Graduate Research Opportunities at the *Linac Coherent Light Source*

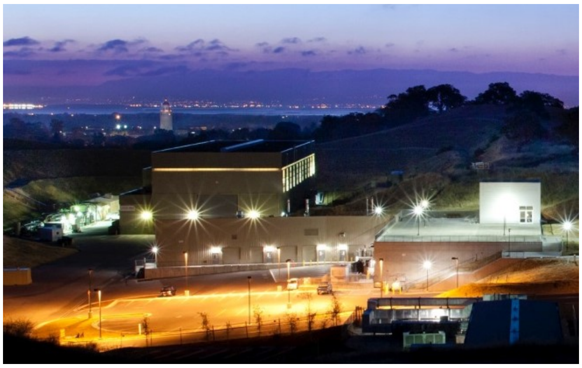
Science with X-rays – A broad field with exciting new opportunities

The use of X-ray is ubiquitous in daily life but also at the forefront of science and technology. X-rays see where atoms are and what they are doing. They have become the favored tool for understanding the microscopic structure and dynamics of matter. X-ray applications range from imaging atoms in biological molecules in order to design methods to cure diseases, to observing the carefully orchestrated dance of electrons in superconductors.

The 100-meter-long undulator: where the coherent x-ray photons are born.

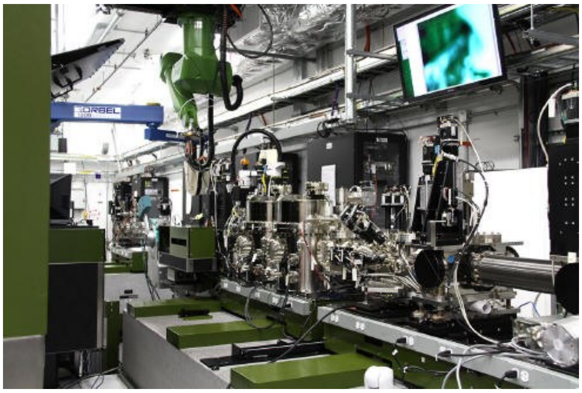
LCLS – A Unique Opportunity for Unprecedented Research

LCLS is changing the world of x-ray science in a similar fashion as optical lasers opened up countless opportunities in optics research. As the world’s first ever hard X-ray laser and the only one in the U.S., we embark on unique and completely novel scientific and technological endeavors every day. 10 years since the start of LCLS operation, we are still barely scratching the surface of what can be done. LCLS-II, the next x-ray laser at SLAC which start operation in less than 2 years will be 1000 times brighter.



Near Experimental Hall at dawn with Hoover Tower in the back ground

Graduate research opportunities at LCLS cover many interdisciplinary topics spanning research fields including physics, material science, chemistry, biology, as well as engineering. LCLS brings transformational research opportunities as well as extreme technical challenges in all these areas.



One of the X-ray Instruments at LCLS: where the science experiments take place.

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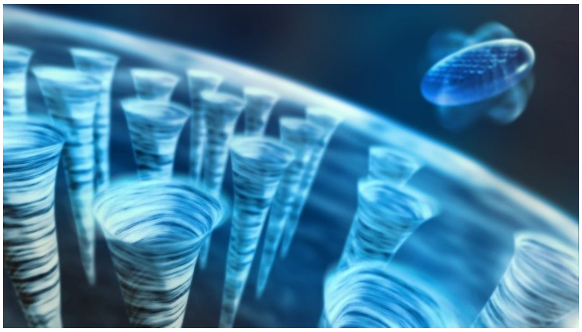
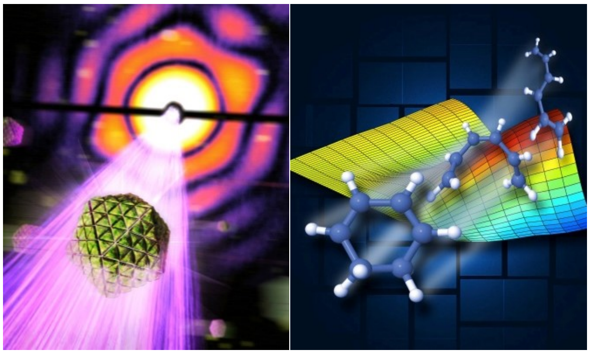
LCLS is a multi-disciplinary experimental platform at the very forefront of x-ray science with a wide range of experimental challenges. Rotation projects will be designed based on your previous background and skill set, with a goal to get you familiar with the basics of the x-ray free electron laser, an overview of science activities, and x-ray laser experiment methods. Below are examples of potential areas for thesis topics.



3D grid of quantum vortices in nanoscale superfluidic helium droplets

Structural determination of matter

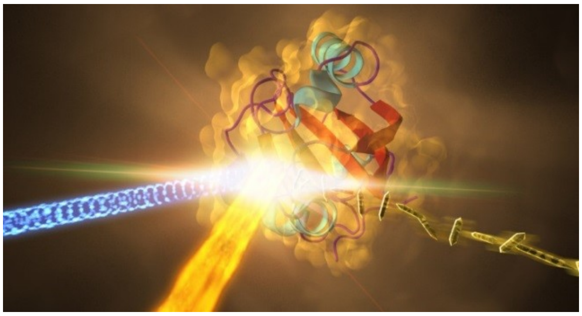
X-ray diffraction was one of the primary tools for investigation the structure of matter at the atomic scale. The unprecedented brightness of the x-ray free electron laser leads to new developments in protein structure determination via serial femtosecond crystallography, high resolution imaging of cells, viruses, nanoparticles, even quantum vortices in superfluidic helium droplets, as well as how new structure emerges in materials, e.g. crystallization within polymers. Many experimental challenges need to be addressed for further improving the performance of these new techniques and extending their scientific applications.



Left: direct imaging of the 3D structure of a virus. Right: molecular movie of a ring opening reaction captured via femtosecond x-ray scattering.

Ultrafast dynamics of atoms and molecules

The intense and short pulses from LCLS act as an atomic scale flash light, which empowers us to track changes in the electronic and atomic structures of matter at their intrinsic time scales. Potential projects include using time-resolved crystallography to observe a biomolecule undergoing a light driven configuration changes, or time-resolved spectroscopy to track the migration of electrons during light harvesting and catalytic processes.



Light driven femtosecond dynamics in biological molecules

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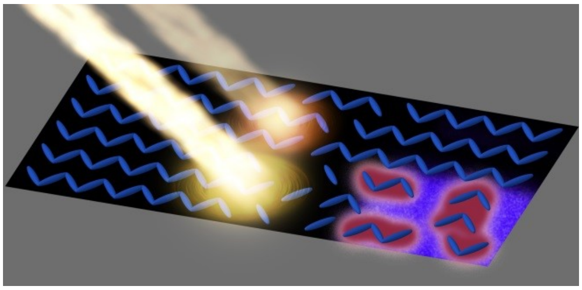
Dynamics in Quantum Materials

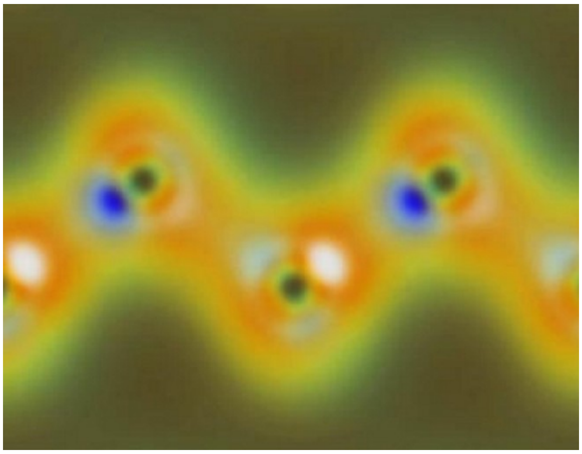
Ultrafast optical and THz excitations can be used to probe and manipulate the properties of various condensed matter systems. These changes can then be tracked at the femtosecond timescale with X-ray diffraction. Applications of ultrafast diffraction methods include measurement of structural phase transition processes, or structural determination of new and transient phases of matter, as well as understanding and control of the fundamental ground state properties of e.g. correlated materials, by looking at how they respond to external disturbances.



Tracking the metal-to-insulator transition in a complex oxide using femtosecond diffraction

Nonlinear x-ray physics

With the advent of the x-ray free electron laser, for the first time we have sufficient intensity at the x-ray wavelength to conduct nonlinear optics experiments such as second harmonic generation and parametric down conversion. This is still largely unchartered territory with many opportunities for new discoveries starting from understanding the basics of high intensity x-ray matter interaction to developing new nonlinear spectroscopy techniques.



An atomic view of charge modulation induced by an optical laser in a crystal, measured by sun frequency generation at the x-ray wavelength.

Planetary Science

High power lasers can be used to create conditions similar to those experienced in a large meteorite strike. Phase transitions of various rocks can be observed within the first few nanoseconds. Kinetics of such non-equilibrium processes by which atoms rearrange themselves advances our understanding of phase transformation pathways and this knowledge is of general importance and great interest in planetary science.

Recreation and characterization of the meteorite strike process

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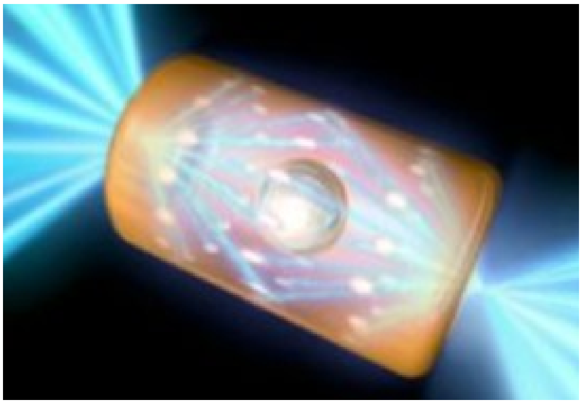
Nuclear Fusion

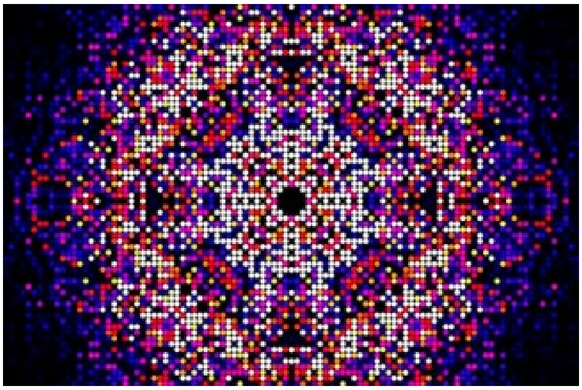
At the heart of the *National Ignition Facility* at SLAC's partner lab LLNL, a plastic capsule is imploded by x-rays produced by focusing 192 extremely high power laser beams into a gold *hohlraum*. Understanding the behavior of the capsule as it implodes is crucial to the success of laser driven fusion. At LCLS, we can recreate critical phases of the implosion, allowing scientists to investigate and optimize the fusion process.



Understanding the key aspects in laser driven nuclear fusion

Plasma Physics & Lab Astrophysics

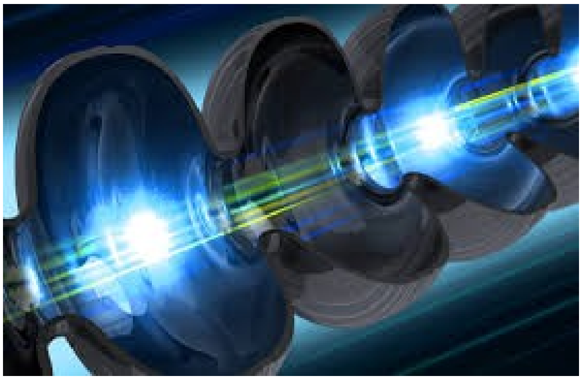
Optical lasers with extremely high intensity can generate relativistic plasma flows similar to those associated with the phenomena of astrophysical shocks. The X-ray pulses from LCLS can then be used to directly visualize the nanoscale filaments as they evolve on the femtosecond time scale inside the dense plasma.



datagram from 100,000+ diffractions

LCLS-II and the big data challenge

On going upgrade at LCLS will give three orders of magnitude more x-rays delivered in the form of MHz femtosecond pulses. Many new x-ray laser based experimental techniques uses high pixel count fast detectors that generates scientific data on the multi-petabyte scale. We are in the process of building the computing infrastructure to enable these new experiments that can effectively acquire, process, and analyze these scientific data on the fly. Machine learning approaches are being actively explored and developed for optimizing the x-ray laser performance, as well as extracting hidden information in very large datasets.



LCLS-II: A superconducting linac driven FEL that is 10,000 times brighter!