Capturing the Ultrafast

LCLS | Linac Coherent Light Source

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On the atomic level, our world is in constant flux. Atomic nuclei and clouds of electrons continually interact, driving chemical and physical processes that are crucial to our lives. To capture this fascinating and largely unexplored world, researchers at SLAC – in collaboration with coll eagues from around the world – design and run experiments on cutting-edge scientific instruments that act like high-speed cameras.

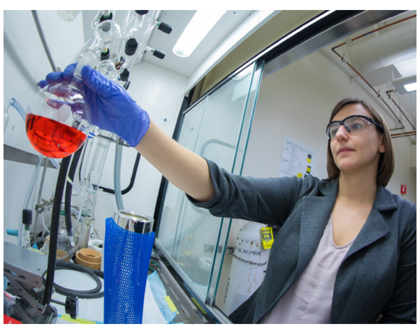
Accelerator physicists, detector specialists, laser experts and X-ray scientists work hand in hand, and partner with Stanford through a series of joint institutes that provide faculty, students and postdocs with career-defining opportunities. They help us better understand the ultrafast motions that hold the key to designing new materials with unprecedented properties, sustainable chemical and industrial processes, clean energy technologies, and novel drugs for medical therapies.

Superb X-ray vision

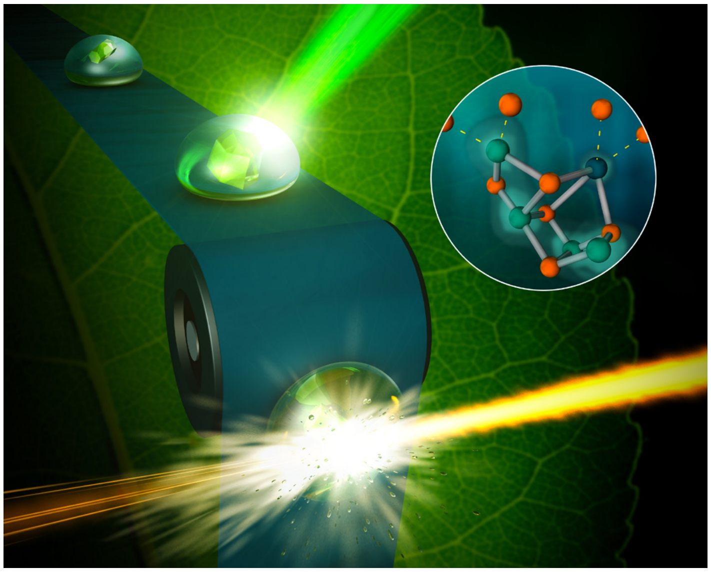
In a competitive process, researchers across the globe with the best ideas are selected to take advantage of the unique capabilities of SLAC's Linac Coherent Light Source (LCLS), the world's most powerful X-ray free-electron laser, or XFEL. As a Department of Energy Office of Science User Facility, LCLS gives them access to ultrafast flashes of X-ray light used to take atomic snapshots of materials and living things at unprecedented rates of up to 1 million pulses per second. These images are strung together to create movies of the speediest chemical and physical processes.

Ultrafast 'Electron Camera'

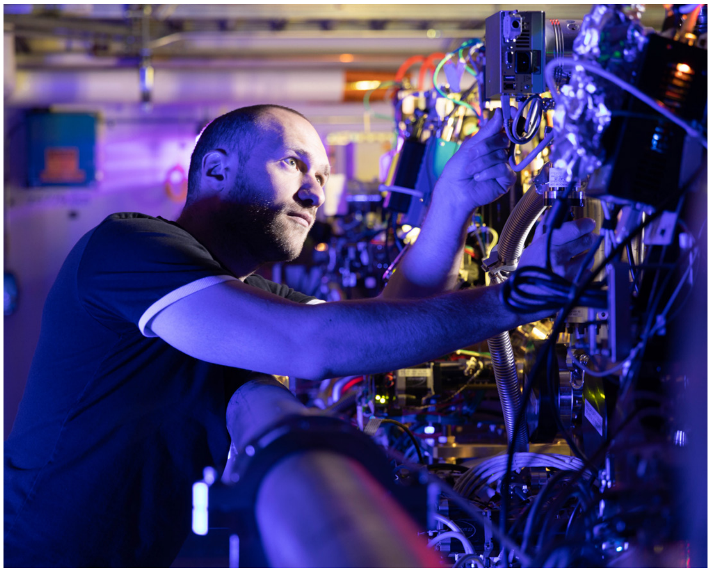
To complement the X-ray laser, SLAC developed one of the world's fastest "electron cameras," which uses a very bright beam of high-energy electrons to study atomic motions faster than 100 femtoseconds. The instrument, which is



Above: A SLAC scientist at the Stanford PULSE Institute studies chemical reactions that convert sunlight into useable energy. Scientists' work goes beyond classic beaker-and-test-tube chemistry into a new frontier of ultrafast science, where they use X-ray lasers to watch chemical reactions happening in millionths of a billionth of a second. (Chris Smith/SLAC National Accelerator Laboratory) Top: X-ray laser pulses can probe specific atoms in a molecule to study how energy flows. (Greg Stewart/SLAC National Accelerator Laboratory)



A femtosecond laser pulse from LCLS intersecting a droplet that contains crystals of photosystem II, the protein that is responsible for generating nearly all the oxygen on Earth. These studies inform the design of new clean energy technologies. (Greg Stewart/SLAC National Accelerator Laboratory)



A SLAC scientist at LCLS's X-ray pump probe instrument. (Olivier Bonin/SLAC National Accelerator Laboratory)

based on a technique known as ultrafast electron diffraction and called MeV-UED, allows scientists to combine both methods for cutting-edge research in chemistry, materials science and biology.

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 also use these lasers to control the properties of quantum materials and chemical reactions, creating new solutions for ultrafast computing and global sustainability of manufacturing and energy production.

Doing complex math

Researchers develop complex theories and run sophisticated computer simulations to help 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. These computers are also used to process the data from LCLS, which will be able to produce a terabyte of data every second – equivalent to a thousand online movies squeezed into each second.

Breaking ultrafast limits

The motions of individual atoms are driven by electrons that move even faster, shaping how energy flows across molecules. 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 ultrafast science, SLAC researchers invented a way to observe the movements of electrons with powerful X-ray laser bursts just over a hundred attoseconds long. Studies on these timescales can reveal, for example, how to control chemical reactivity in biomolecules, or the electron coherence that drives the function of quantum materials.

A SLAC-led team produced the world's shortest and most powerful X-ray laser pulses, just a couple of hundred attoseconds, or billionths of a billionth of a second long. These reveal the fastest motions of electrons that drive chemistry and quantum science. (Greg Stewart/SLAC National Accelerator Laboratory)