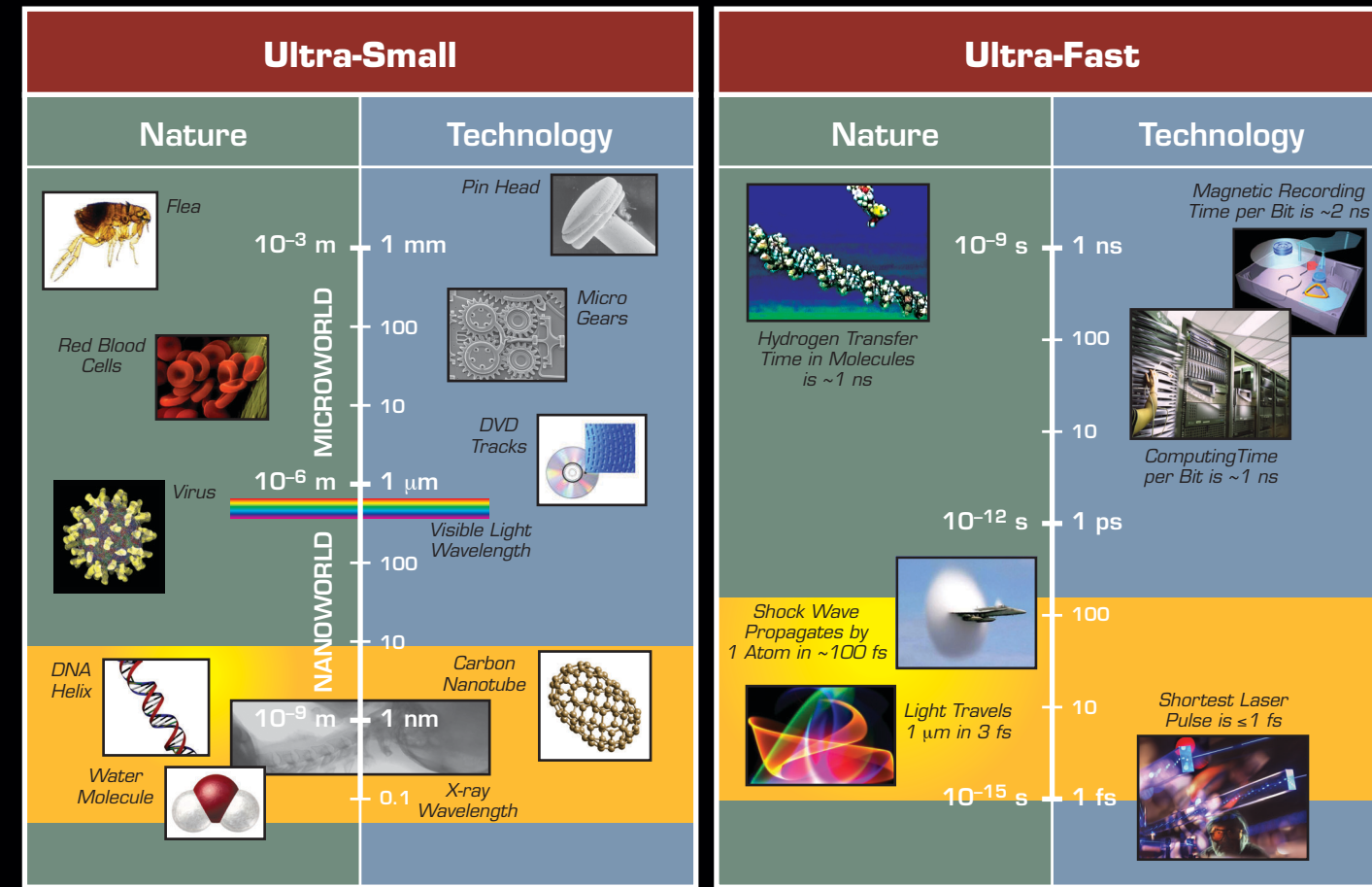


## The LCLS Scale

X-rays have Opened the Ultra-small World  
X-ray Free Electron Lasers Open the Ultra-small and Ultra-fast Worlds



LCLS Operating Range

A quadrillionth of a second, called a femtosecond, is tremendously short. Light races to the moon in less than 1.3 seconds, but only travels the thickness of a sheet of paper in 150 femtoseconds.

## Breathtaking Brilliance

The brighter the x-ray beam, the sharper and more detailed the pictures. LCLS will take a phenomenal leap in peak brightness, making almost as much progress in one jump as has been made in several steps over the previous 100 years.

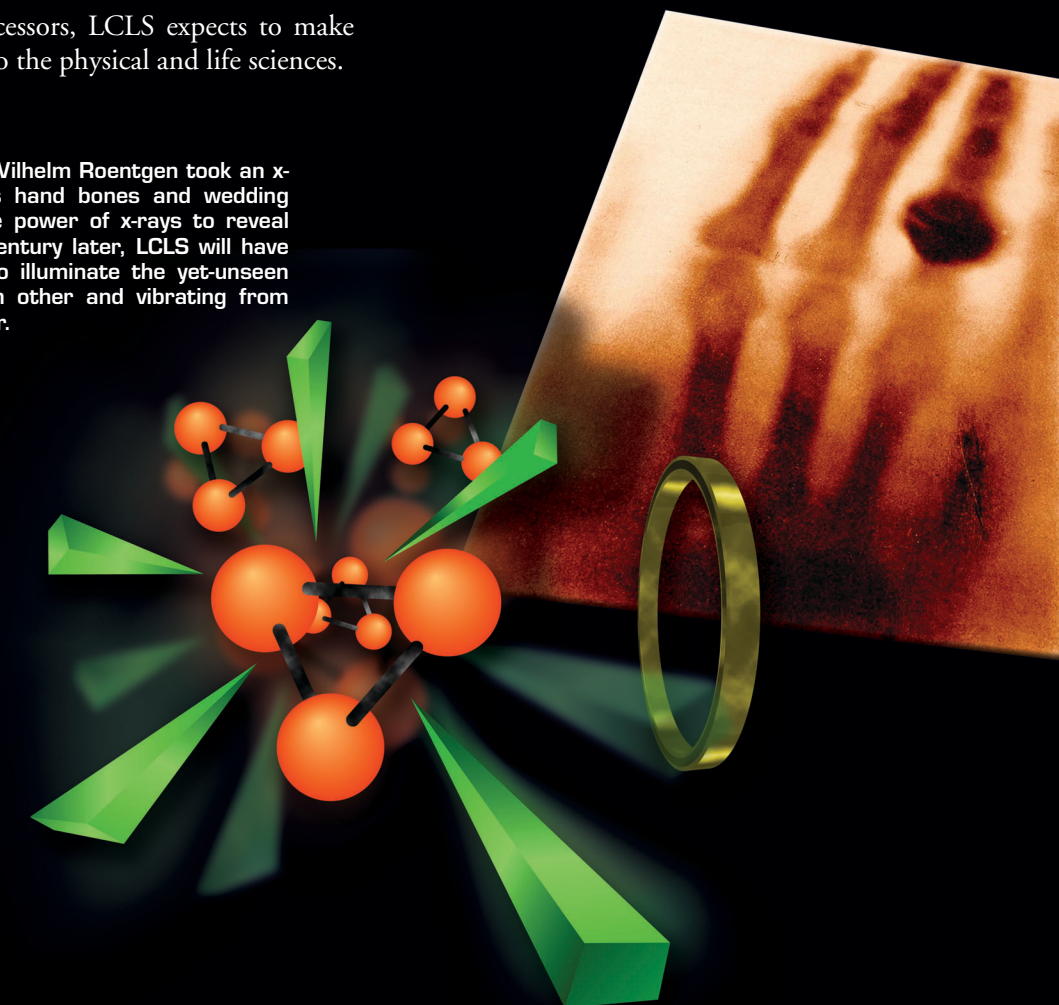
To produce x-ray beams 10 billion times brighter than today's best—the practical and prolific synchrotron light sources—LCLS will pack a trillion tightly focused x-ray photons into each swift pulse.

LCLS merges two of the most important technologies from the last century: x-rays and lasers. X-rays completely changed our ability to see through opaque bodies and objects, and became our most widely used and essential tool for understanding biological molecules like DNA's double helix, and materials such as metals, ceramics, polymers and plastics. Lasers, which produce perfectly aligned light of one wavelength, enabled applications such as barcode scanning at supermarkets, CDs and CD players, and "bloodless" surgery.

Like its synchrotron predecessors, LCLS expects to make tremendous contributions to the physical and life sciences.

When he discovered x-rays, Wilhelm Roentgen took an x-ray photograph of his wife's hand bones and wedding ring, an early preview of the power of x-rays to reveal hidden worlds in nature. A century later, LCLS will have the tremendous resolution to illuminate the yet-unseen world of atoms jostling each other and vibrating from one quantum state to another.

*Like its synchrotron predecessors, LCLS expects to make tremendous contributions to the physical and life sciences.*



## Building the Future

A collaboration of high-energy physics, laser, and synchrotron experts are working together to design and build LCLS. The Stanford Synchrotron Radiation Laboratory at Stanford Linear Accelerator Center (SLAC) is leading the collaboration and will host the machine, continuing its tradition of pioneering x-ray science since 1972. The other partners are the Advanced Photon Source at Argonne National Laboratory, Lawrence Livermore National Laboratory and the University of California, Los Angeles.

The Department of Energy's Office of Basic Energy Sciences is funding the project. The current cost is approximately \$315 million. More than \$300 million will be saved by using the final kilometer of the existing linear accelerator at SLAC. Project engineering and design continues through 2006, when construction is scheduled to begin. Project completion is expected in 2008, with the first experiments in 2009.

## LCLS Design Parameters:

- X-ray wavelength: 1.5 to 15 Ångströms (on the scale of atoms)
- Ultra-short pulse duration: 1 to 230 femtoseconds
- Peak brightness: 0.8 to 0.06  $\times 10^{33}$  Photons/(s mm<sup>2</sup> mrad<sup>2</sup> 0.1% bandwidth) (10 billion times brighter than existing x-ray sources)
- X-rays per pulse: 1.1 to 29  $\times 10^{12}$  (one trillion in a needle-thin beam)
- Electron beam energy: 4.5 to 14.3 Giga electron Volts
- Peak current: 3.4 kiloAmperes
- Fundamental saturation power at exit: 8 to 17 GigaWatts
- Meters of undulator magnets to generate x-rays from electrons: 112
- Laser properties: coherent x-rays at same wavelength

[www-ssrl.slac.stanford.edu/lcls/](http://www-ssrl.slac.stanford.edu/lcls/)

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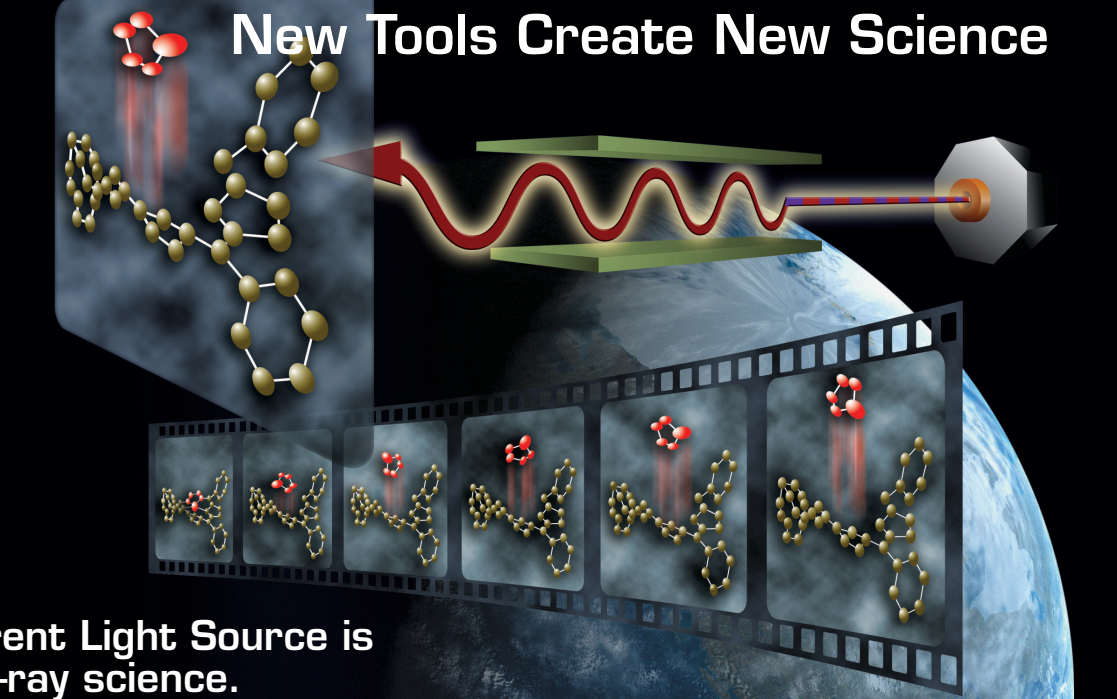


The "first light" to experiments will mark the beginning of new ultrafast science research initiatives at SLAC's Stanford Synchrotron Radiation Laboratory and Stanford. The LCLS design provides room for expanding the machine from the initial six experimental stations to 30-50 stations on additional beam lines that fan out from the initial line. The expanded 4 km complex would utilize the entire 3 km linear accelerator at SLAC.

*SLAC is leading the collaboration and will host the machine, continuing its tradition of pioneering x-ray science since 1972.*

# LCLS

## Linac Coherent Light Source



The Linac Coherent Light Source is a revolution in x-ray science.

Just as the invention of x-ray machines a century ago astonishingly revealed the inside of our bodies and began new sciences, the world's first x-ray laser will open up unprecedented opportunities.

Pioneering experiments will advance our understanding of everything from the hidden physics inside planets, to how proteins function as the engines of life, to building nanotechnology devices for the backbone of future industry and technology.

The applications are legion: medicine, electronics, biology, solid-state physics, nanotechnology, energy production, industry and fields that do not yet exist.

The LCLS is dramatically different from any x-ray source ever built thanks to its laser properties: exceptionally bright, coherent, short pulses of x-ray light. It is also different from any other laser because it will produce light at x-ray wavelengths that can probe matter on the atomic scale.

Like a lightning-quick strobe light, LCLS will take freeze-frame snapshots—essentially x-ray motion pictures—of phenomena no other machine or eye can see. This is the astonishingly small realm of molecules and atoms, where everything hums, vibrates, and changes states and locations in quadrillionths of a second.

A quadrillionth of a second, called a femtosecond, is tremendously short. Light races to the moon in less than 1.3 seconds, but only travels the thickness of a sheet of paper in 150 femtoseconds. LCLS will take clear pictures at these phenomenal speeds, from 230 femtoseconds down to 1 femtosecond.

Until now, our only glimpses into this realm have been long exposure shots that give an average image of these constantly moving objects, like a blurred picture of a hummingbird's wing beats.

With its fast, extraordinarily bright x-ray pulses, the LCLS will illuminate new territory.

## Breakthrough Science

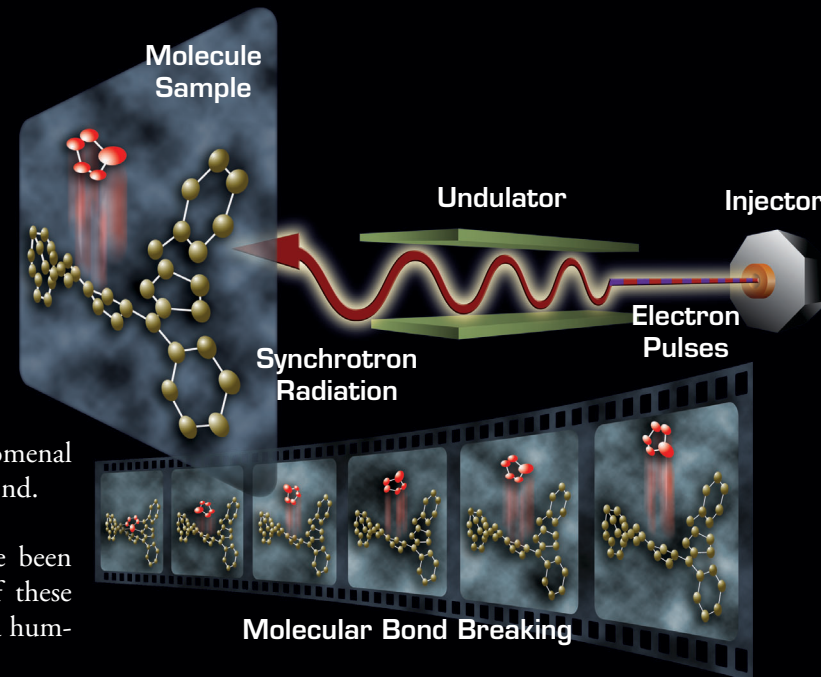
LCLS will shine light on burning scientific questions far beyond the reach of today's brightest x-ray sources. Operating with extremely short wavelengths, and fast x-ray pulses, LCLS will investigate:

### Chemical Dynamics

Textbooks give us "before" and "after" drawings of how molecules make and break chemical bonds in processes such as photosynthesis, which harnesses sunlight to make food. The real chemical reaction happens on a timescale too fast to see how it occurred. LCLS will be able to capture the action, revealing the reaction "frame by frame" to see for the first time what happens, where and when.

Understanding these fundamental processes will open the way to controlling chemical reactions that are important in medicine, agriculture, clean energy, industrial production and many other fields.

*The LCLS is dramatically different from any x-ray source ever built...*



### Protein Structures

Proteins are the engines of life. Their shape is literally the key that opens biological doors. Learning their complex structure and how they interact with other molecules sheds light on life processes such as cancer and cell regeneration. Synchrotron x-ray research on proteins has already led to new medicines and new insight into disease.

With its fast "shutter" speed and super brightness, LCLS could take pictures of an important class of proteins that cannot be x-rayed any other way. This class includes proteins residing in cell membranes, the protective lining of living cells. Illuminating them could point to new tactics to keep viruses out of our cells and let medicines in.

LCLS will give us dramatically better understanding of how nature works at this most basic atomic level.

### Extreme States of Matter – Atomic Physics and Plasma Physics

LCLS's extremely energetic and copious x-rays will actually create and observe new phenomena in atoms and plasmas.

Atoms deluged by LCLS x-rays will be excited to states never before observable in the laboratory. This will clarify

how the cloud of electrons whizzing around an atom's nucleus gets arranged by the forces of attraction to the nucleus and repulsion from other electrons. These extremely excited atoms may themselves be harnessed to make a unique laser.

Plasmas are hot, dense soups of ionized atoms—atoms missing electrons—and free electrons. Scientists need high-density plasmas in the attempt to make fusion energy. LCLS's x-rays will be able to pass through these plasma "pellets" to scrutinize their nature and behavior.

A type of plasma called warm dense matter is believed to exist inside proto-stars and giant planets like Jupiter, accounting for much of the universe's matter. LCLS will create and probe this extreme state of matter to further study the universe.

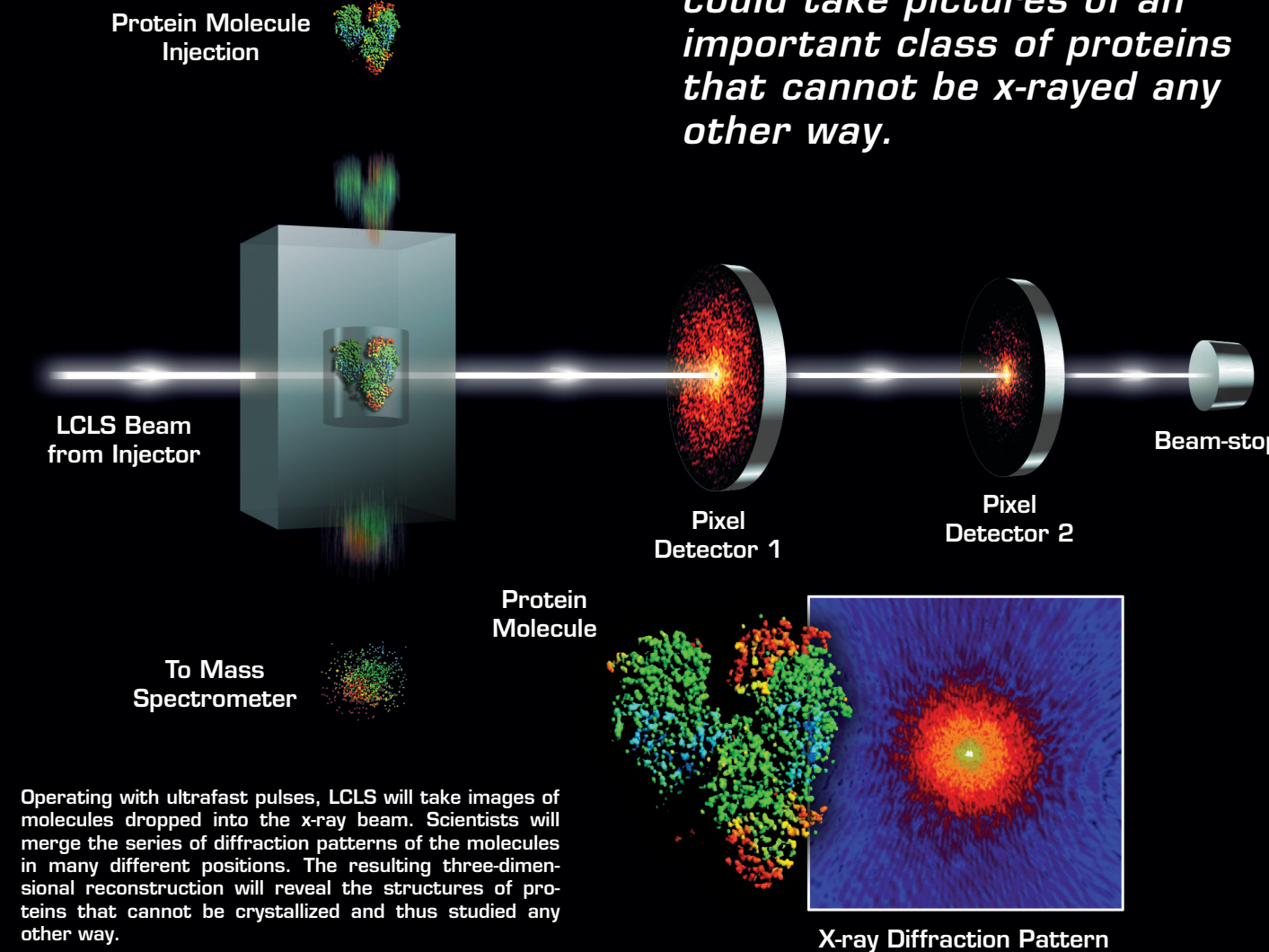
### Nanoscale Dynamics

Electronic devices, computer chips, and the liquid crystal displays on digital watches already use nanoscale materials. These materials are only billionths of a meter in size and have specially designed properties.

Building machines and computers from components containing only a few thousand atoms has moved from a daydream to a real endeavor. LCLS will observe these nanomachines in action to see how forces like magnetism affect each part in a material, how large-scale characteristics like viscosity result from the motion of individual molecules, and other dynamics that happen on ultra-fast time scales.

As engineered materials continue to get smaller and faster, LCLS will provide the data to build better technology.

*With its fast "shutter" speed and super brightness, LCLS could take pictures of an important class of proteins that cannot be x-rayed any other way.*



Operating with ultrafast pulses, LCLS will take images of molecules dropped into the x-ray beam. Scientists will merge the series of diffraction patterns of the molecules in many different positions. The resulting three-dimensional reconstruction will reveal the structures of proteins that cannot be crystallized and thus studied any other way.

### Ultra-Fast Phenomena

Quantum mechanics says that in the realm of atoms, energy comes in discreet amounts. Like a child on a staircase, an electron can jump from one energy state, or step, to another, but not stay somewhere in between. With pulses in the range of just one femtosecond, LCLS will catch the electrons in mid-jump as they transition from one quantum energy state to another, giving a glimpse into this currently hidden instant of time.

### New Science

New tools create new science, and LCLS is a completely new tool, qualitatively and quantitatively better than what came before. Time and again, quantum leaps in pure science generate important real world applications. LCLS discoveries are certain to create vital opportunities.

A likely source of surprises and new science is the x-ray beam's "temporal coherence." Temporal coherence is what distinguishes a loud random noise from a loud, pure musical note.

## Why the World's First Free Electron X-ray Laser is Revolutionary

LCLS offers the ideal scientific tool to explore how ultra-small, ultra-fast things work. The machine will make x-ray pulses of the right wavelength and time duration to freeze and see the action.

LCLS, a free-electron x-ray laser, will use the last kilometer of the powerful linear accelerator (linac) at the Stanford Linear Accelerator Center (SLAC). The upgraded linac will accelerate electrons packed into tiny bunches at nearly the speed of light. The electrons then ride a zig-zagging path through an undulator magnet. Every time the electrons change direction, they release x-rays. This magnet trick is how many of the 50-odd synchrotron light sources around the world currently operate.

A key difference is that the LCLS x-rays will be emitted coherently and with the same wavelength—the essential properties of a laser. Coherent means all the x-ray photons are in phase with each other and going in the same direction, like skiers making simultaneous, in-sync S-turns down a mountain slope. Conventional lasers excite electrons that are

bound to atoms within the lasing cavity. LCLS is a "free electron" laser because the electrons are independent from atoms: they fly down the linac unchaperoned.

The photons will be produced at "hard" x-ray wavelengths, between 1.5 and 15 Ångströms, much shorter and more energetic than visible light. That wavelength is ideal for investigating matter on the atomic scale, because the typical distance between atoms in a molecule is about 1 Ångström. There are 10 billion Ångströms in one meter.

The tiny electron bunches translate into really short x-ray pulses, 1,000 times shorter than those from current synchrotron x-ray sources.

To make the x-ray beam tremendously bright, LCLS will use a new technique called Self-Amplified Spontaneous Emission. SASE takes advantage of the intense electromagnetic fields generated by the electron bunches and radiated x-rays moving through the undulator magnet. The electromagnetic fields amplify the number of emitted x-rays. This means one bunch of 6 billion electrons can generate a pulse with one trillion coherent x-rays. More x-rays results in more precise pictures of smaller things.

This powerful combination—laser light, extreme brightness (a trillion x-rays in a needle-thin beam), short wavelength (on the scale of atoms) and short pulse duration (one to a few hundred femtoseconds)—makes LCLS a revolutionary machine.

*LCLS offers the ideal scientific tool to explore how ultra-small, ultra-fast things work.*

*The LCLS design provides room for expanding the machine from the initial six experimental stations to 30-50 stations on additional beam lines that fan out from the initial line.*

*More than \$300 million will be saved by using the final kilometer of the existing linear accelerator at SLAC.*

