleration and plasma wakefield acceleration. These techniques have the potential to replace traditional radio-frequency acceleration, which generates some tens of millions of electron volts of acceleration per meter, with systems that could generate billions of electron volts of acceleration per meter.

Integration

SLAC started as a particle physics laboratory. Since the 1970s, synchrotron radiation research has been growing in importance and, more recently, particle astrophysics has become a major force. This has been a natural evolution, growing logically from the competencies of an exceptional staff and from the most pressing science challenges. Nothing was imposed. This natural growth has created a laboratory with a unique ability to integrate and share its strengths. LCLS was only possible because of advanced accelerator studies for particle physics, and now accelerator studies for LCLS will be directly beneficial to the ILC. Data intensive computing developed for BaBar will be used for the LSST telescope.

"While the scientific drivers are changing, the core competencies needed for our future success are exactly those we possess so strongly today," says Dorfan.

Using accelerators, observatories, and instruments in space, on the ground and underground, SLAC's future is a drive for discovery over a vast spectrum of science. As Stanford University Provost John Etchemendy commented, "SLAC has a glorious past, but the future looks even brighter."