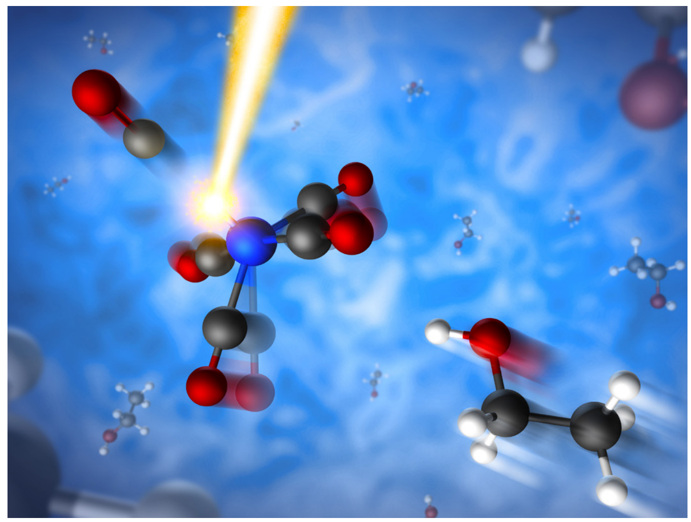
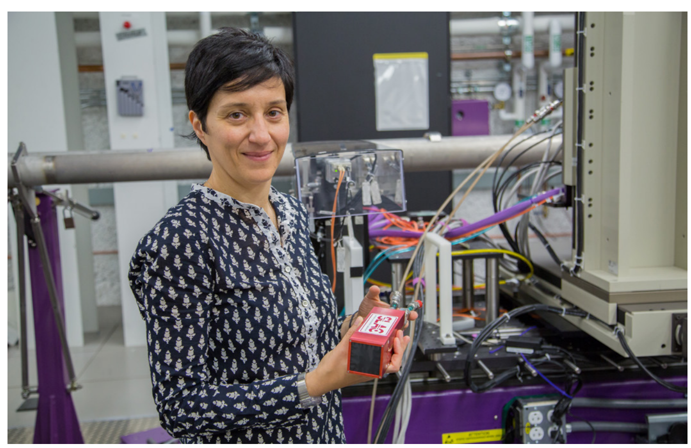
SLAC NATIONAL ACCELERATOR LABORATORY

SLAC Science
Capturing the Ultrafast

Imagine filming the world at a timescale of millionths of a billionth of a second, or femtoseconds. Researchers at SLAC do just that: They engineer and run experiments on cutting-edge scientific instruments that act like high-speed cameras, capturing a fascinating and largely unexplored world in which atoms relentlessly buzz around. Insights into these fundamental, ultrafast motions could help solve some of the mysteries of the natural world and support the development of innovative materials, energy solutions, medicines and more.



Above: This artistic rendering, based on data obtained with the LCLS X-ray laser, shows a molecule that is severed by laser light. Within hundreds of femtoseconds, a second molecule rushes in to bond with one of the fragments of the first one. (Greg Stewart/SLAC)
Below: SLAC researchers develop advanced detectors with extraordinary sensitivity and resolution for cutting-edge research in ultrafast science. (Andy Freeberg/SLAC)



A Femtosecond World

On the atomic level, our world is in constant flux. Atomic nuclei and clouds of electrons continually bounce around, driving chemical and physical processes that are crucial to our lives. These motions shape the unique properties of materials, determine how molecules form and break during chemical reactions, allow plants to harvest sunlight and turn it into useable energy, and control how our bodies behave during illness or in perfect health.

No matter what the process, the first steps often involve atomic motions that last only a few femtoseconds – just enough time for light to travel a fraction of the width of a human hair. Scientists want to understand these ultrafast phenomena because they hold the key to designing new materials with unprecedented properties, more efficient chemical processes and solar cells, and novel drugs for medical therapies.

At SLAC, researchers and engineers build and operate premier discovery machines, perform groundbreaking experiments and develop complex theories that reveal the femtosecond world in never-before-seen detail. Accelerator physicists, detector specialists, laser experts and X-ray scientists work hand in hand. SLAC and Stanford also jointly operate the Stanford PULSE Institute for ultrafast science.

Superb X-ray Vision

Scientists from around the globe come to SLAC to take advantage of the unique capabilities of the Linac Coherent Light Source (LCLS). A Department of Energy Office of Science User Facility, LCLS was the first hard X-ray free-electron laser, or XFEL. Its powerful flashes of X-ray light – each as brief as 5 femtoseconds and a billion times brighter than those available before – take atomic snapshots of materials

SLAC National Accelerator Laboratory
2575 Sand Hill Road
Menlo Park, CA 94025–7015

slac.stanford.edu
lcls.slac.stanford.edu

U.S. DEPARTMENT OF ENERGY
Office of Science

and living things at a rate of 120 per second. These images can be strung together to become unprecedented movies of the speediest chemical and physical processes. LCLS-II, a major upgrade to the current laser, will deliver 8,000 times more X-ray pulses per second. The project is already under construction and will take ultrafast X-ray science to a whole new level.

Ultrafast 'Electron Camera'

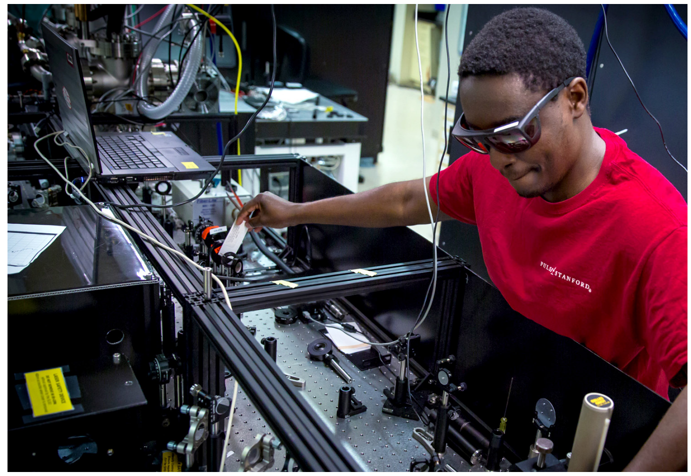
SLAC also built one of the world's fastest "electron cameras," which uses a very bright beam of high-energy electrons to look at atomic motions faster than 100 femtoseconds. The instrument, which is based on a technique known as ultrafast electron diffraction (UED), complements ultrafast studies at the LCLS X-ray laser, and scientists combine both methods for cutting-edge research in chemistry, materials science and biology. A long-term goal is to capture atomic motions as fast as 10 femtoseconds.

Powerful Laser Flashes

To map out motion on the atomic scale, state-of-the-art lasers produce femtosecond pulses of infrared, visible or ultraviolet light that are used to trigger ultrafast processes, which can then be followed over time with electrons or X-rays. In some cases the laser pulses pack enough power to create extreme states of matter, similar to those inside stars and giant planets. Researchers are also searching for new ways of manipulating and controlling the properties of materials with ultrafast lasers.

Doing Complex Math

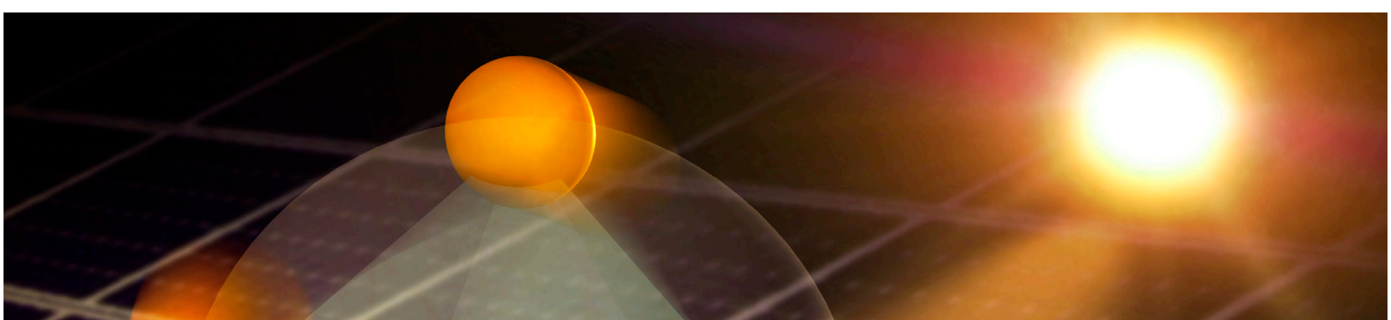
To better understand the physics behind ultrafast processes and discover how their extremely powerful sources affect the systems they study, SLAC researchers develop complex theories and run sophisticated computer simulations. This helps them analyze their data, design better experiments and ultimately derive a deeper understanding of nature's high-speed phenomena. Their demanding simulations require the development of "exascale" computers, able to perform a billion billion calculations per second.



Above: Many SLAC experiments looking at high-speed processes in nature involve powerful, state-of-the-art laser systems. (Chris Smith/SLAC)
Below: Using a technique called "ultrafast electron diffraction," SLAC scientists look at ultrafast atomic motions in solar cell materials. (Greg Stewart/SLAC)

Beyond Femtoseconds

Ultrafast science doesn't end with femtoseconds. The femtosecond motions of individual atoms are driven by electrons that move even faster. This is the realm of attoseconds, or billionths of a billionth of a second, which sets the stage for all the chemical and physical processes that follow. Working at the forefront of attosecond science, SLAC researchers and engineers use high-power lasers to extract attosecond light pulses from atoms, and they're working on techniques to turn femtosecond pulses from the LCLS X-ray laser into much shorter light flashes to capture these processes in action.



SLAC is operated by Stanford University for the U.S. Department of Energy Office of Science

INC0135972-3-2017