Welcome and SLAC Overview

SLAC, May 9, 2006

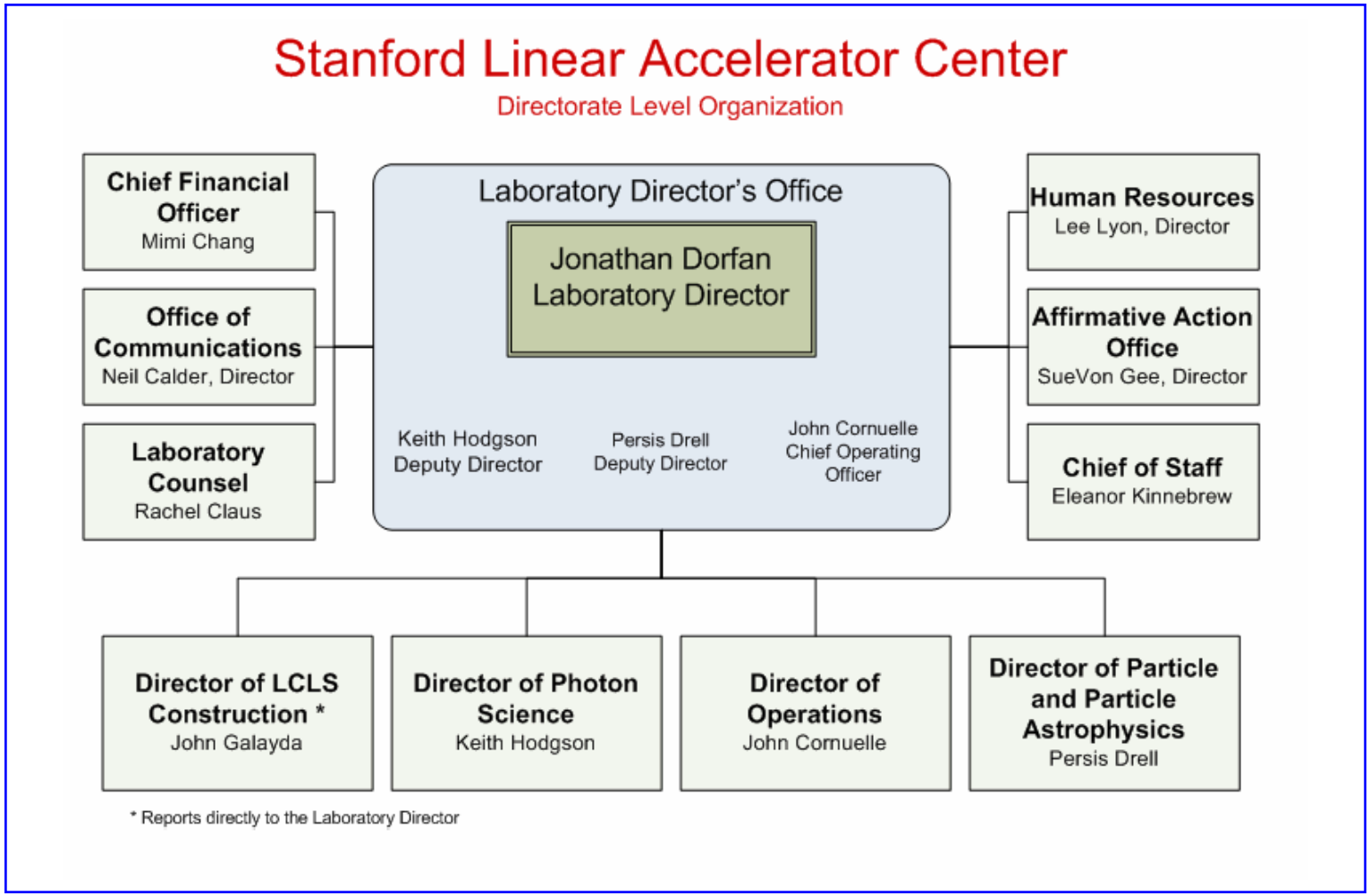
Keith Hodgson
Deputy Director, SLAC

SLAC operation is funded by the US Dept. of Energy, Office of Science

Brief Perspective on SLAC's history and programs

- A government-owned facility operated by Stanford University and located on about 430 acres of Stanford land leased to the federal government at no cost
- SLAC was conceived by Stanford faculty in the late 1950's and was approved by the Stanford Trustees in 1962. Construction started in 1963 and the first experiments began in 1966
- SLAC is open to all scientists worldwide on the basis of proposals submitted for peer review. Laboratory conducts fundamental research, unclassified in nature, and widely published in the open literature
- The laboratory has remained on the frontiers of science through continued upgrades and additions to its initial complement of accelerator facilities

Laboratory Organization



SLAC — An Integral Part of Stanford University

- SLAC benefits greatly from being an intimate and integral part of Stanford University
- SLAC is a School of Stanford with two faculties (departments). The HEP faculty comprises 33 active professors, the Photon Science faculty comprises 20 active professors
- SLAC's history is one of cutting-edge technical innovation combined with outstanding scientific accomplishments. The close intimacy with a premier research University, Stanford, has been one of the key elements for this success

What Characterizes SLAC?

- **SLAC built a world-class scientific laboratory because its program has always been:**

  Driven by outstanding science which has

  Pushed the limits of discovery

  Sustained by exceptional technical innovation

- **Driven by the scientific opportunities of the coming decades, supporting the mission of the DOE, recognizing our unique opportunities as a part of a great research university, and furthering our role as a major scientific user facility, we have crafted a new vision for SLAC centered on the most challenging and exciting problems in photon science and in particle physics, particle astrophysics/cosmology**

Two Main Science Programs

- **Photon Science**

  The use of ultra high-intensity x-ray and soft x-ray beams (ten million or more times the intensity of x-ray tubes) for studies in physics, biology, chemistry, medicine, and environmental sciences

- **High Energy Physics / Particle Astrophysics**

  Experiments, theory, accelerator development for studies of the ultimate structure of matter, the forces between the fundamental entities, the birth and evolution of the universe

- ~3000 scientists from about 25 nations use SLAC facilities

- Science program at SLAC generates 800-900 publications per year

Crucial Assets

- **Intellectual Capital: SLAC Staff (~1300)**
  - **The Laboratory's greatest asset - exceptional quality, extensive skills and experience, and knowledge base**
  - **Staff provides national and international scientific and technical leadership**
  - **Unique relationship with Stanford University is key to our world-class staff**

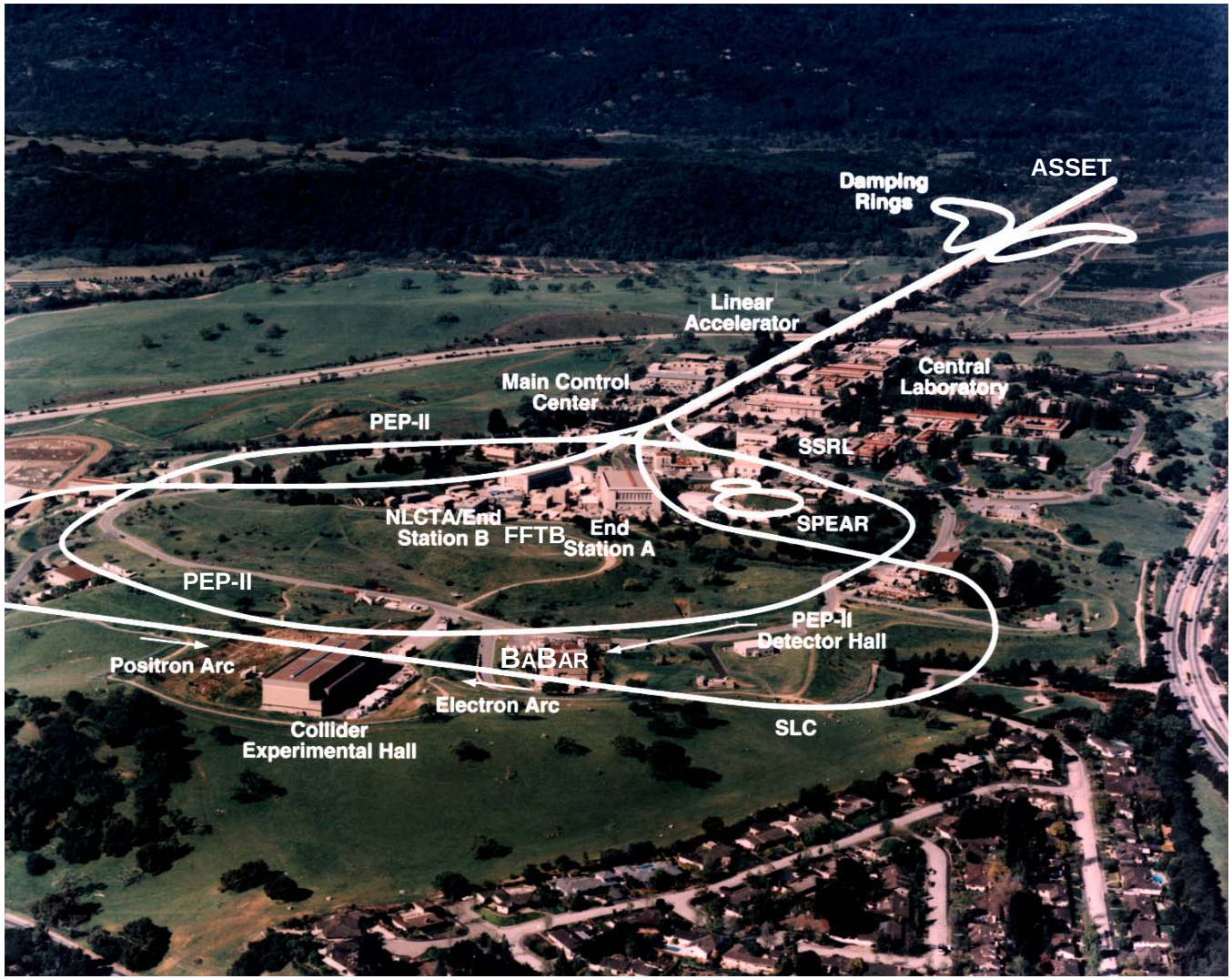
- **Physical Infrastructure:**
  - **Accelerators that are uniquely positioned to drive photon science, particle physics and accelerator R&D into the next decade and beyond**
  - **High energy, low emittance, high intensity and short pulse length of our electron and positron beams are unique**
  - **Extensive physical space available to develop and construct complex and/or large scientific instruments**

SLAC's Business Plan

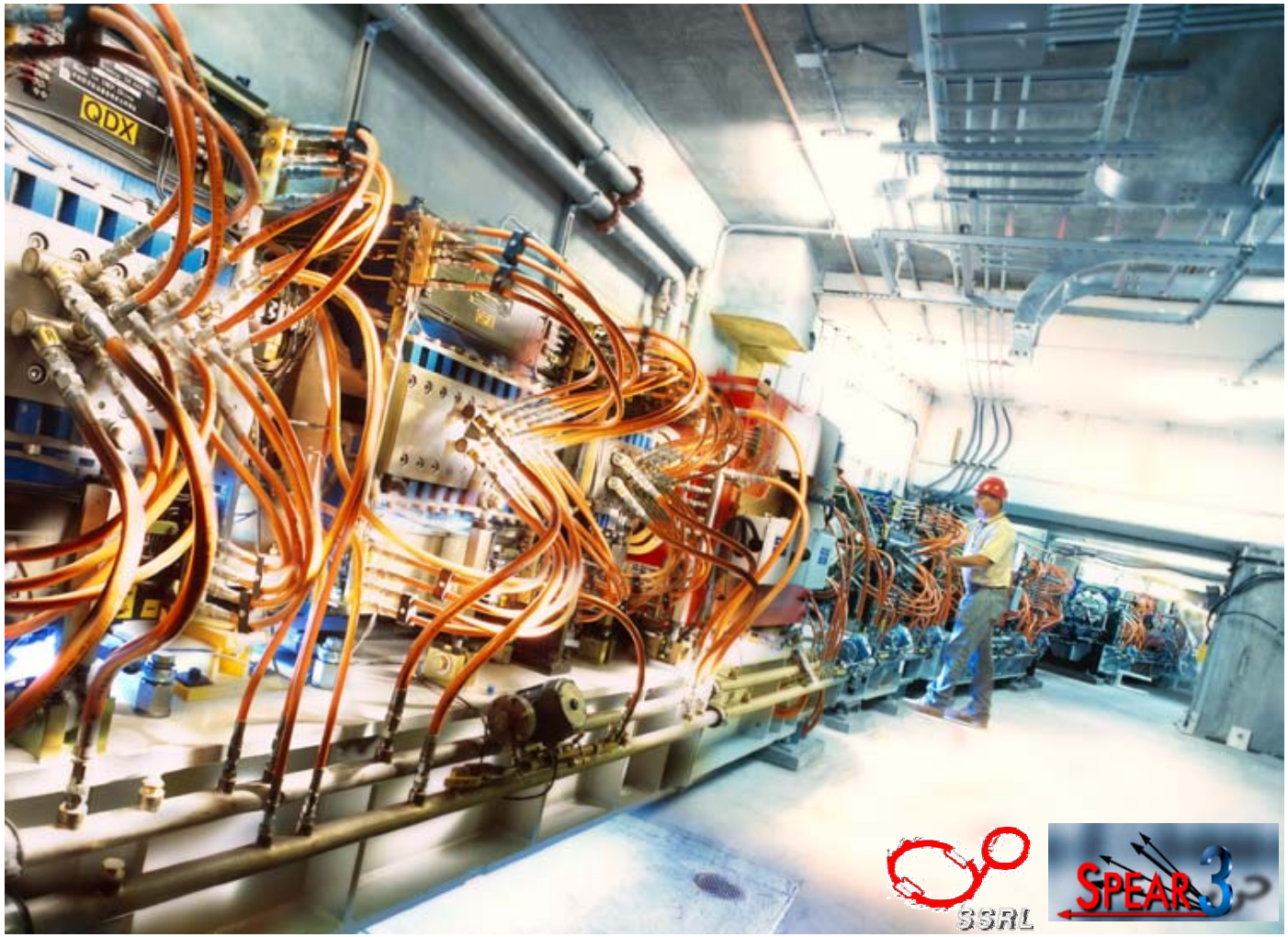
Business Lines	Distinguishing Capabilities	Distinguishing Performance	Mission Relevance
Photon Science	• **Ultrafast X-ray science;** • **Complex/correlated & magnetic materials science;** • **Molecular, environmental & interface science;** • **Nano- & atomic-scale structural biology;** • **Strong coupling and integration with outstanding research university (Stanford), providing leadership and vision across a range of disciplines.** • ***Stanford Synchrotron Radiation Laboratory, SPEAR 3***	World's brightest, ultra short pulse (80 fs) X-ray source, now pioneering experiments in fs domain (SPPS); Successful SPEAR3 upgrade on time, within budget, makes the Stanford Synchrotron Radiation Laboratory (SSRL) a 3rd generation light source; Will deliver the world's first X-ray free electron laser in 2009 with unprecedented brightness, coherence and short pulses of X-rays (LCLS).	Advance core disciplines of basic energy sciences and biological and environmental research; Contribute to science and technology that advances the energy security and health of our nation; Master convergence of physical and life sciences for health and medicine.
Particle Science	• **CP violation in B mesons, precision particle physics at the electron energy frontier, and non accelerator tests of the Standard Cosmological Model through investigations of Dark Matter and Dark Energy;** • **Strong integration with outstanding research university (Stanford).** • ***B Factory, PEP-II, BaBar***	World's highest luminosity electron-positron storage rings –*shared with KEK;* Collaboration in international effort to build e+e- linear collider – *shared with DESY and KEK;* Major collection of accelerator physics talent.	Explore and discover the laws of nature as they apply to the basic constituents of matter, and the forces between them; Advance accelerator technology for the benefit of particle science and other disciplines for whom accelerators are a primary tool.
LCLS	• **Ultrafast X-ray science;** • **Complex/correlated & magnetic materials science;** • **Molecular, environmental & interface science;**	World's first X-ray free electron laser	Lead nanoscale science revolution; Master control of energy-relevant complex systems.

From DOE Laboratory Plans FY2007 - FY2011

The SLAC Accelerators

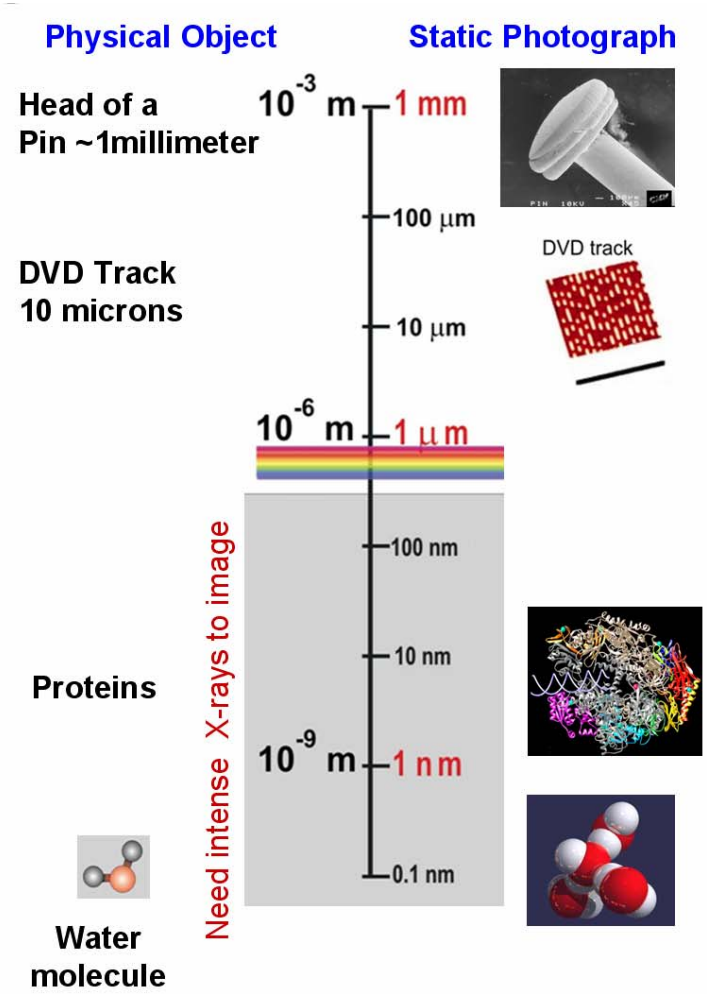


SPEAR3 – A New Generation Accelerator for Synchrotron Science



$60M Upgrade shared equally by DOE and NIH and completed in FY2004 and now in full and effective operation

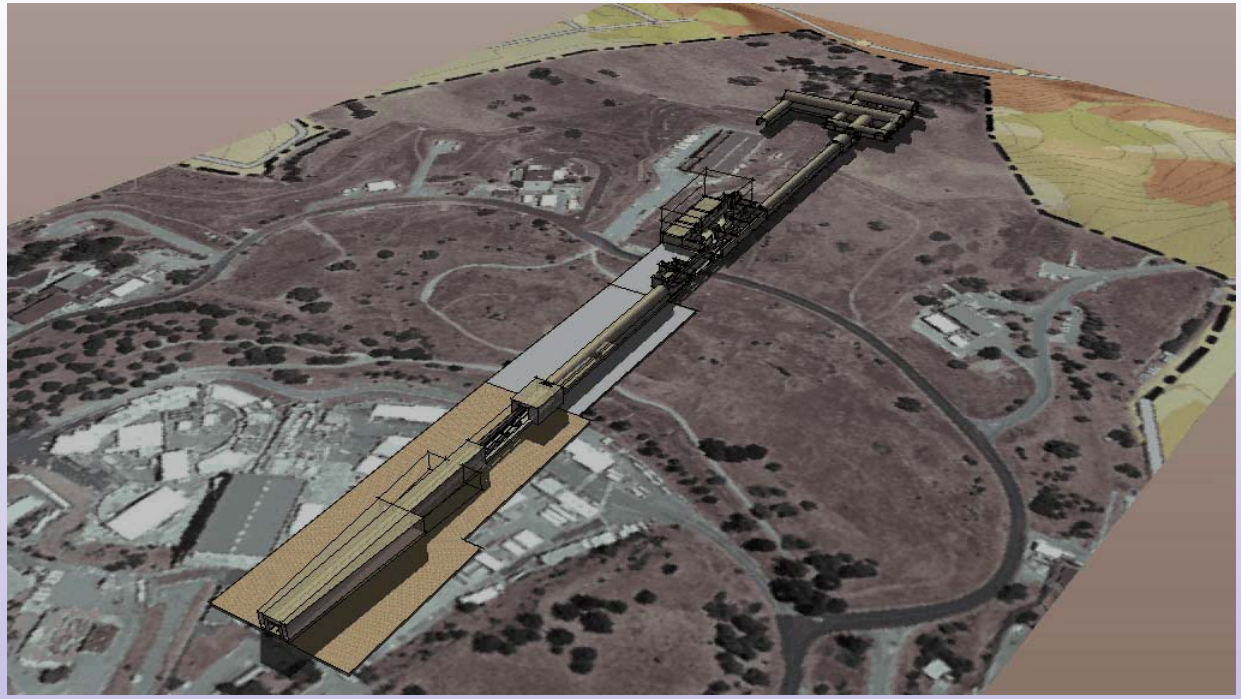
X-Rays have opened the Ultra-Small World -- Realm of *SPEAR3*

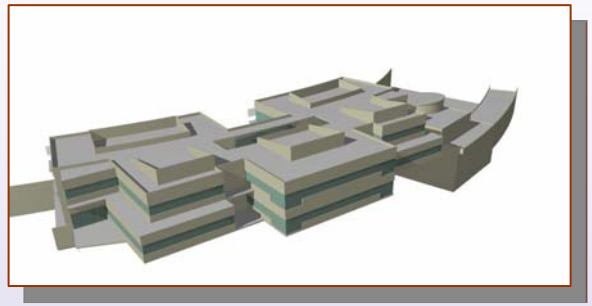


There is still an enormous amount to be learned about the ultra-small world of the physical, chemical, biological, materials, environmental and medical sciences

SPEAR3 has a long and exciting life of discovery!

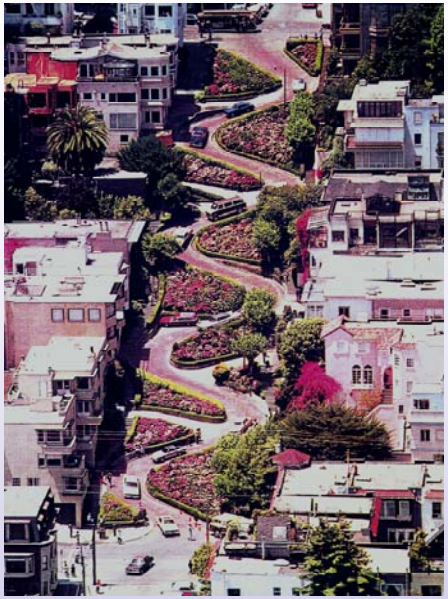
LCLS – a X-ray Free Electron Laser *being* Built at Stanford



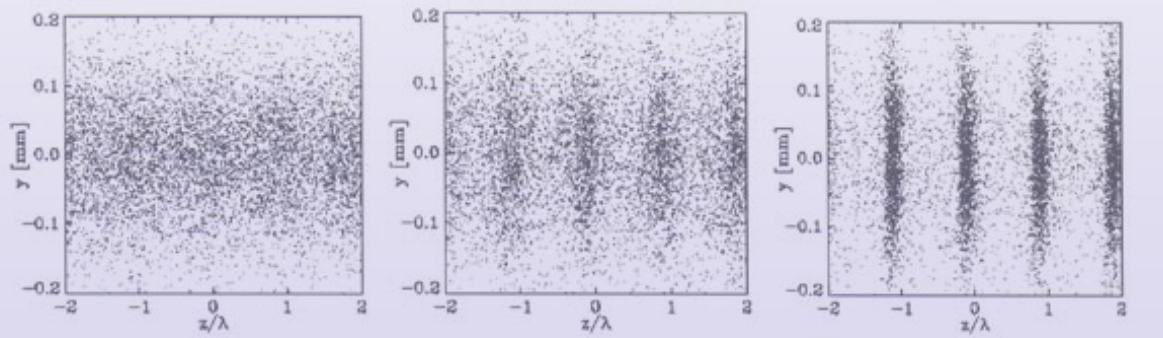


- LCLS is now in its construction phase
- Construction and commissioning completed by April, 2009, operation then begins
- LCLS will provide ultrashort and ultrabright x-ray photon pulses – delivering in a few tens of femtoseconds (what today's 3rd generation synchrotrons provide in a second).
- LCLS construction is funded by US DOE and the total project cost is about $380M

For LCLS - We Need a Path and Amplifier of Coherent Motion



100 meter long undulator



Excerpted from the TESLA Technical Design Report, released March 2001

LCLS Construction

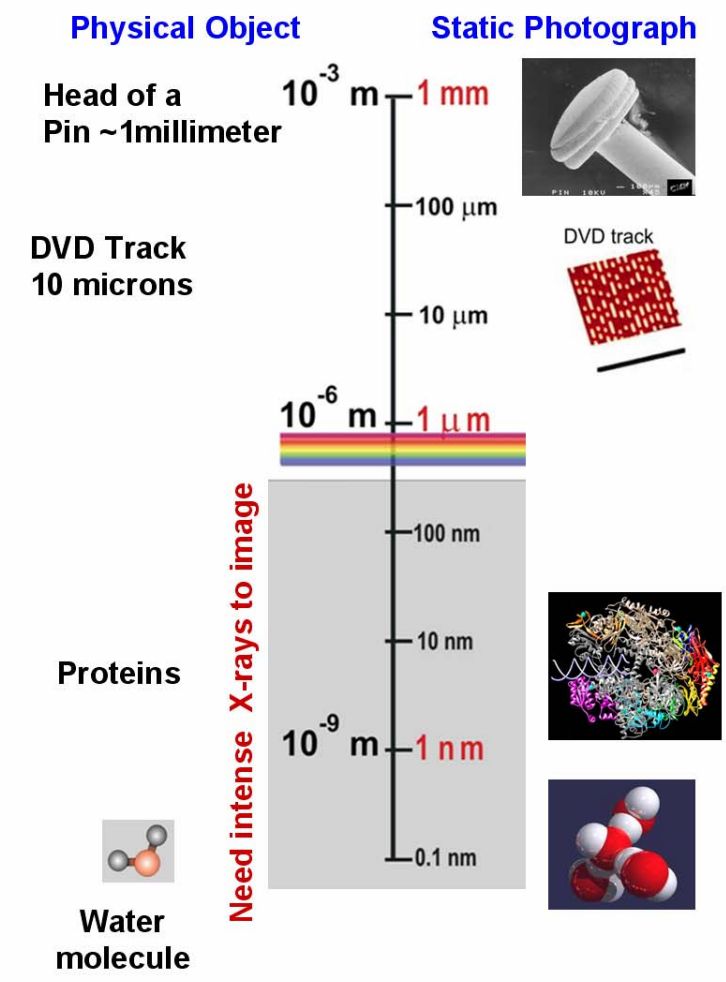
- **Budget - $379M through 2009. Commissioning in FY2008. Operations start in April 2009**

Linac Coherent Light Source Funding Profile (AYM$)									
	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Total
TEC Funding	0.00	5.93	7.46	50.08	85.54	105.50	50.50	10.00	315.00
OPC Funding	1.50	0.00	2.00	4.00	3.50	16.00	15.50	21.50	64.00
Total Funding	1.50	5.93	9.46	54.08	89.04	121.50	66.00	31.50	379.00

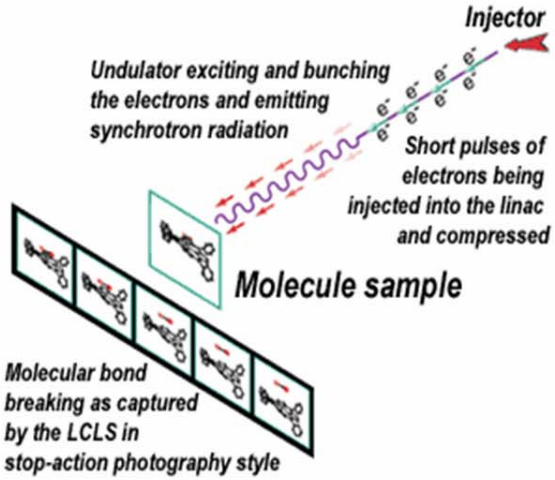
- **LCLS is a significant endeavor and large scale construction project – major construction begins in early Summer, 2006**
- **Commission begins in 2008 and operations in mid-2009**
- **Anticipate R&D on major upgrades to begin ~2009**
- **Stanford/SLAC in partnership with DOE has created the Ultrafast Science Center to provide a broad-based intellectual focus to underpin the LCLS program**

Stanford Linear Accelerator Center · SSRL · Advanced Photon Source · UCLA

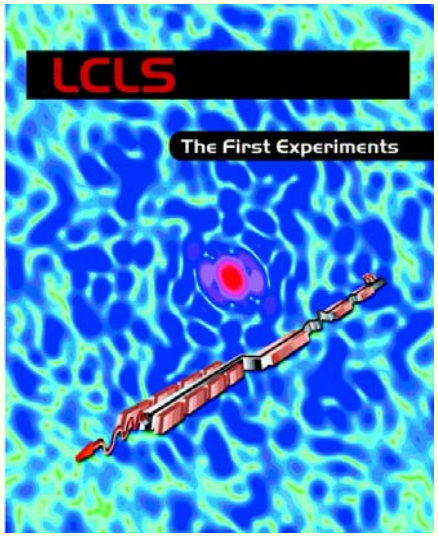
X-ray Lasers will open the Ultra-Small and Ultra-Fast Worlds –Realm of *LCLS*



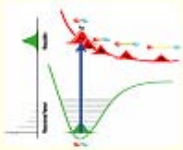
What if one wants to *see the ultra-fast motion of ultra-small objects*? LCLS can take a atomic scale "movie" of ultra-small objects performing their tasks.



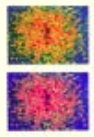
LCLS Science Program – New Opportunities for Discovery



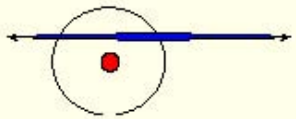
Program recommended by the LCLS SAC and being developed by SSRL/LCLS working with an international team of scientists working with accelerator and laser physics communities



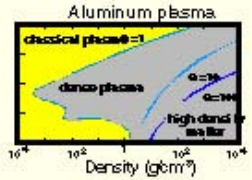
***Femtochemistry and Biology** – watching motions of atoms and molecules*



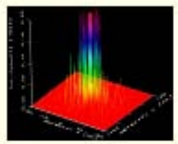
***Nanostructured Materials** – structure dynamics and function at sub nm scales*



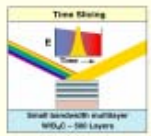
***Atomic Physics** – exploring how electrons move*



***Plasmas and Warm Dense Matter** – creating and studying exotic states of matter*

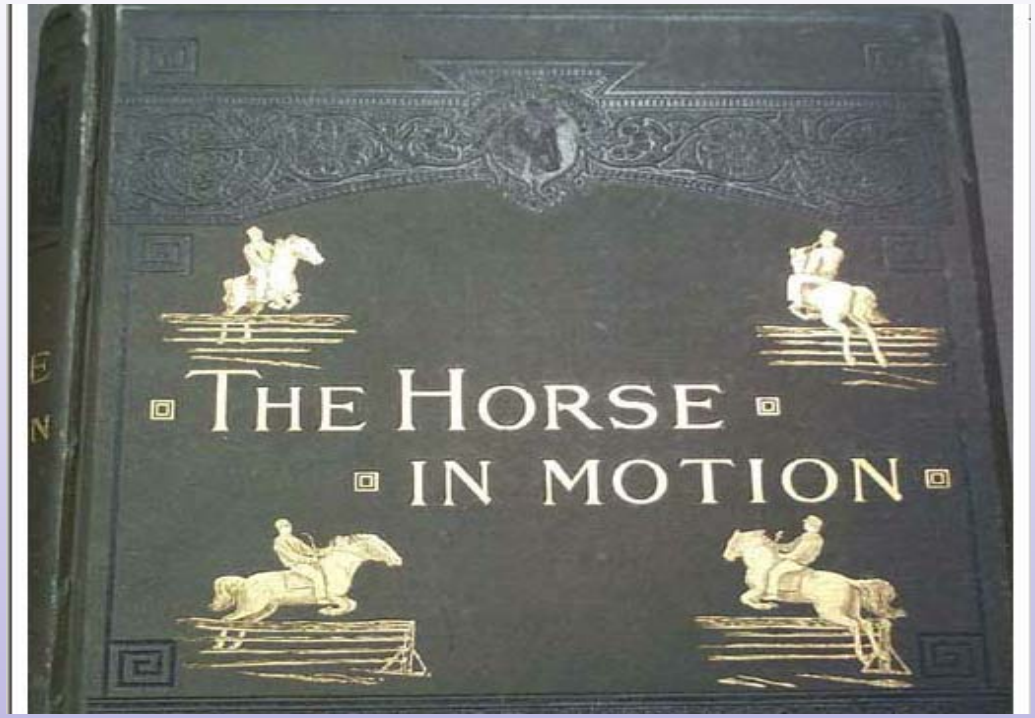


***Imaging of Nanoclusters and Single Biomolecules** – structures without crystals*

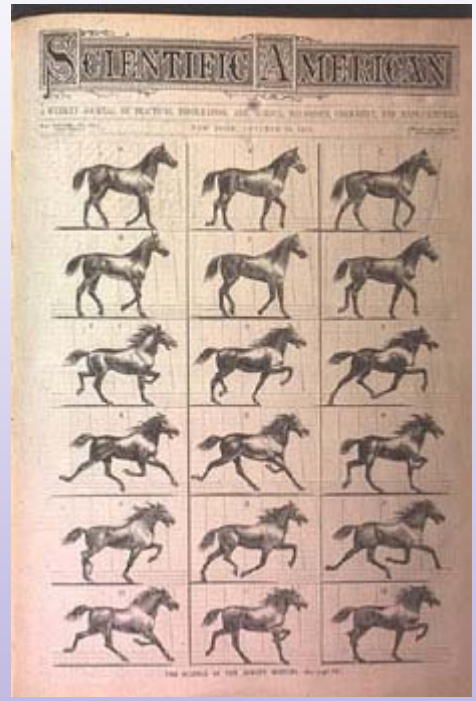


***X-ray Laser Physics** – pushing the boundaries of x-ray properties*

In Late 19th Century – Interest in the Question About Nature of How a Race Horse Galloped…



The Horse in Motion, J. B. D. STILLMAN, 1882



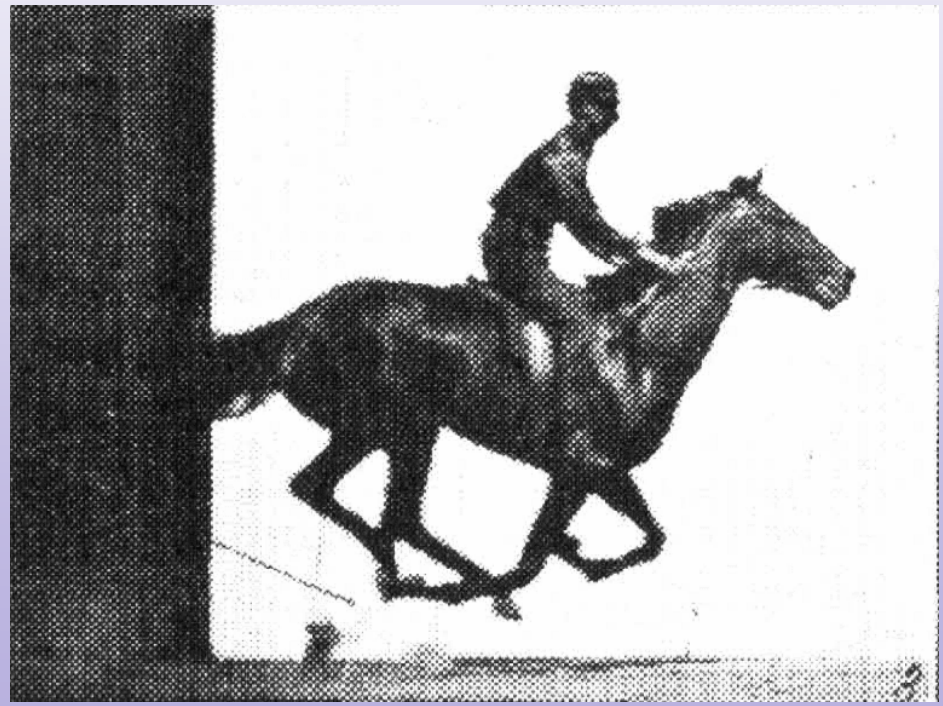
"THE SCIENCE OF THE HORSE'S MOTIONS" Scientific American, OCT 19, 1878

1878: Eadward Muybridge at Stanford – a Man Who "Stopped Time" by "Trip Wire" Photography

E. Muybridge

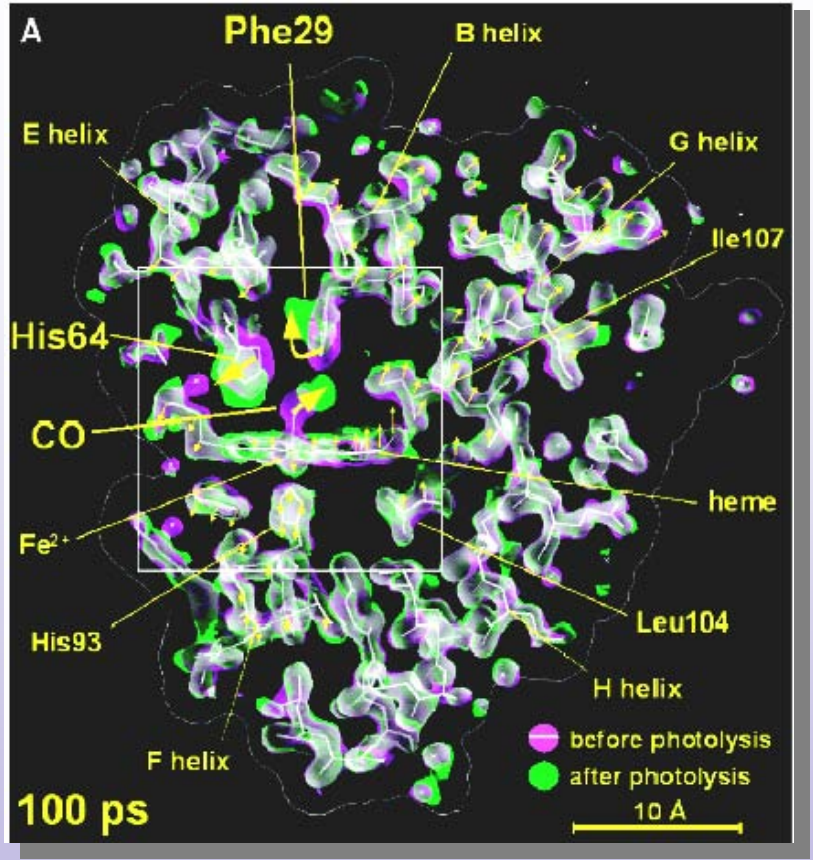
Muybridge and Leland Stanford disagree whether all feet leave the ground at one time during the gallop of a horse… a wager was resolved by a very clever series of "time lapsed" photographs

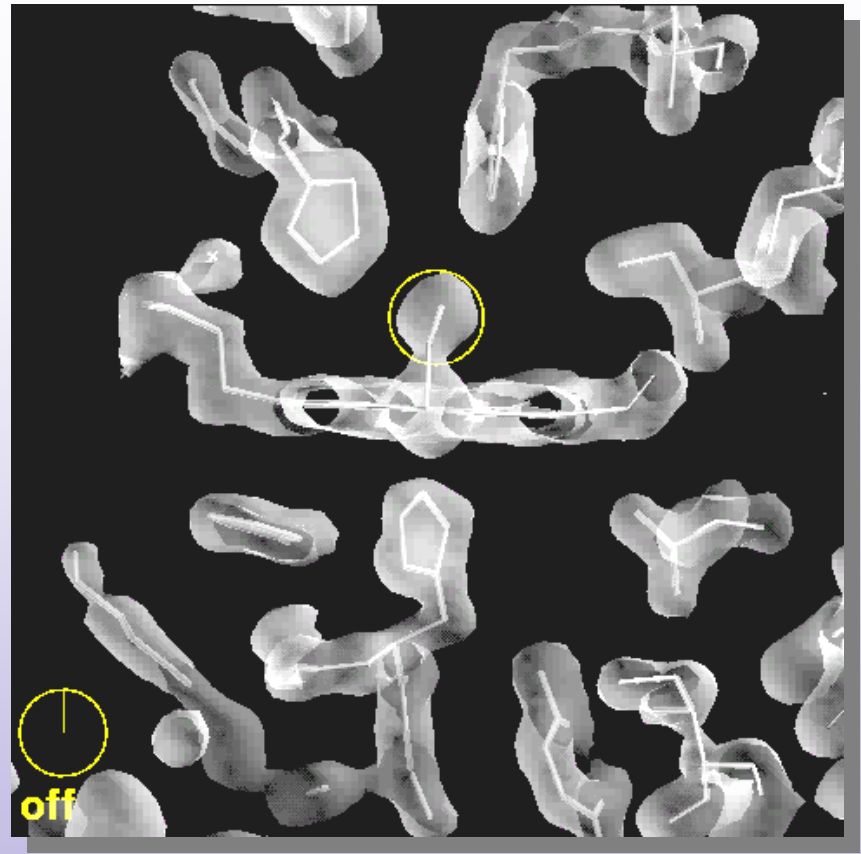
"The experiments photographing a horse at Stanford's Palo Alto stock ranch in 1878… Muybridge had improved a shutter to 1/1000 of a second and also improved the chemistry. He used 12 stereoscopic cameras in a 50 foot long shed alongside the track of the horse. In front of each camera was a shutter that consisted of two slides with an opening or a slit in each of them. Both slides were connected to two India-rubber bands and on release moved in opposite directions. In the brief moment these slits were both in front of the lenses the photograph was taken."



E. Muybridge, Animals in Motion, *ed.* by L. S. Brown (Dover Pub. Co., New York 1957) or go to www.google.com and type "Eadward Muybridge" for numerous links.

Time-resolved Structural Biology - Current State-of-the-art is ~100 psec



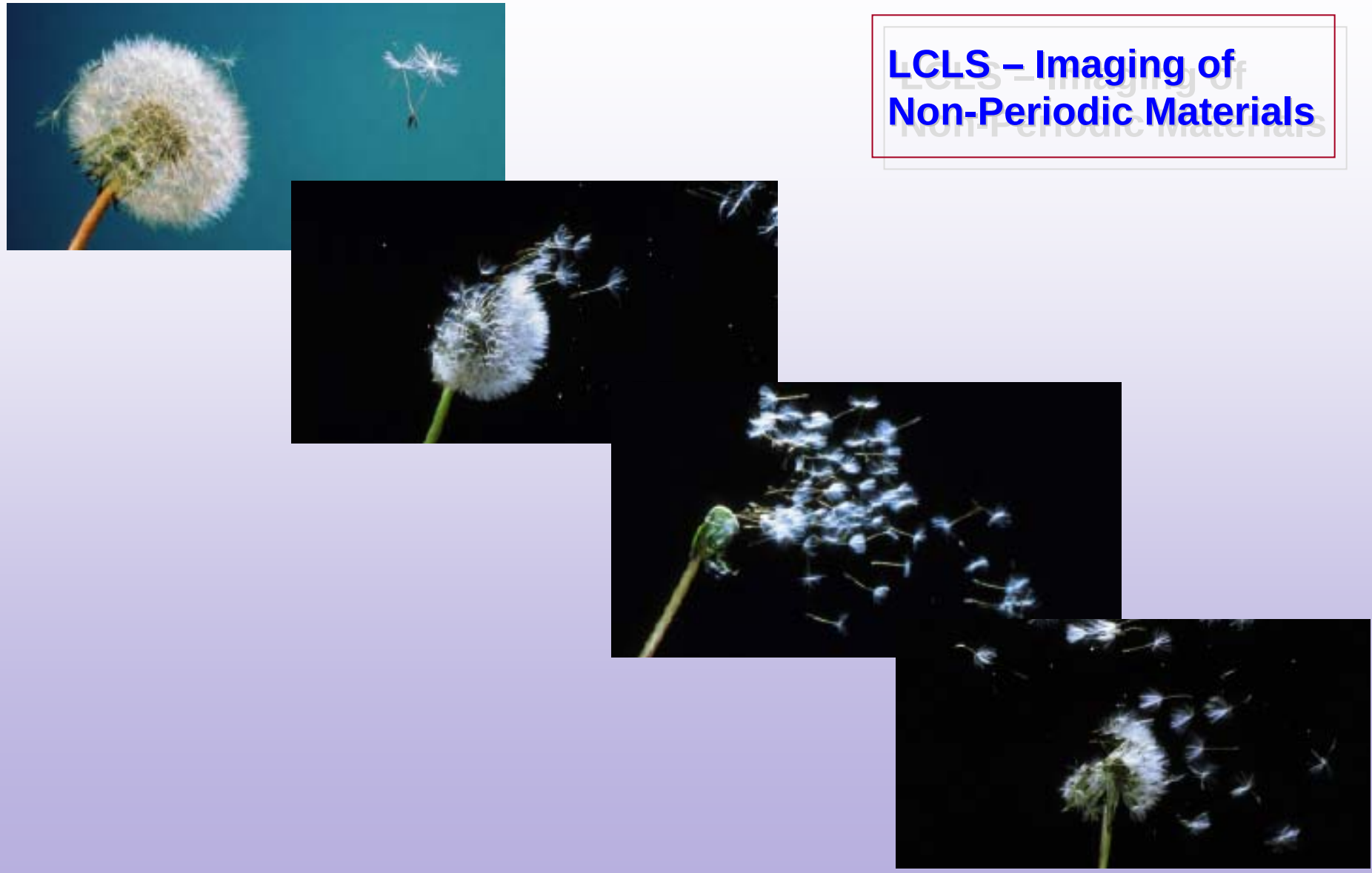


- **Correlated motions of heme, protein backbone/side chains already evident at 100 psec**
- **Early displacements of side chains much more dramatic than static differences between Mb and MbCO**
- **CO first moves ~2 Å (site 1), then escapes into sites 2 and 3 and by 32 ns appears in sites 4 and 5. Elapsed time of video is 0 to 3.16 μs.**

LCLS will enable ~1000 times faster time resolution

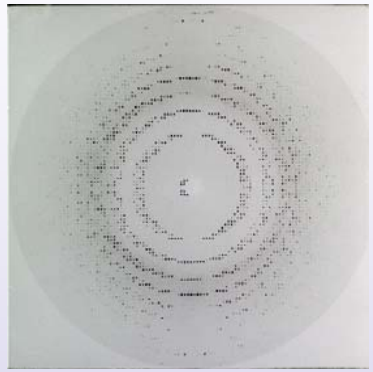
Schotte *et al*., *Science* **300**, 1944 (2003)

LCLS – Imaging of Non-Periodic Materials

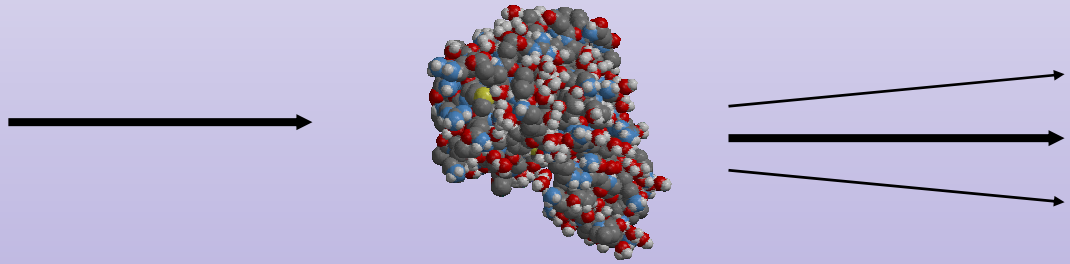


Imaging of Single Particles and Biomolecules at Atomic Resolution

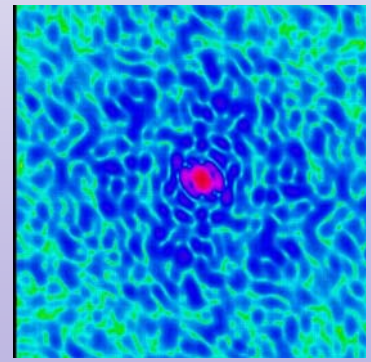
Conventional method: x-ray diffraction from crystal



LCLS approach: x-ray scattering from single protein molecule

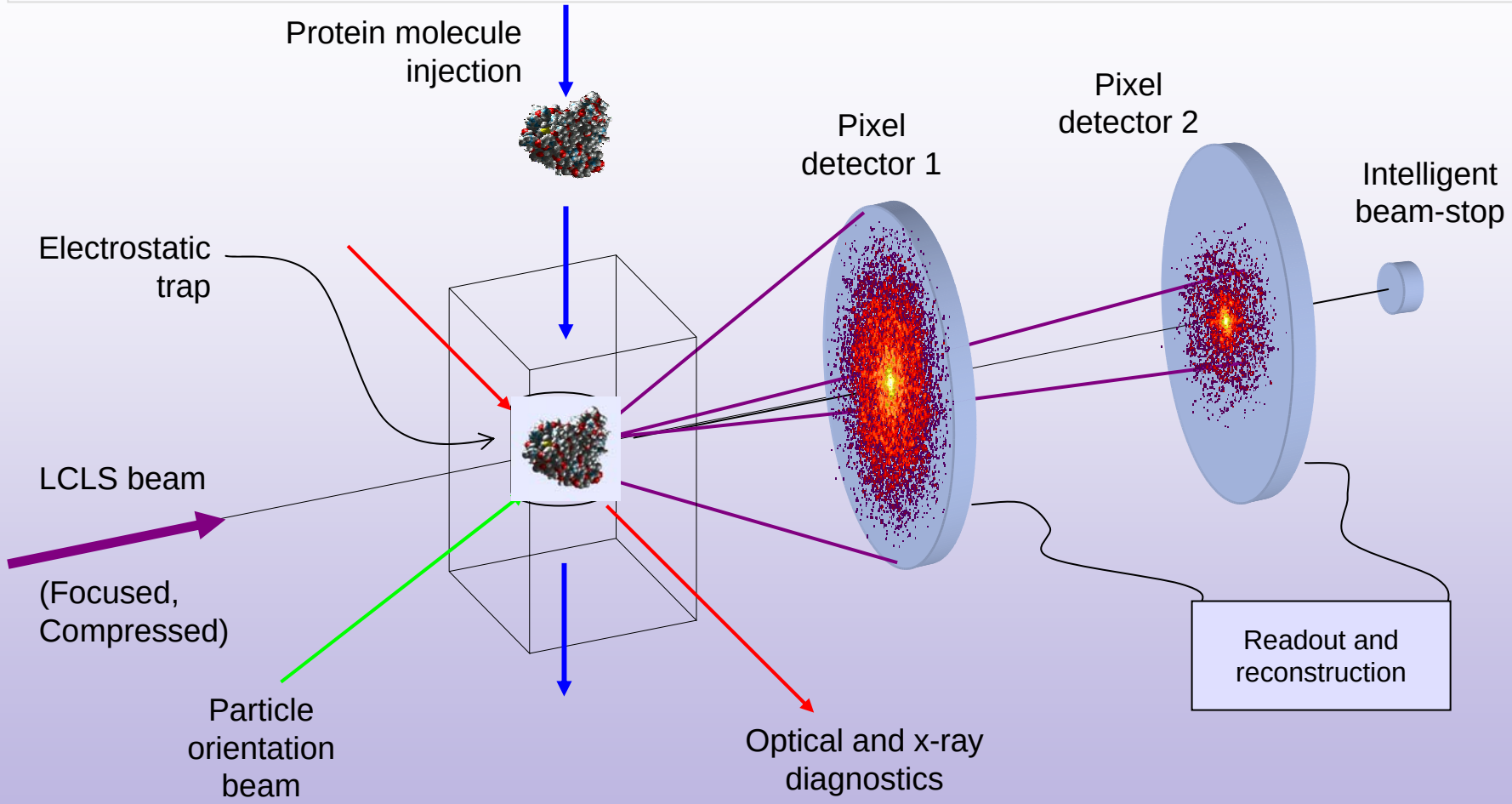


Lysozyme



Calculated scattering pattern from lysozyme molecule

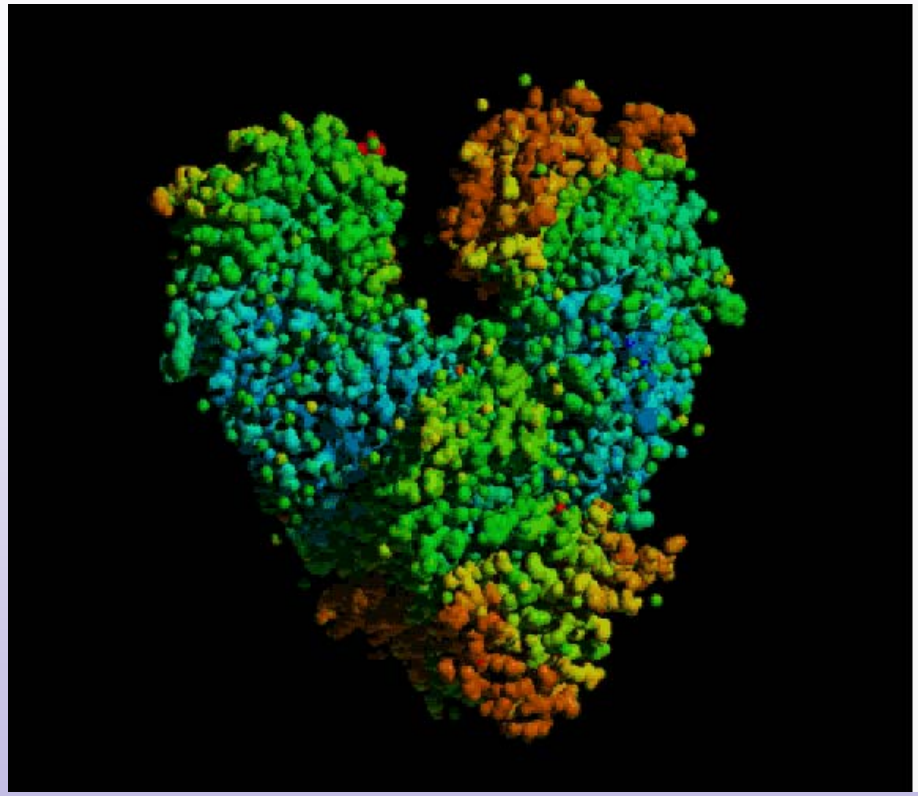
LCLS - with ~10^{12} Photons/pulse - Has Potential to Image Single Large Biomolecules or Clusters

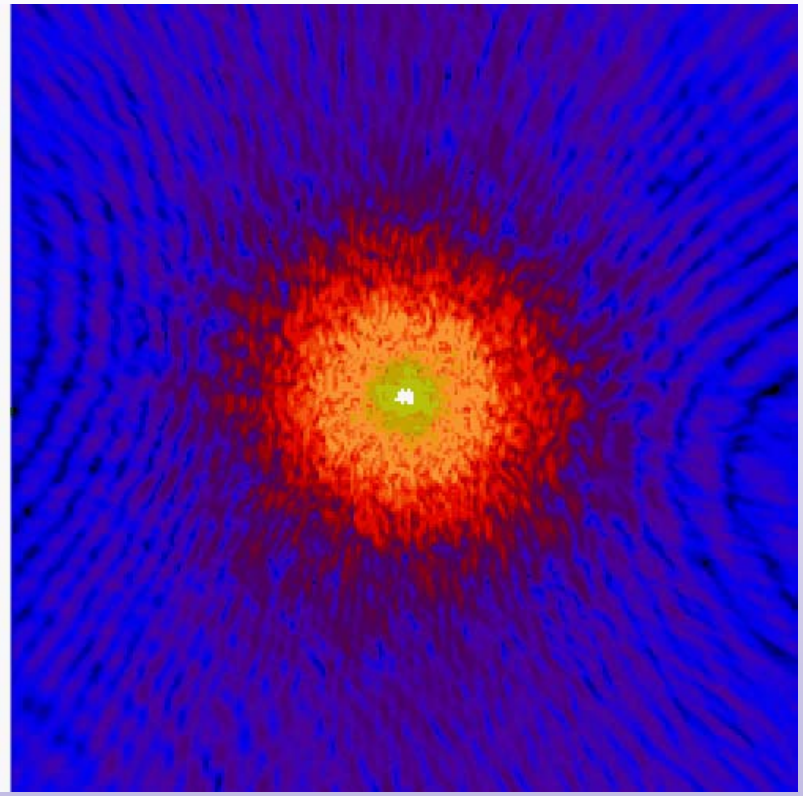


A key question: **Can we produce an x-ray pulse that is**

short enough?
intense enough?

Non-periodic Biomolecules or Clusters Imaging – the Potential Outcome

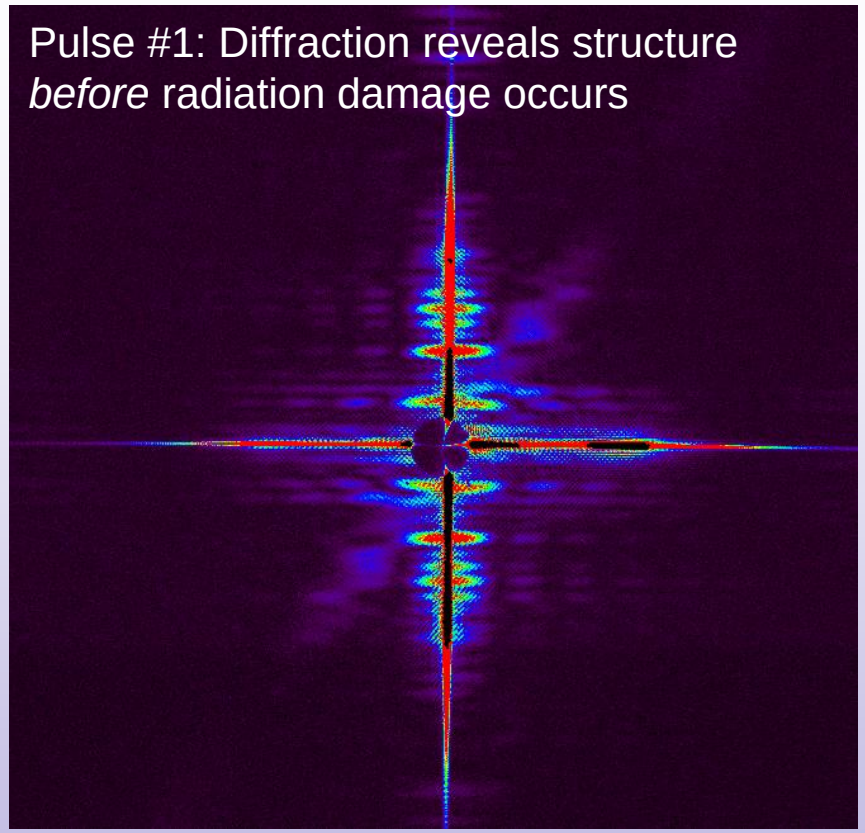


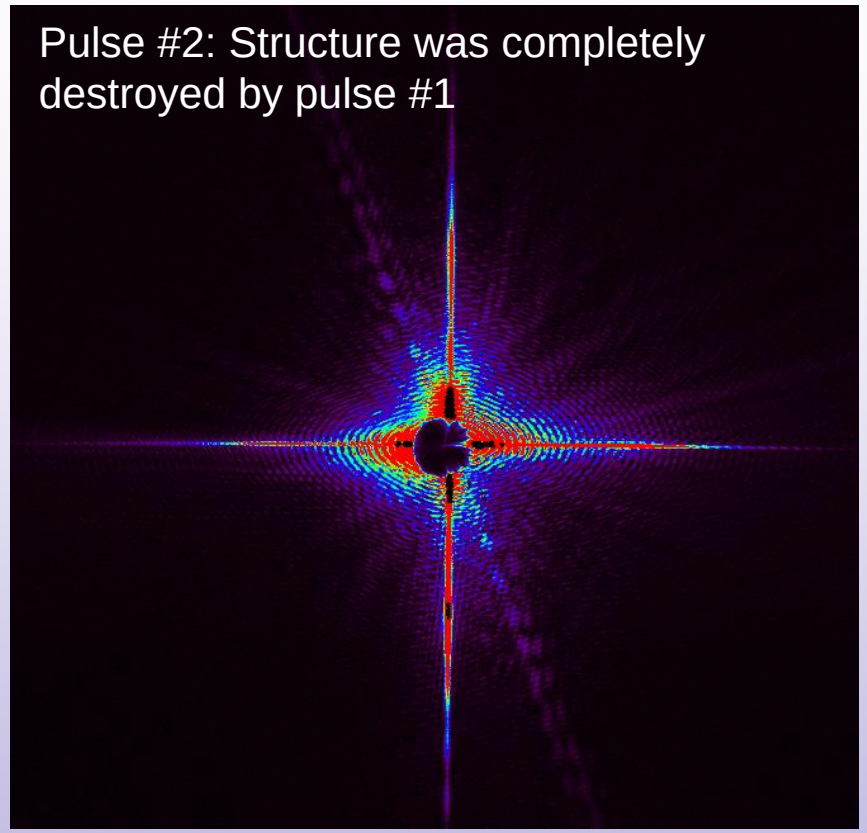


Diffraction patterns of the molecule in many orientations are measured – from which an image can be reconstructed

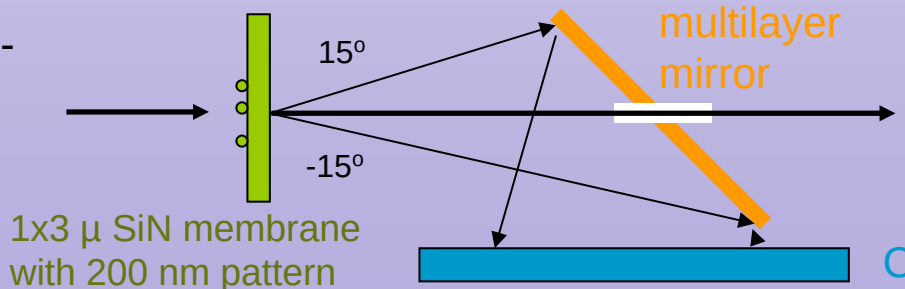
Chapman and collaborators, *unpublished*; also see work by Miao, Hodgson and collaborators, *Proc. Natl. Acad. Sci. USA* ***98,*** 6641 (2001).

Ultrafast Coherent Single Shot X-ray Diffraction
– The First Demonstration at the VUV-FEL at DESY 2/1/06

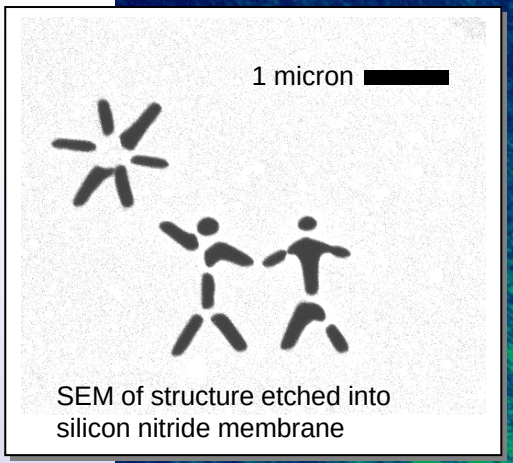


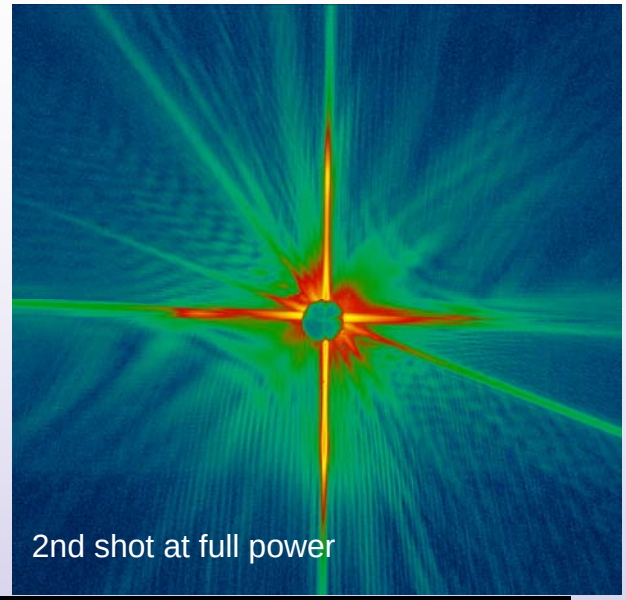


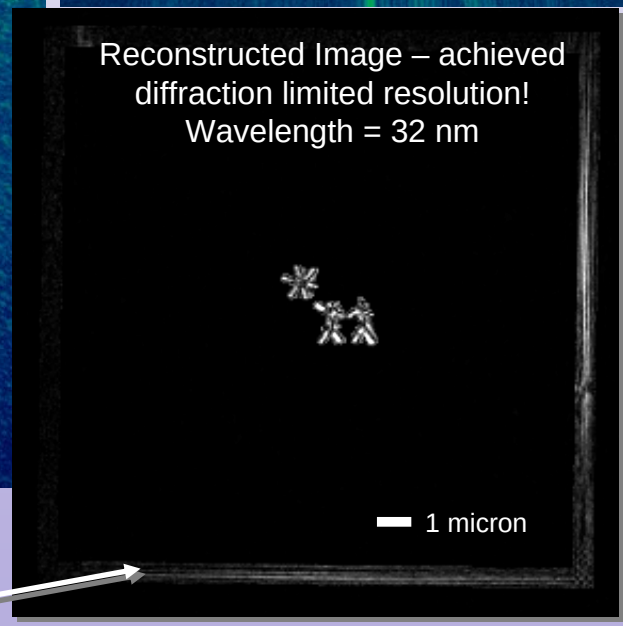
Incident VUV-FEL pulse:
30 fs, 32 nm,
3 x 10^{13} W cm^{-2}



Ultrafast Coherent Single Shot X-ray Diffraction
– Image Reconstructed Using Oversampling Algorithm







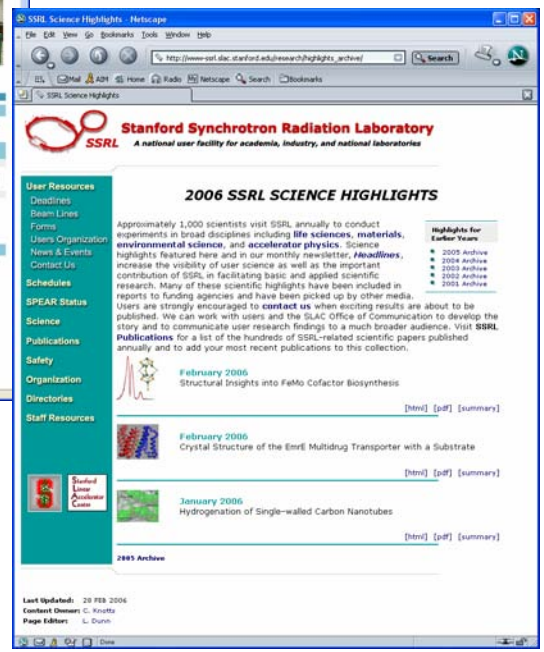
Edge of membrane support
also reconstructed

Chapman, *etal. Nature*, submitted

For Further Information

See http://www.slac.stanford.edu/

See http://www.today.slac.stanford.edu/



http://www-ssrl.slac.stanford.edu/research/highlights_archive/

May 9, 2006

For Further Information

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