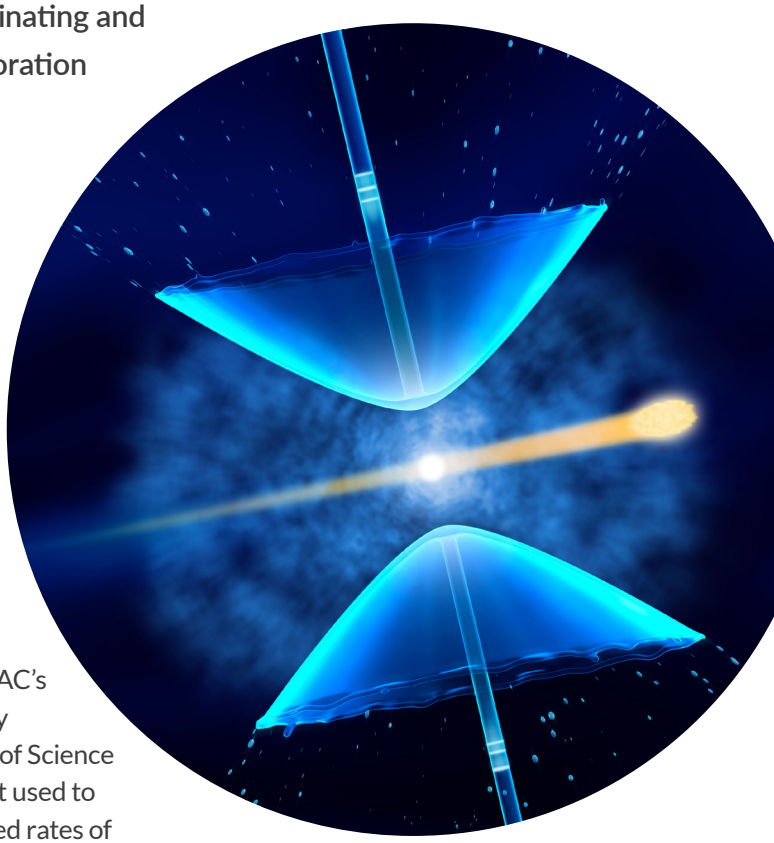
Capturing the ultrafast

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 colleagues 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 University 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 fusion energy technologies, new materials with unprecedented properties, chemical and industrial processes 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 U.S. 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.

Research at SLAC

X-ray & ultrafast science

Physics of the universe

Advanced accelerators

Science of life

New technologies

Energy sciences

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

U.S. DEPARTMENT of ENERGY

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 – a femtosecond lasts just a millionth of a billionth of a second. The instrument, which is 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

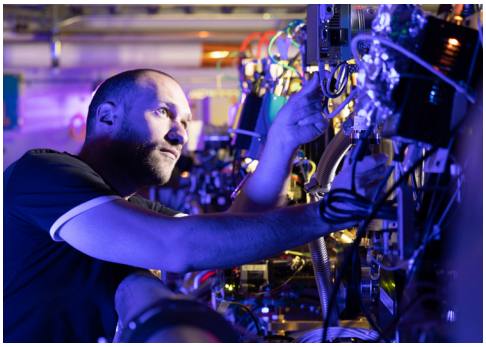
To map out motion on the atomic scale, state-of-the-art lasers produce femtosecond pulses of infrared, visible or ultraviolet light that are used to trigger ultrafast processes, which can then be followed over time with electrons or X-rays. In some cases, the laser pulses pack enough power to create extreme states of matter, similar to those inside fusion reaction chambers, stars and giant planets. Researchers also use these lasers to manipulate the properties of quantum materials and chemical reactions, creating new solutions for ultrafast computing and global sustainability of manufacturing and energy production.

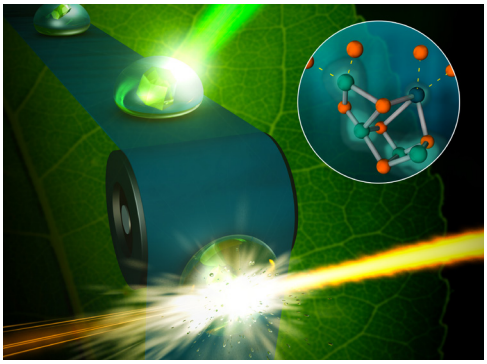
Feeding the Super Intelligence (SI) revolution

Ultrafast experiments at LCLS produce data at speeds and volumes that humans cannot process in real time. X-ray pulses arriving at up to a million times per second will generate up to 40 terabytes of data in as much time. Left unprocessed, this will add up to zettabytes (1 billion terabytes) of data each year. To put that in perspective, the world's 30 billion smart devices connected to the cloud today produce 100 zettabytes. These enormous, unique data sets will bolster our national SI science strategy and lead to future technologies with broad societal benefits.

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.





Front left image: The control room at LCLS's X-ray Pump Probe (XPP) instrument. (Angela Anderson/SLAC National Accelerator Laboratory) Right: Researchers made the first microscopic movies of liquids getting vaporized by SLAC's X-ray free-electron laser, LCLS. (All images by Greg Stewart/SLAC National Accelerator Laboratory, unless otherwise noted)

Top: A SLAC-led team produced the world's shortest and most powerful X-ray laser pulses, just a couple of hundred attoseconds, which revealed the fastest motions of electrons that drive chemistry and quantum science. Middle: A SLAC scientist at LCLS's XPP instrument. (Olivier Bonin/SLAC National Accelerator Laboratory) Bottom: 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.