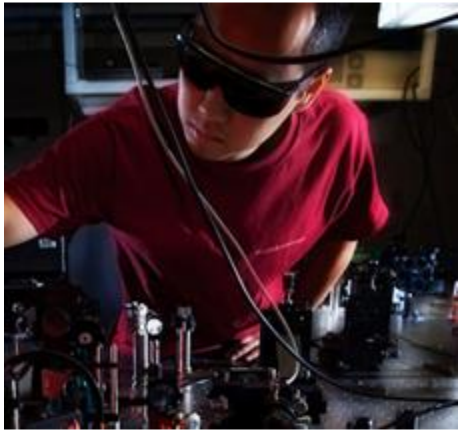
Photon Sciences at SLAC / Stanford University

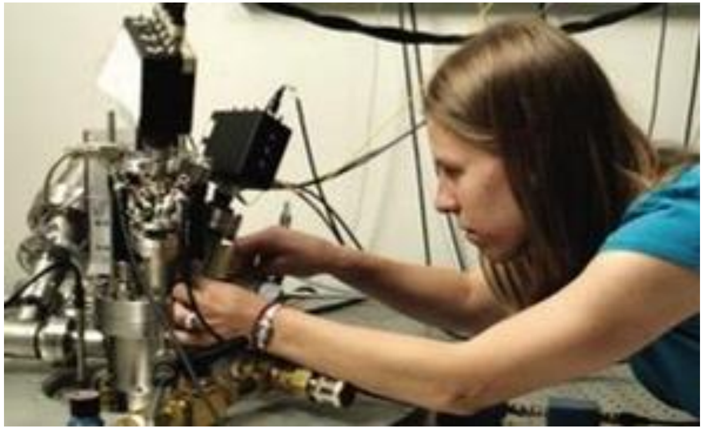
Benjamin Ofori-Okai, (Incoming) Assistant Professor in Photon Science, contact: benofori@stanford.edu

Photon Science faculty and scientists at SLAC lead interdisciplinary research teams driving internationally leading research

Photon Science has 39 faculty (+1!) (13 full, 14 joint, 12 term-limited)
over diverse disciplines
Applied Physics, Physics, Chemistry, Materials Science, Chemical Engineering, Electrical Engineering, Geosciences, Structural Biology, Bioengineering, …



Chair: Phil Bucksbaum, phb@SLAC.stanford.edu



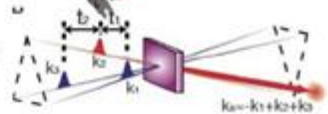
- **Joint Research Institutes and Research Divisions:**
  HEDS, PULSE, SIMES, SUNCAT
- **Unique Facilities:**
  LCLS, **LCLS-II**, SSRL, UED, FACET,
  cryo-EM, ASC-labs, etc.

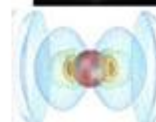
Stanford PULSE Institute
Advancing the frontier of ultrafast science using LCLS

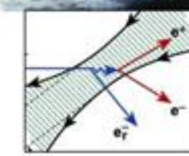
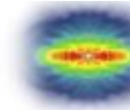
Research conducted in the **PULSE institute** is driven by the opportunities introduced by ultrafast and high field science with X-rays.

thus we are engaging in work that was not possible prior to the introduction of the LCLS.

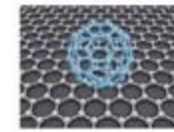
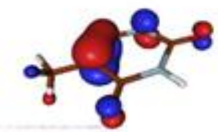
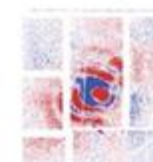
- Ultrafast Theory and Simulation

- Attosecond science

- Ultrafast Chemistry

- X-ray Movies of Molecules in Motion

- High Energy Densities

- QED at the Schwinger limit

- Strong Field AMO Physics

- Solild State High Harmonics

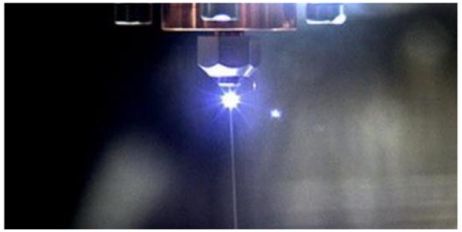
- Nonlinear X-ray interactions

- Electron Dynamics on the Nanoscale

- Ultrafast X-Ray Spectroscopy

- Ultrafast Materials Science


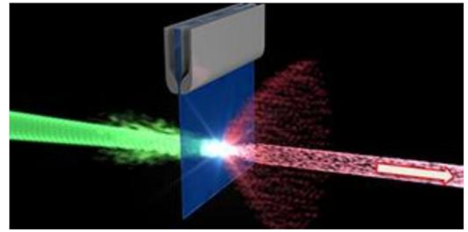
Director: Prof. David Reis, dreis@stanford.edu
Website: https://ultrafast.stanford.edu

High Energy Density Sciences (HEDS) Division
Interrogating the fundamental properties of matter at extremes

The **High-Energy Density Science (HEDS)** division investigates the physical properties of warm dense matter, shocks, and high-intensity laser-plasma interactions in the relativistic regime.



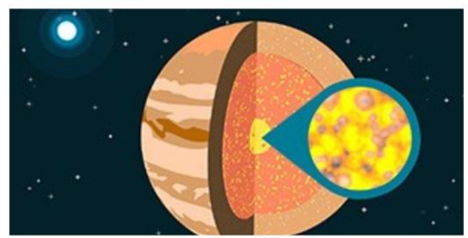
Target Development →



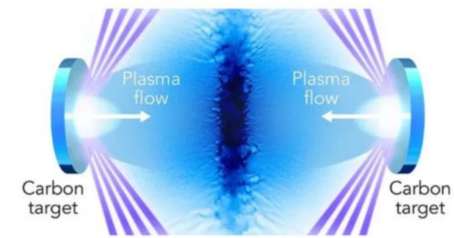
Monoenergetic Proton Beams →

Theory and Simulations →

Record Peak Brightness →



Warm Dense Matter →

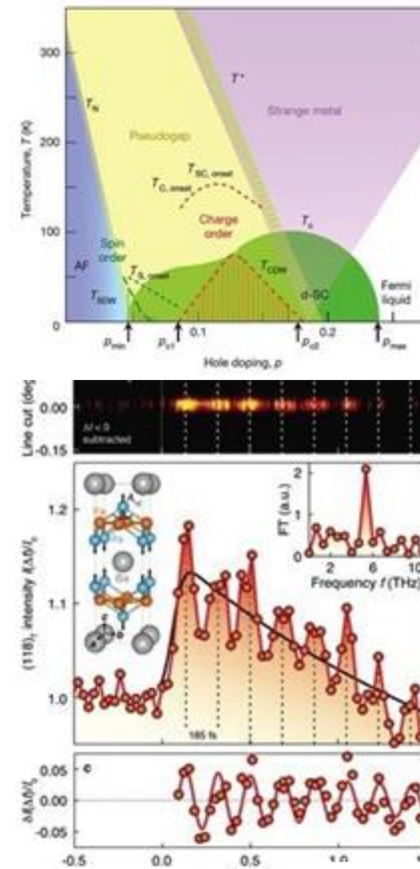


Plasma Diagnostics →

Director: Prof. Siegfried Glenzer, glenzer@SLAC.Stanford.edu,
Website: https://HEDS.slac.stanford.edu

Stanford Institute for Material and Energy Sciences (SIMES)
Addressing grand challenges in the science of energy-related materials

- Why do **quantum electronic materials** have unique emergent properties?
- What are **pathways to convert** photons into energy and to store energy chemically?
- How can we **design and synthesize materials**, both physically- and bio-inspired, that exhibit these amazing quantum and energy transformative properties?
- How can we **best measure, probe, and simulate** the ultrafast photonic and electronic processes that drive all of the above?



Director: Prof. Harold Hwang, hyhwang@stanford.edu,
Website: https://simes.stanford.edu

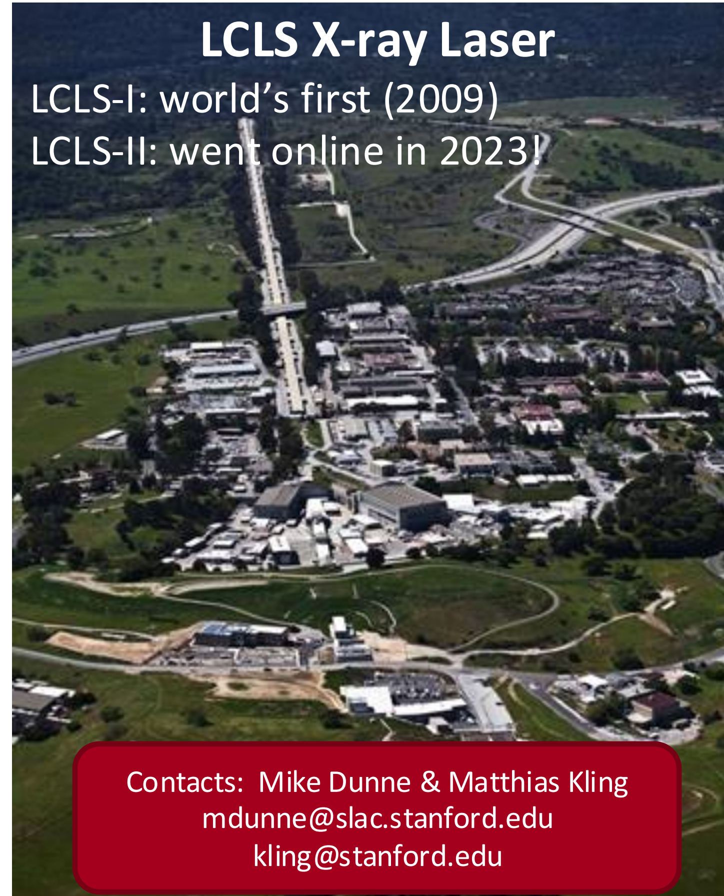
There are world-class X-ray facilities at SLAC that can be used for ground-breaking science

SSRL Synchrotron Radiation

Contacts: Paul McIntyre & Piero Pianetta
pcm1@stanford.edu
pianetta@stanford.edu

LCLS X-ray Laser

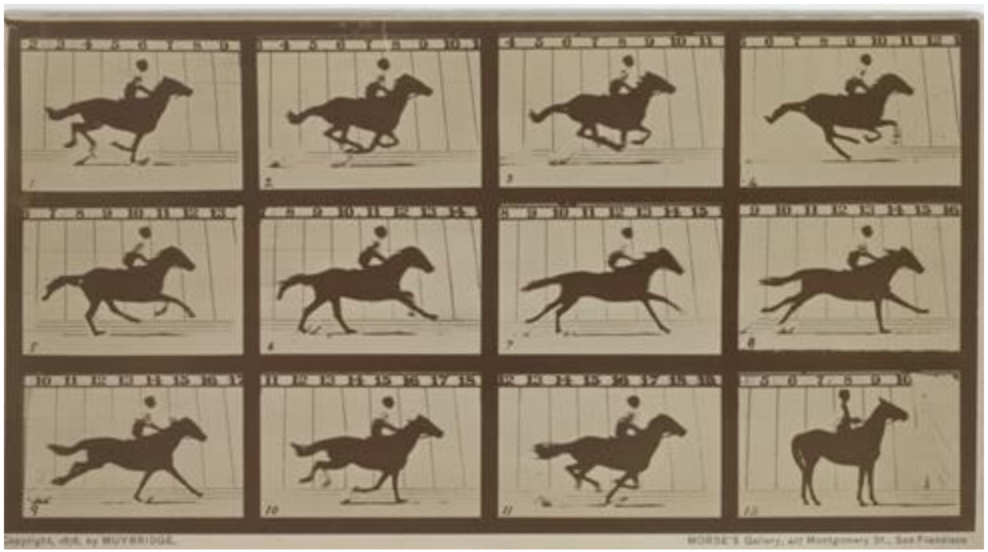
LCLS-I: world's first (2009)
LCLS-II: went online in 2023!



Contacts: Mike Dunne & Matthias Kling
mdunne@slac.stanford.edu
kling@stanford.edu

Ultrafast Imaging @ Stanford

The first movie (recorded at Stanford)



The Horse in Motion ("Sallie Gardner," Owned by Leland Stanford; Running at a 1:40 Gait Over the Palo Alto Track, 19th June 1878)

E. Muybridge

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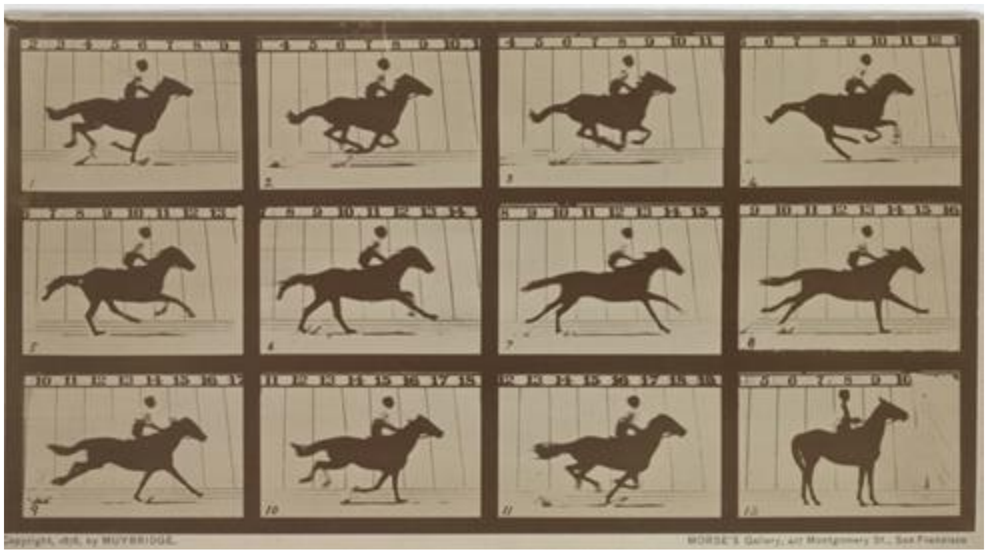

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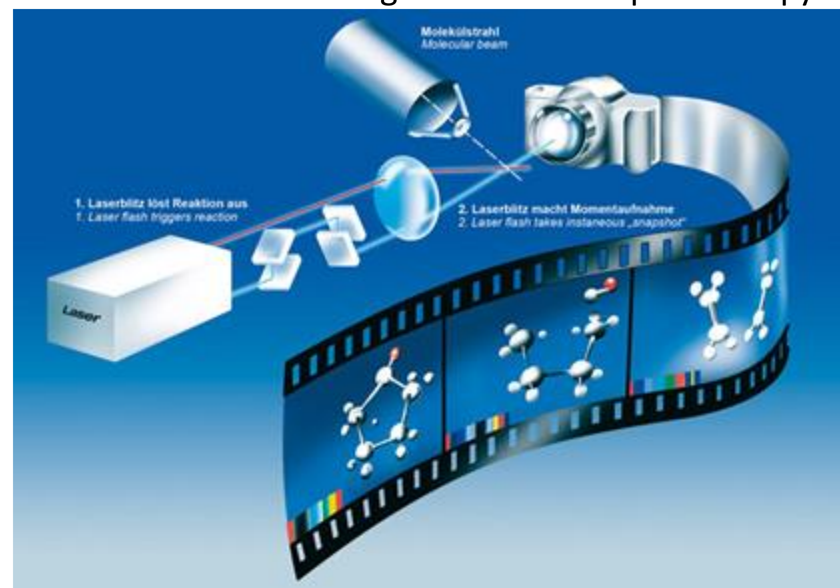
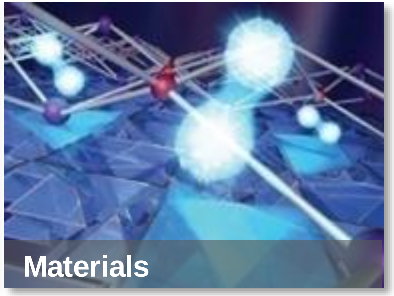
E. Muybridge

Nobel Prize
in chemistry
1999

Ahmed H. Zewail for „for his studies of the transition states of chemical reactions using femtosecond spectroscopy"



SLAC's unique facilities enable high-impact scientific discoveries addressing national challenges in climate, clean tech, microelectronics



The Linac Coherent Light Source delivers ultrafast x-rays for a broad range of science

World's first hard X-ray free-electron laser achieves first light

[LCLS] will give scientists an unprecedented tool for studying and understanding the arrangement of atoms in materials …and biological molecules, with wide-ranging impact on advanced energy research and other fields.

Stanford report, April 21, 2009

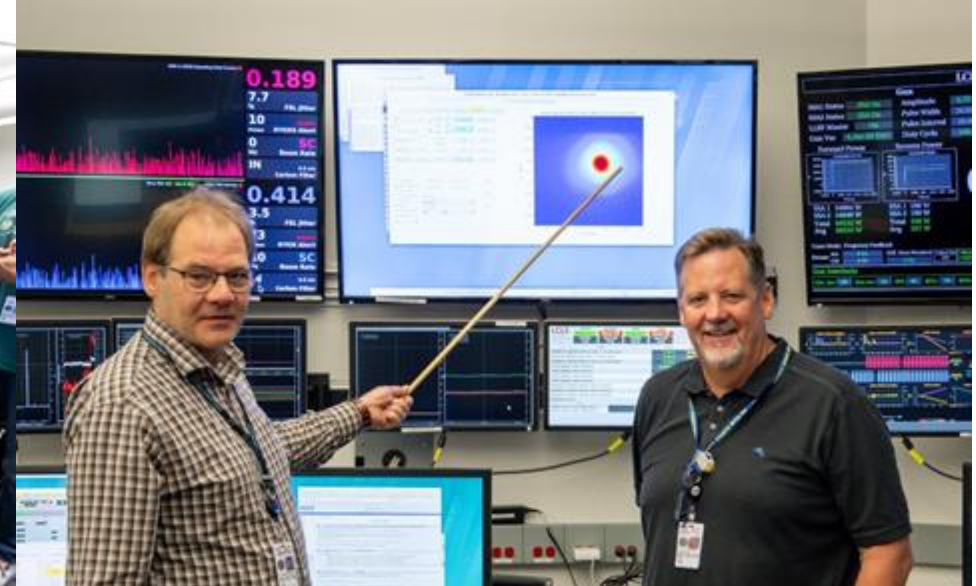
A billion times brighter than next brightest source…

SLAC fires up the world's most powerful X-ray laser

With up to a million X-ray flashes per second, LCLS-II transforms the ability of scientists to explore atomic-scale, ultrafast phenomena that are key to a broad range of applications.

Stanford report, September 18, 2023

Ten-thousand times brighter than LCLS

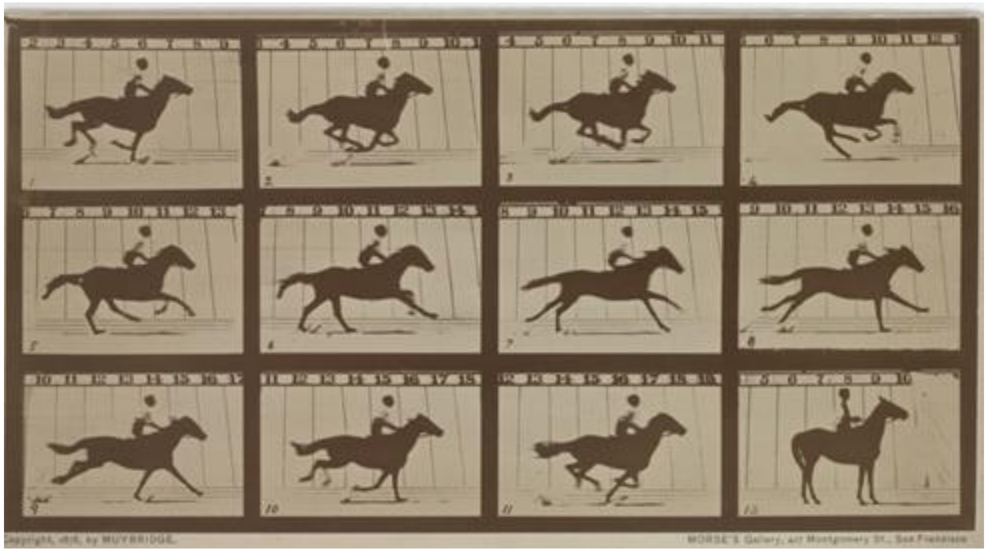


One of the most exciting times in Photon Science at Stanford!

Now: The time axis – recording (ultra) fast movies

Ultrafast Imaging @ Stanford

The first movie (recorded at Stanford)



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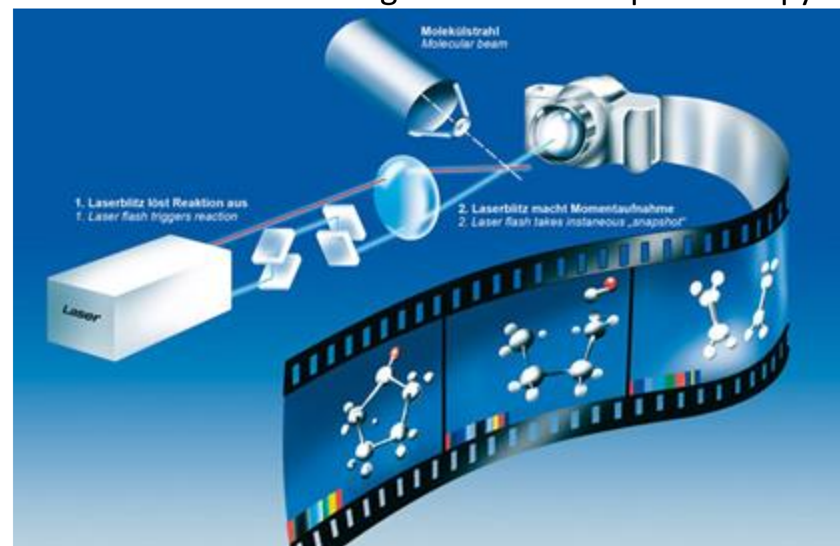
E. Muybridge

State-of-the-art: femtosecond flashes of light

1 fs = 0.000 000 000 000 001 s (10^{-15} s)

Nobel Prize
in chemistry
1999

Ahmed H. Zewail for „for his studies of the transition states of chemical reactions using femtosecond spectroscopy"



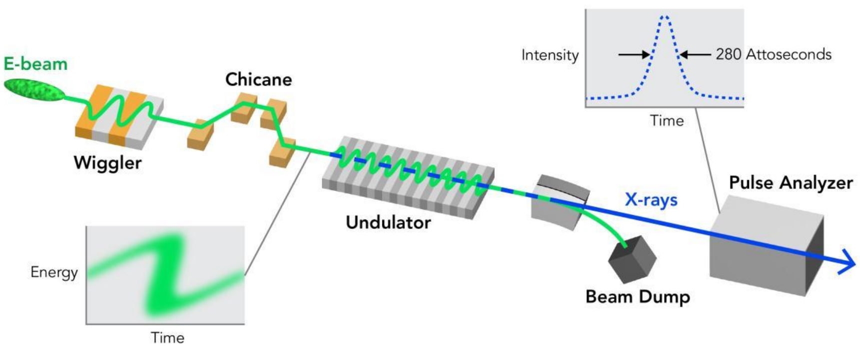
Credit: DESY

Beyond! Measuring and harnessing electron dynamics

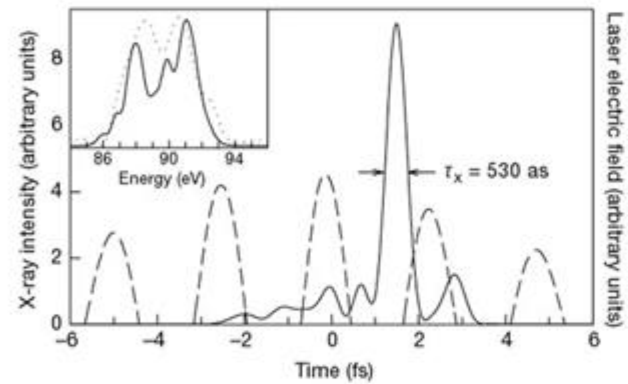
Nobel Prize
in Physics 2023

**Pierre Agostini, Ferenc Krausz,
and Anne L'Huillier**
„for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter”

Now: Attosecond flashes of light at Stanford
1 as = 0.000 000 000 000 000 001 s (10^{-18} s)

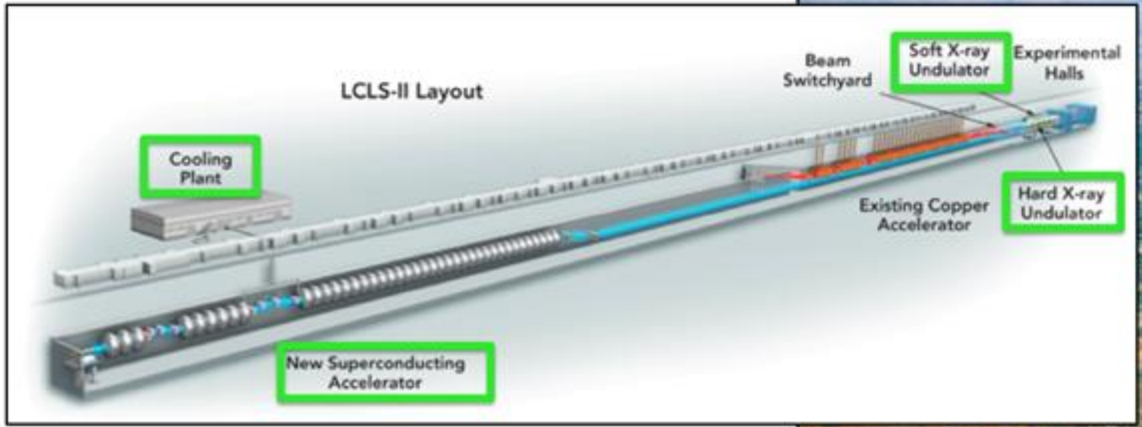


Greg Stewart/SLAC National Accelerator Laboratory

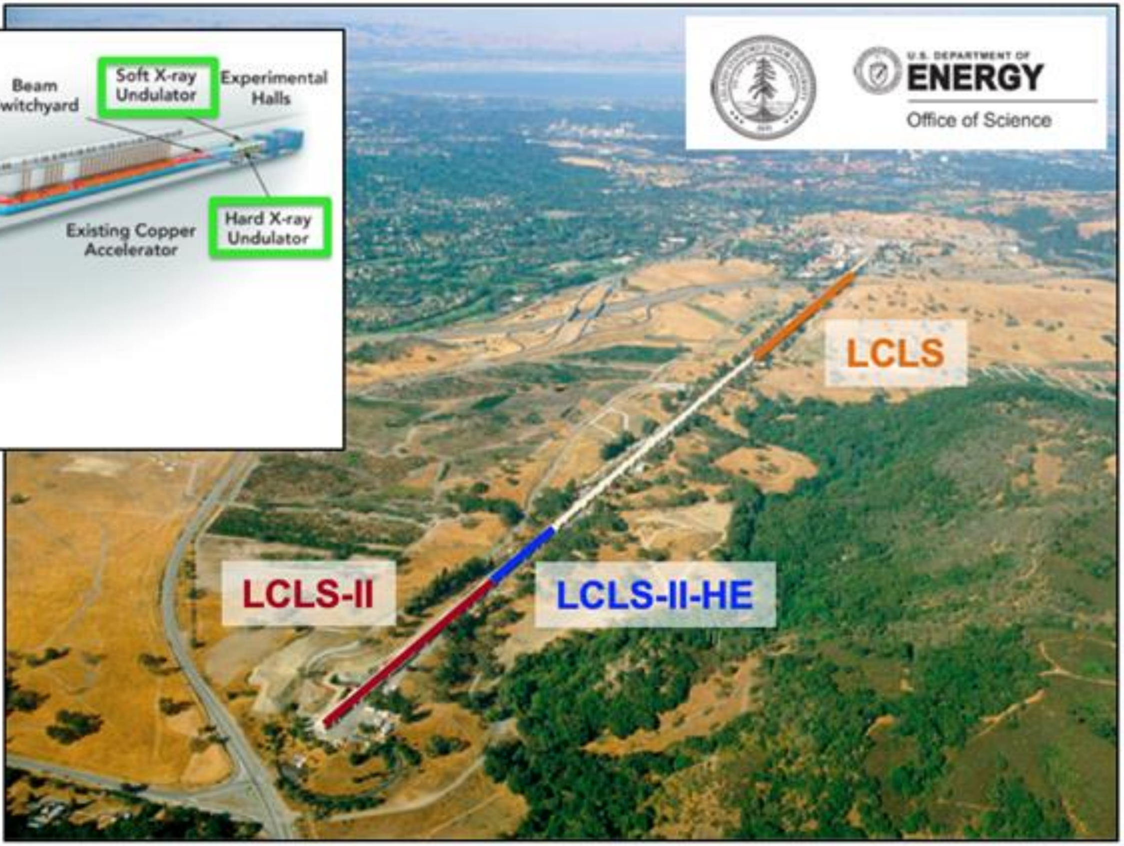


Hentschel, M. *et al.,* Attosecond metrology, *Nature* **414**, 509–513 (2001).

LCLS-II and LCLS-II HE upgrades will provide new tools and capabilities for addressing questions in many scientific areas

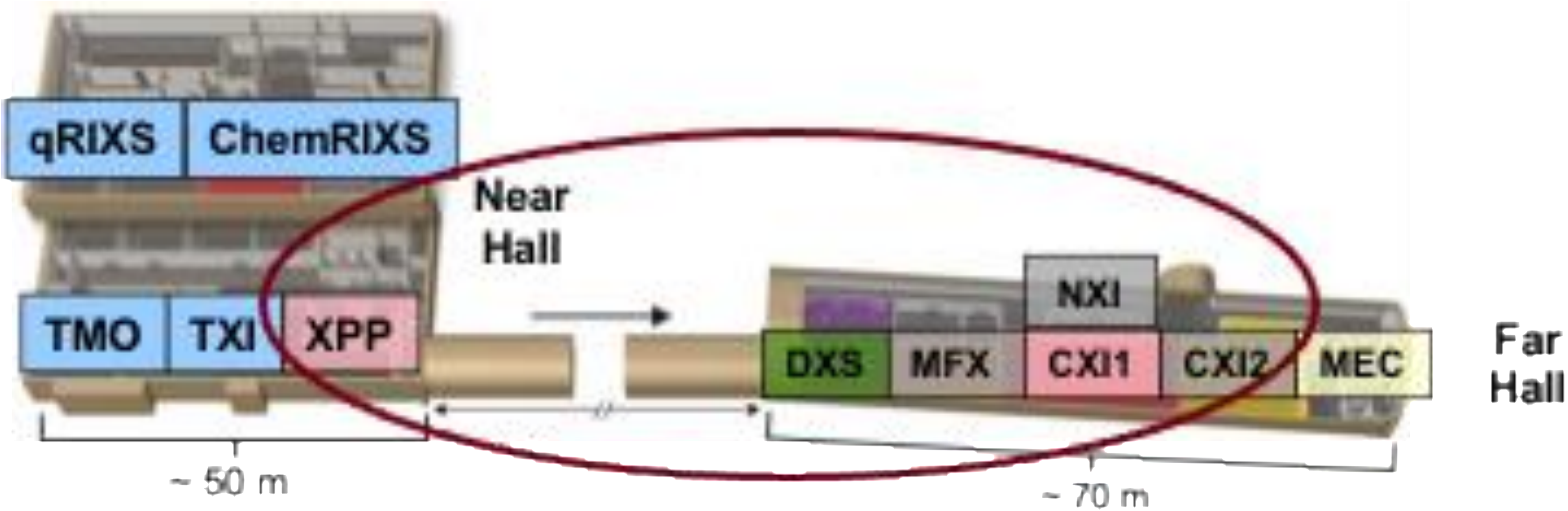


Up to 1 MHz pulses, programmable structure
Extend 120 Hz operation to >25 keV (fundamental)
Variable gap undulators for rapid tuning of X-ray energy
Significant increase in number of experiments



New endstations are being designed with high field, high rep-rate capabilities which will enable new and exciting experiments

New LCLS-II instruments | **LCLS-II-HE instruments**



New research areas include:

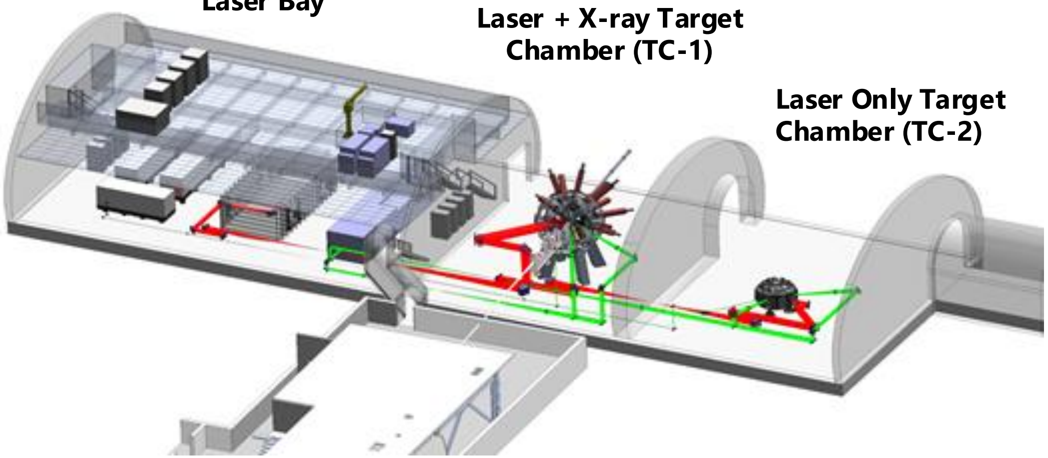
- Coupled dynamics of energy and charge in atoms and molecules,
- Catalysis, photocatalysis, environmental & coordination chemistry
- Imaging biological function and dynamics,
- Materials heterogeneity, fluctuations, and dynamics.
- Quantum materials and emergent properties.
- Nonlinear X-ray matter interactions.

Planned upgrades planned for the MEC endstation at LCLS will provide new classes of experiments that can only be done at SLAC

Planned MEC Upgrade

1. kJ laser for high pressure physics (>10^{12} Pa)
   - Specs: **1 kJ, 5 ns, 0.5 μm, shot/30 minutes**
   - Ablator physics, Earthly materials

2. High-energy PW laser
   - Specs: **150 J, 150 fs, 10 Hz, >10^{18} Pa**
   - Bright ion beams,
   - Collision-less shocks



How can students get involved?
Faculty offering core courses in x rays, lasers and ultrafast science

Examples

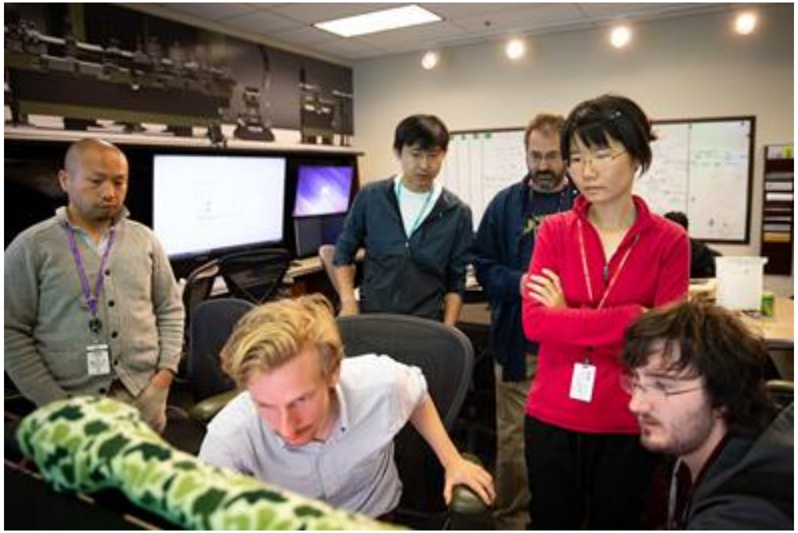
APPPHYS 283: Ultrafast Quantum Physics (PHOTON 283)

Intended for first-year graduate students who are interested in understanding the basic concepts of ultrafast quantum science to prepare for research in AMO physics, condensed matter physics, physical chemistry or quantum information science. The topics in this course are distinct from and complementary to AP 201 (Laser and X-ray Sources and Science) and AP 203 (AMO Physics and Quantum Optics). Topics for this course: Atomic structure probed in the time domain: Wave packets and quantum entanglement. Molecular structure probed in the time domain: Building up and then breaking down the Born-Oppenheimer picture. Extended quantum systems probed in the time domain: Band structure, phonons, and ultrafast disturbances interactions: From multi-photon absorption to tunnel-ionization. X-ray-matter interactions: Excitation, ionization, and linear and nonlinear scattering. Attosecond science: Impulsive excitation, Auger-Meitner decay, charge migration within molecules. Extreme time-domain quantum physics: high-field environments, and matter tunneling from the quantum vacuum.

APPPHYS 325: Synchrotron Radiation and Free Electron Lasers: Principles and Applications. (PHOTON 325)

Synchrotron radiation sources for scientific exploration, and x-ray FELs for studies of ultrafast processes at the atomic scale. Fundamental concepts in electron and photon beams, bending magnet and undulator radiation, one-dimensional and three-dimensional FEL theory and simulations, self-amplified spontaneous emission, seeding and other improvement schemes, x-ray methodology, techniques and instrumentation for the study of ultrafast phenomena. Includes selected laboratory tours of the Linac Coherent Light Source and/or Stanford Synchrotron Radiation Lightsource at SLAC.

Instructors: Kling, M. (PI) ; Marinelli, A. (PI)



How can students get involved?
PULSE Ultrafast X-ray Summer School

Training the next generation(s) of x-ray free-electron laser researchers since 2007

UXSS 2024

Stanford/SLAC

UXSS 2023

DESY/Hamburg

Annually since 2007 (3 years before LCLS)!
Since 2011 Joint with CFEL (Center for Free-Electron Laser Science),
2025 will include Paul Scherer Institute

Come and join us – Photon Science at SLAC/Stanford

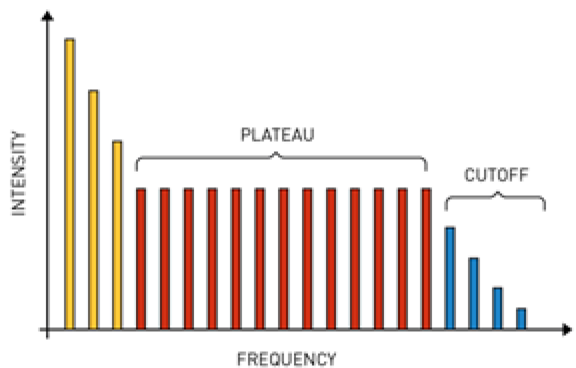
Getting to know us: Rotation opportunities

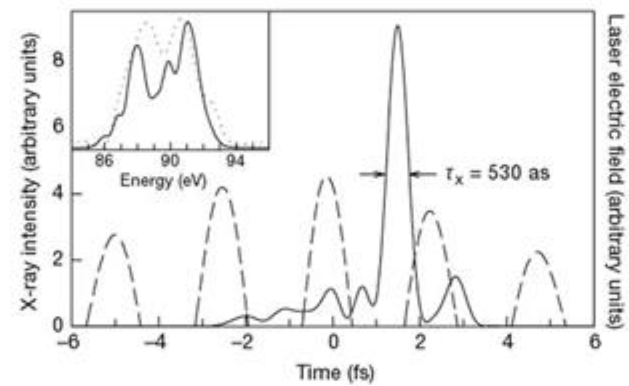
Now: Measuring and harnessing electron dynamics

Nobel Prize
in Physics 2023

Pierre Agostini, Ferenc Krausz, and Anne L'Huillier
„for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter"

Image source and copyright:
San Silvestre Salmantina. Óscar J. González





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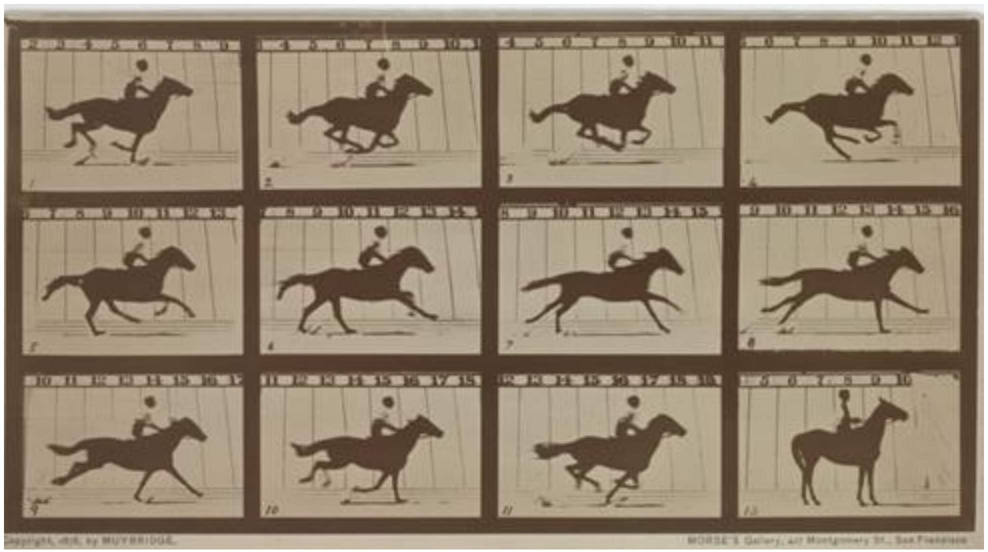
The first movie (recorded at Stanford)



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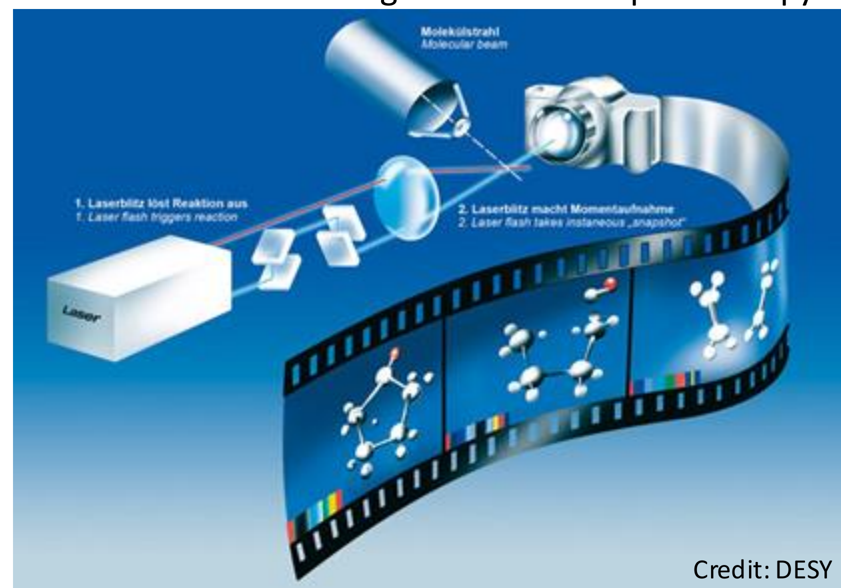


Credit: DESY

LCLS provides unprecedented insight into dynamics and chemical reactivity

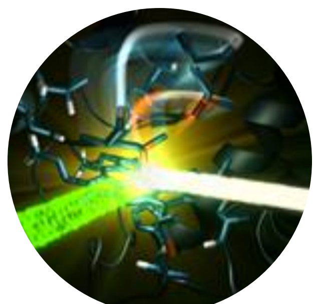
Ultrafast	Atomic Resolution	Extreme brightness	Full coherence

Ultrafast

Revealing coupled electronic and nuclear motion at relevant timescales

Atomic Resolution

Resolving atom-level structures and chemical bonding across time and space



Extreme brightness

Probing local chemistry with monochromatic X-ray pulses for element-specificity

Full coherence

Tracking dynamics in matter using X-ray imaging and correlation spectroscopy methods

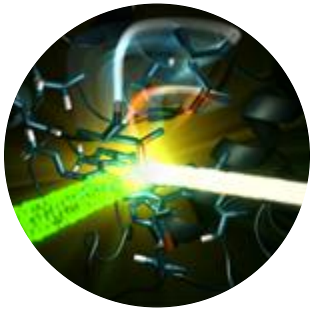
LCLS provides insight into dynamics and chemical reactivity

Ultrafast

Revealing coupled electronic and nuclear motion at relevant timescales

Atomic resolution

Resolving atom-level structures and chemical bonding across time and space



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Tracking dynamics in matter using X-ray imaging and correlation spectroscopy methods