National User Facility Organization Annual Meeting
Brookhaven National Laboratory, Upton, New York, June 8, 2010

Science and Technology of Future Light Sources

Uwe Bergmann

Linac Coherent Light Source
SLAC National Accelerator Laboratory

Famous X-Rays

19 Nobel Prizes Based on X-ray Work

CHEMISTRY:

1936 – Peter Debye

1962 – Max Perutz & Sir John Kendrew

1964 – Dorothy Hodgkin

1976 – William Lipscomb

1985 – Herbert Hauptman & Jerome Karle

1988 – Johann Deisenhofer, Robert Huber & Hartmut Michel*

1997 – Paul D. Boyer & John E. Walker*

2003 – Peter Agre & Roderick Mackinnon*

2006 – Roger Kornberg*

* Used SYNCHROTRON RADIATION

PHYSICS:

1901 – Wilhelm Röntgen

1914 – Max Von Laue

1915 – Sir William Henry Bragg & Sir William Lawrence Bragg

1917 – Charles Barkla

1924 – Karl Manne Siegbahn

1927 – Arthur Compton

1981 – Kai Siegbahn

MEDICINE:

1946 – Hermann Joseph Muller

1962 – Francis Crick, James Watson & Maurice Wilkins

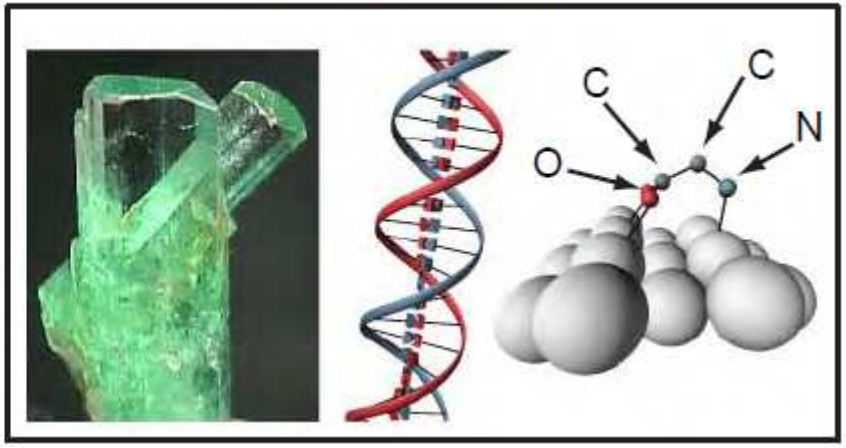
1979 – Alan M. Cormack & Sir Godfrey N. Hounsfield

#20 in 2010 – Ramakrishnan, Steitz, Ada Yonath*

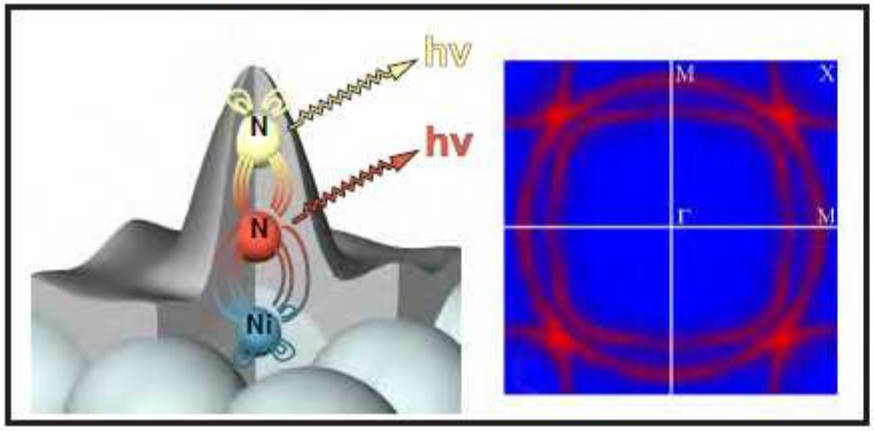
Why X-Rays?

Seeing the invisible

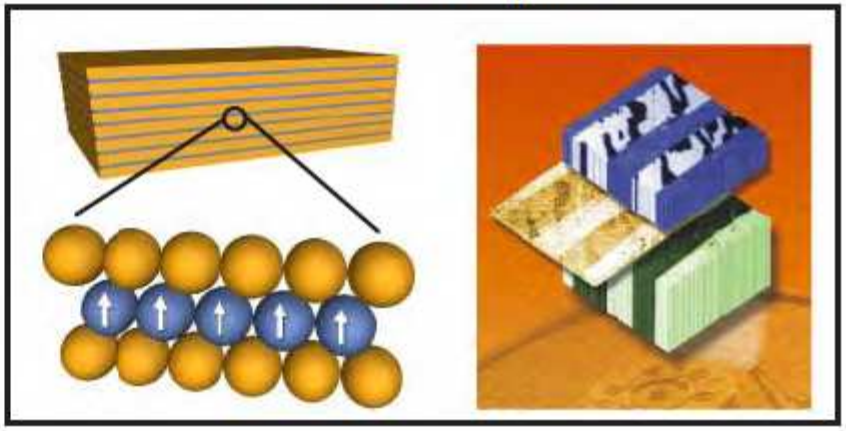
Where are the atoms?



Where are the electrons?



Where are the spins?



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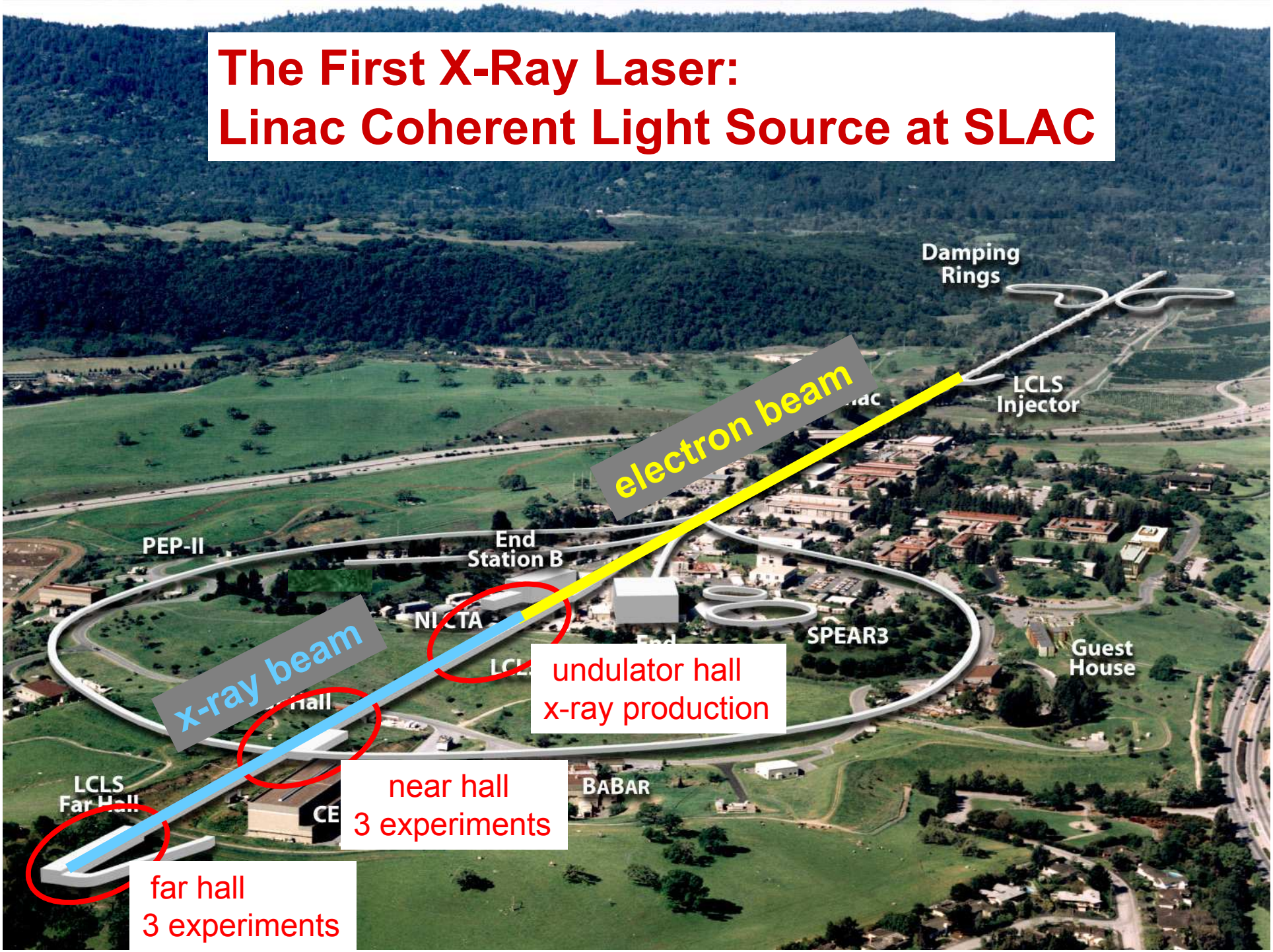
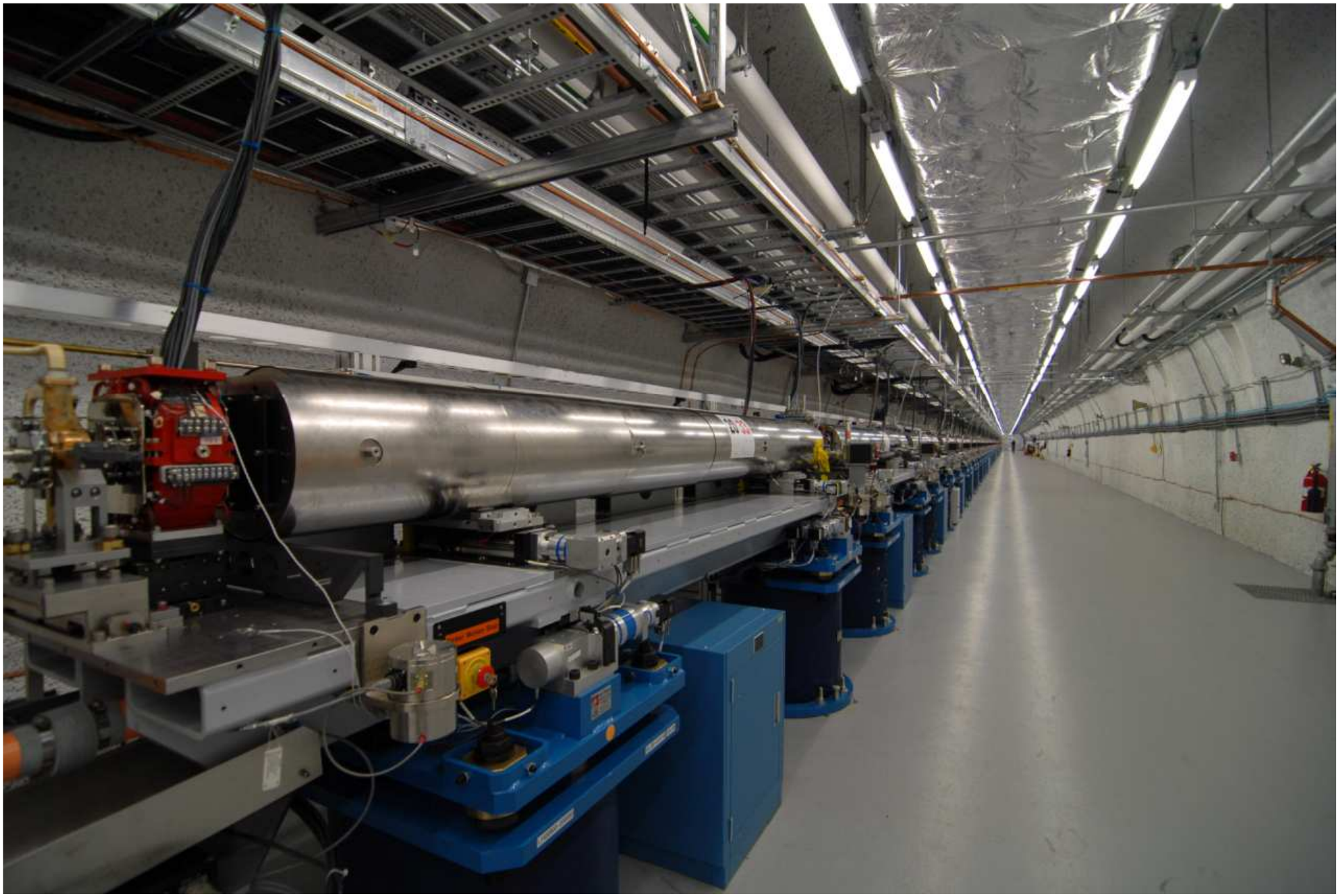
LELAND STANFORD JUNIOR UNIVERSITY 1891

April 15, 2009 First Lasing!

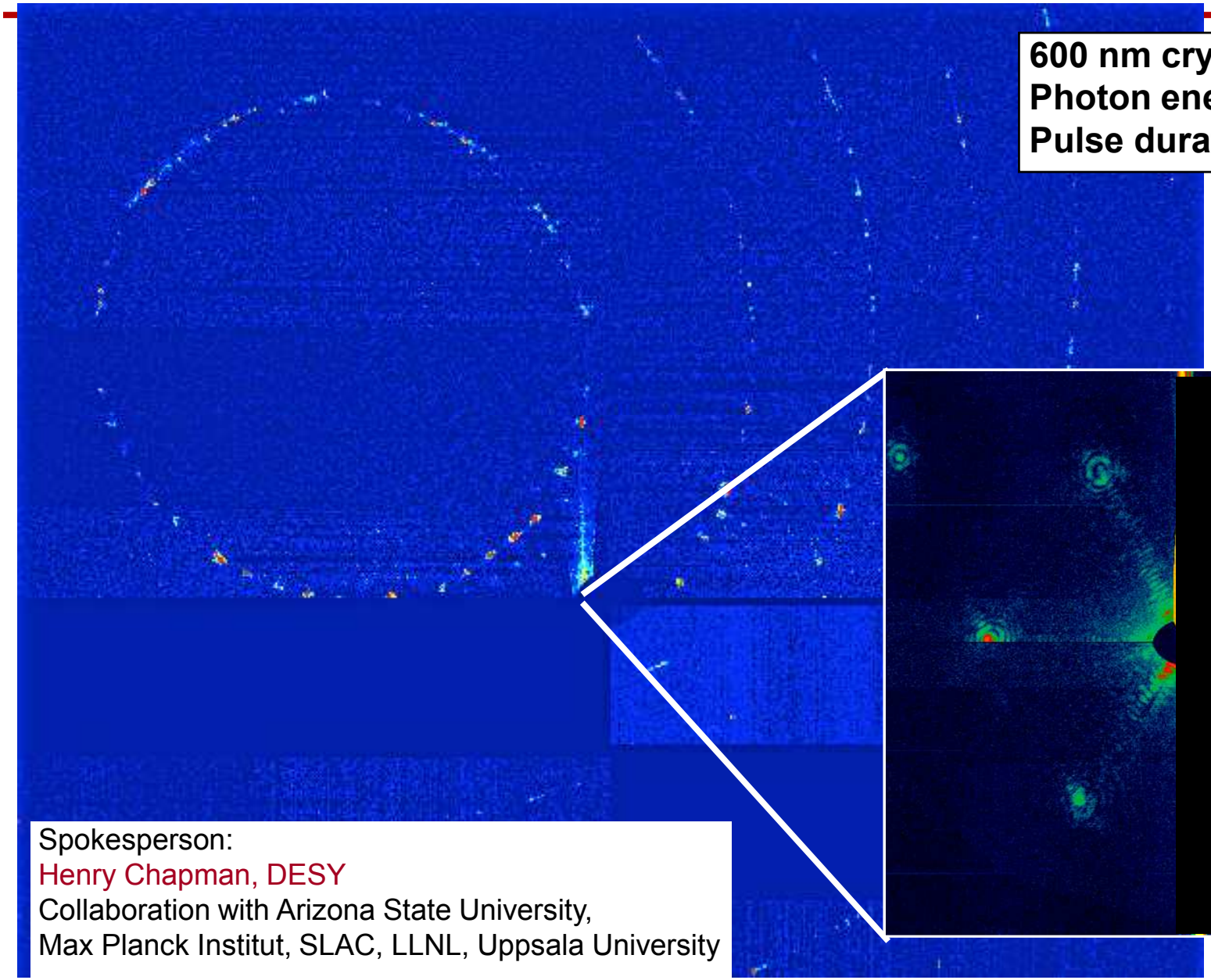
The First X-Ray Laser: Linac Coherent Light Source at SLAC



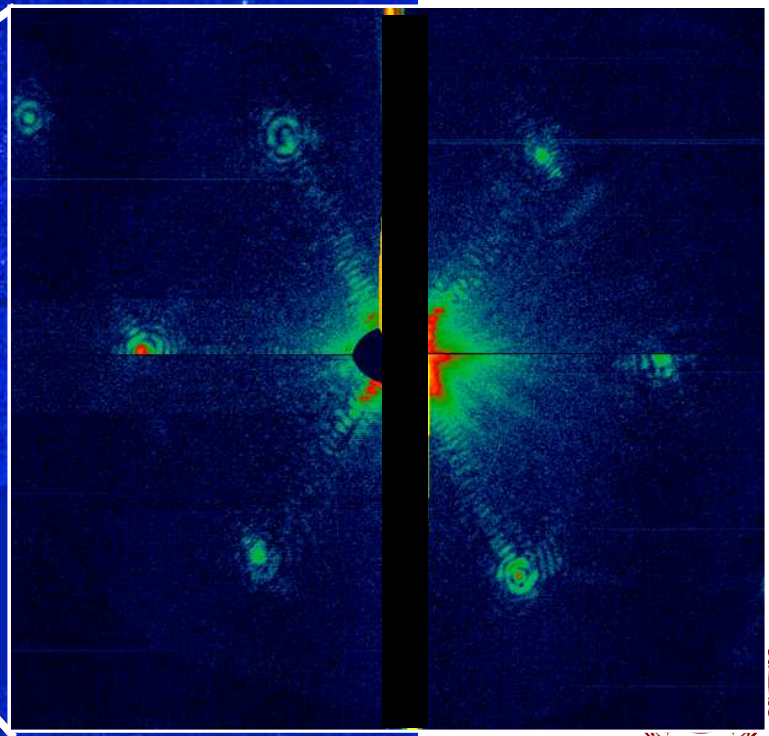
Undulator Hall: Where the X-Rays are Produced



Single-pulse Diffraction Pattern of a Photosystem I Nanocrystal



600 nm crystal in water jet
Photon energy: 1.8 keV
Pulse duration: 80 fs

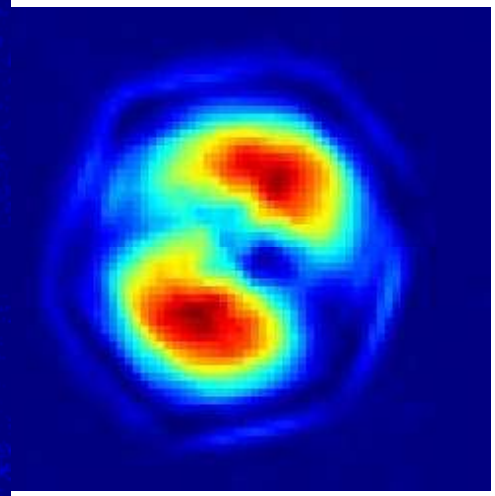


Spokesperson:
Henry Chapman, DESY
Collaboration with Arizona State University,
Max Planck Institut, SLAC, LLNL, Uppsala University

Single-pulse diffraction pattern of a single mimivirus particle

Single virus injected into beam
Photon energy: 1.8 keV
Pulse duration: 70 fs

RECONSTRUCTED WAVE FRONT:



WORK IN PROGRESS

Tomas Ekeberg and Filipe Maia (Uppsala)

Spokesperson:
Janos Hajdu, Uppsala University
Collaboration with DESY, CNRS Marseille, SLAC, LLNL, Max Planck, Arizona State University

Science and Technology of Future Light Sources

A White Paper

Report prepared by scientists from ANL, BNL, LBNL and SLAC. The coordinating team consisted of Uwe Bergmann, John Corlett, Steve Dierker, Roger Falcone, John Galayda, Murray Gibson, Jerry Hastings, Bob Hettel, John Hill, Zahid Hussain, Chi-Chang Kao, Janos Kirz, Gabrielle Long, Bill McCurdy, Tor Raubenheimer, Fernando Sannibale, John Seeman, Z.-X. Shen, Gopal Shenoy, Bob Schoenlein, Qun Shen, Brian Stephenson, Joachim Stöhr, and Alexander Zholents. Other contributors are listed at the end of the document.

Argonne National Laboratory

Brookhaven National Laboratory

Lawrence Berkeley National Laboratory

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December 2008

Science and Technology of Future Light Sources
A White Paper, December 2008

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Janos Hajdu (Uppsala)
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James Murphy (BNL)
Anders Nilsson (Stanford/SLAC)
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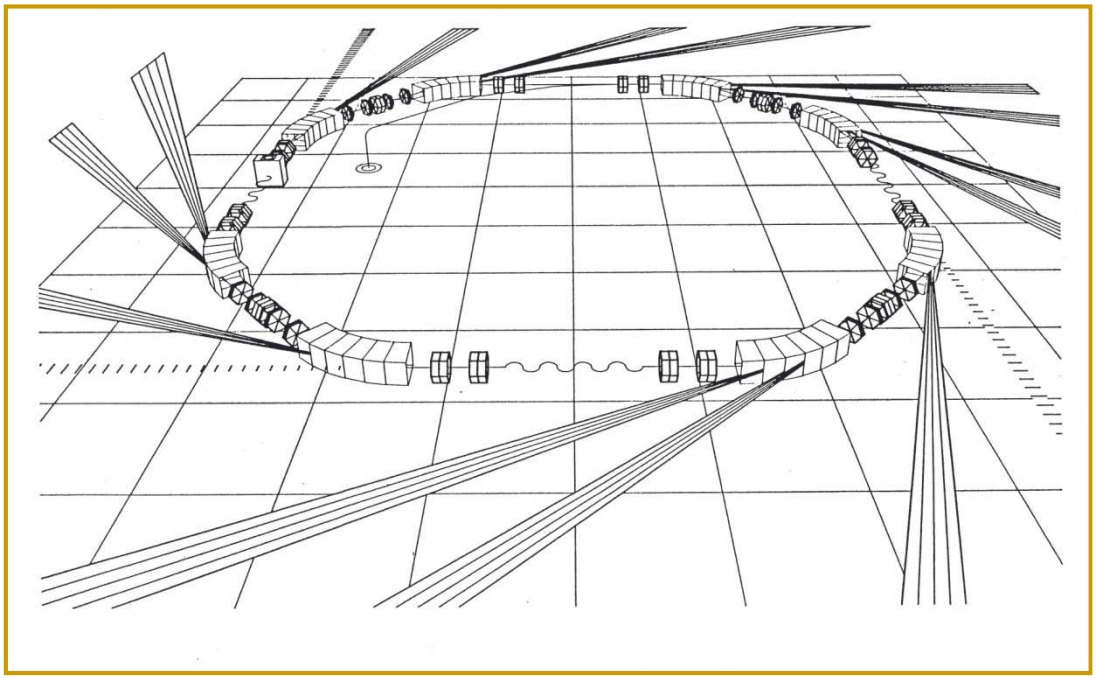
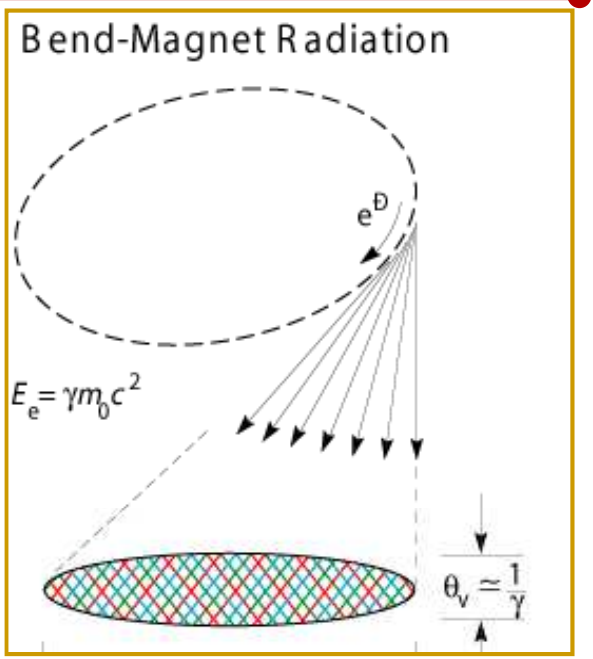
Basic Types of X-Ray Facilities

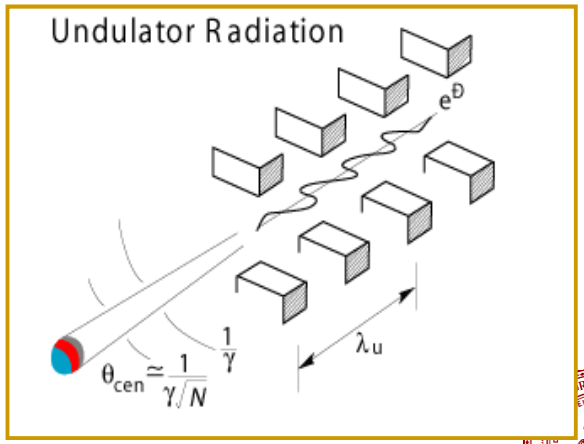
- Storage Rings
- Energy Recovery Linacs (ERLs)
- Free Electron Lasers (FELs)
- High-Harmonic Generation (HHG)

Concept of Synchrotron Storage Ring



Schematics of a synchrotron lab





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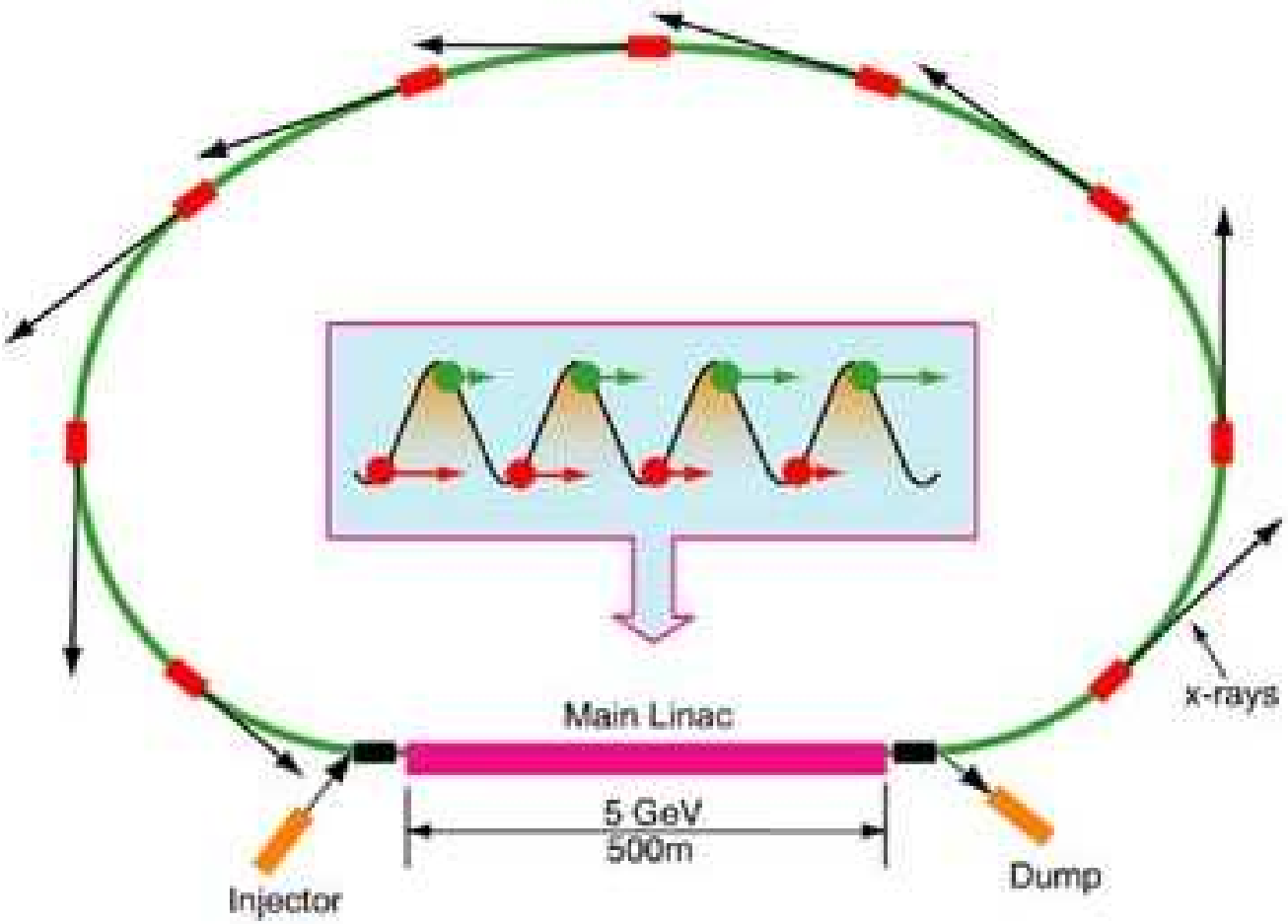
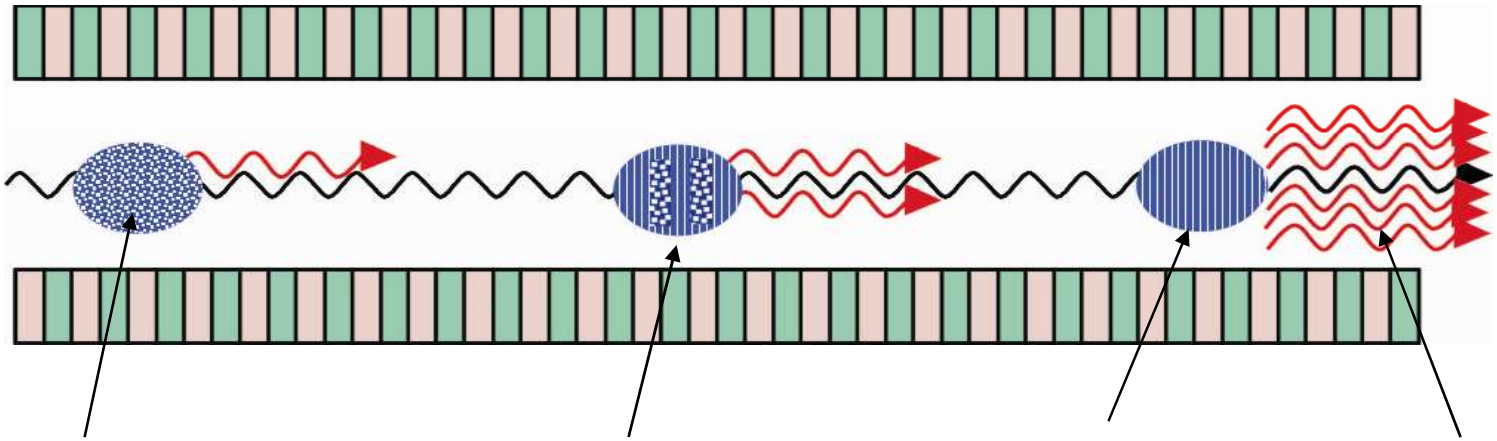
Concept of an Energy Recovery Linac



from CHESS website

Concept of a Free Electron X-Ray Laser

- Replace storage ring by a linear accelerator
  allows compression of electron bunch – use once then throw away
- Send electron bunch through a very long undulator



very short bunch length micrometers

photons from back of bunch create order in bunch

ordered electrons enhance **photon cloning**

cloned photons completely in tune, billion times higher intensity

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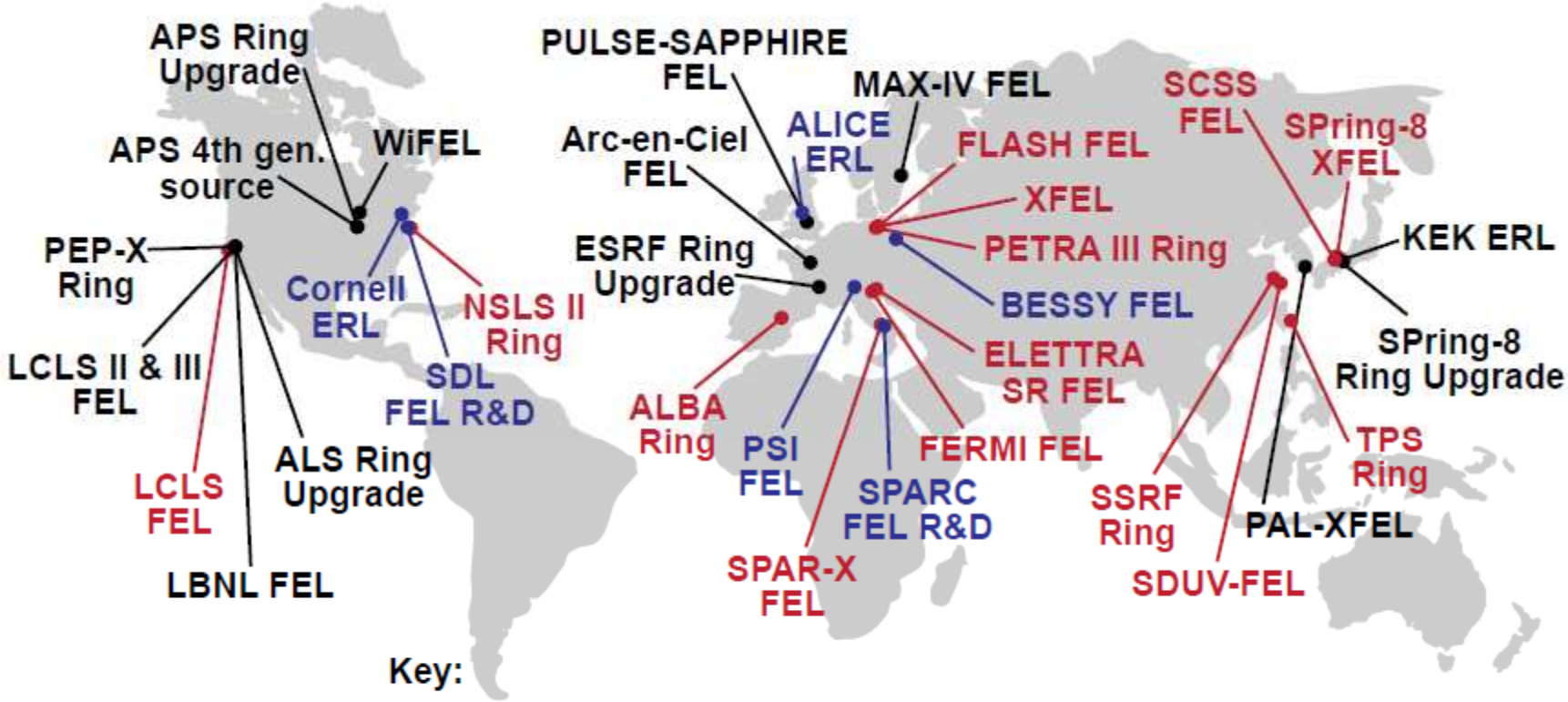
Light Sources around the Wolrd



Key:

Red - funded (operational or under construction)

Blue - funded R&D program

Black - concepts and proposals

10-2008
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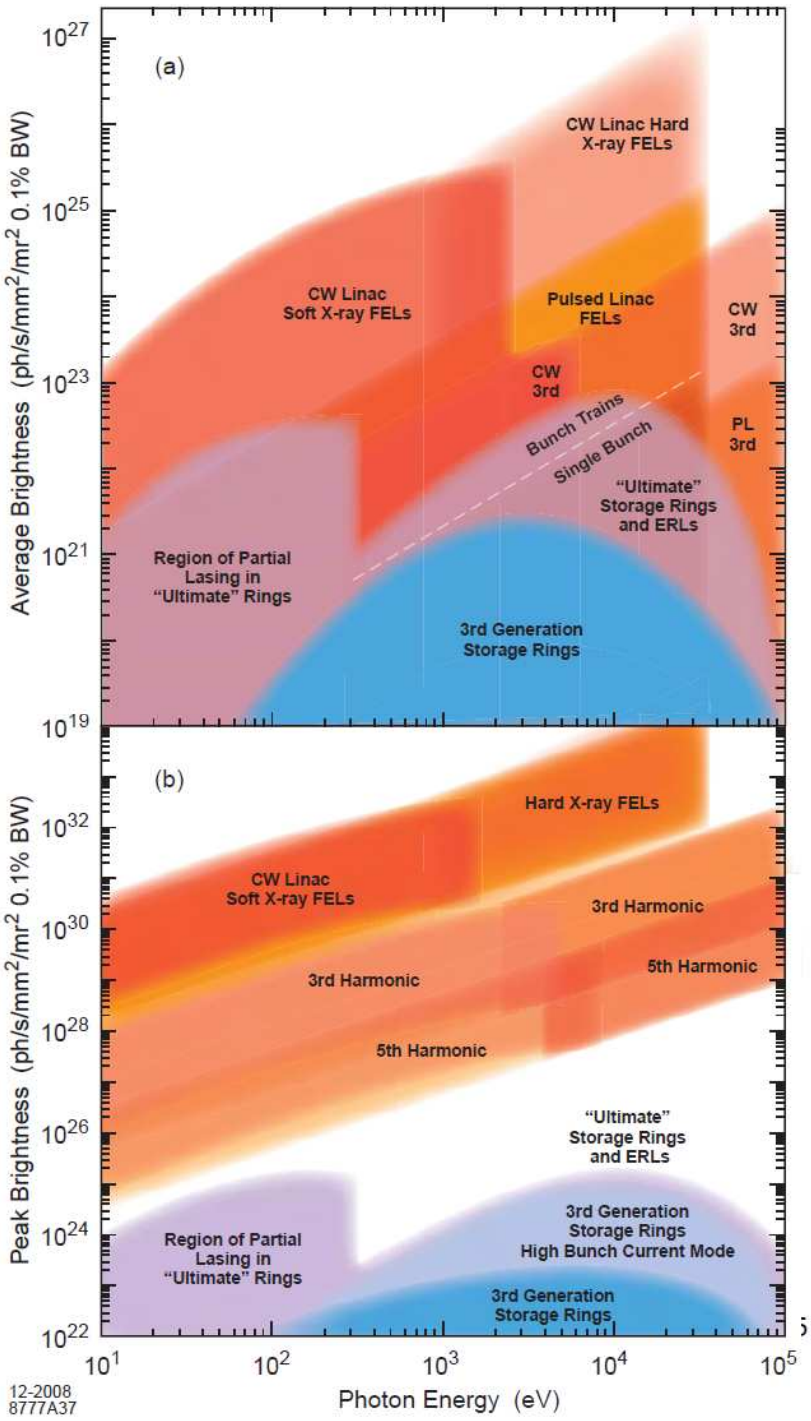

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Photons, Brightness, Flux, Intensity, Power, etc

$$\frac{\text{Number of Photons}}{\text{s mm}^2\ \text{mrad}^2\ 0.1\%\ \text{bandwidth}}$$

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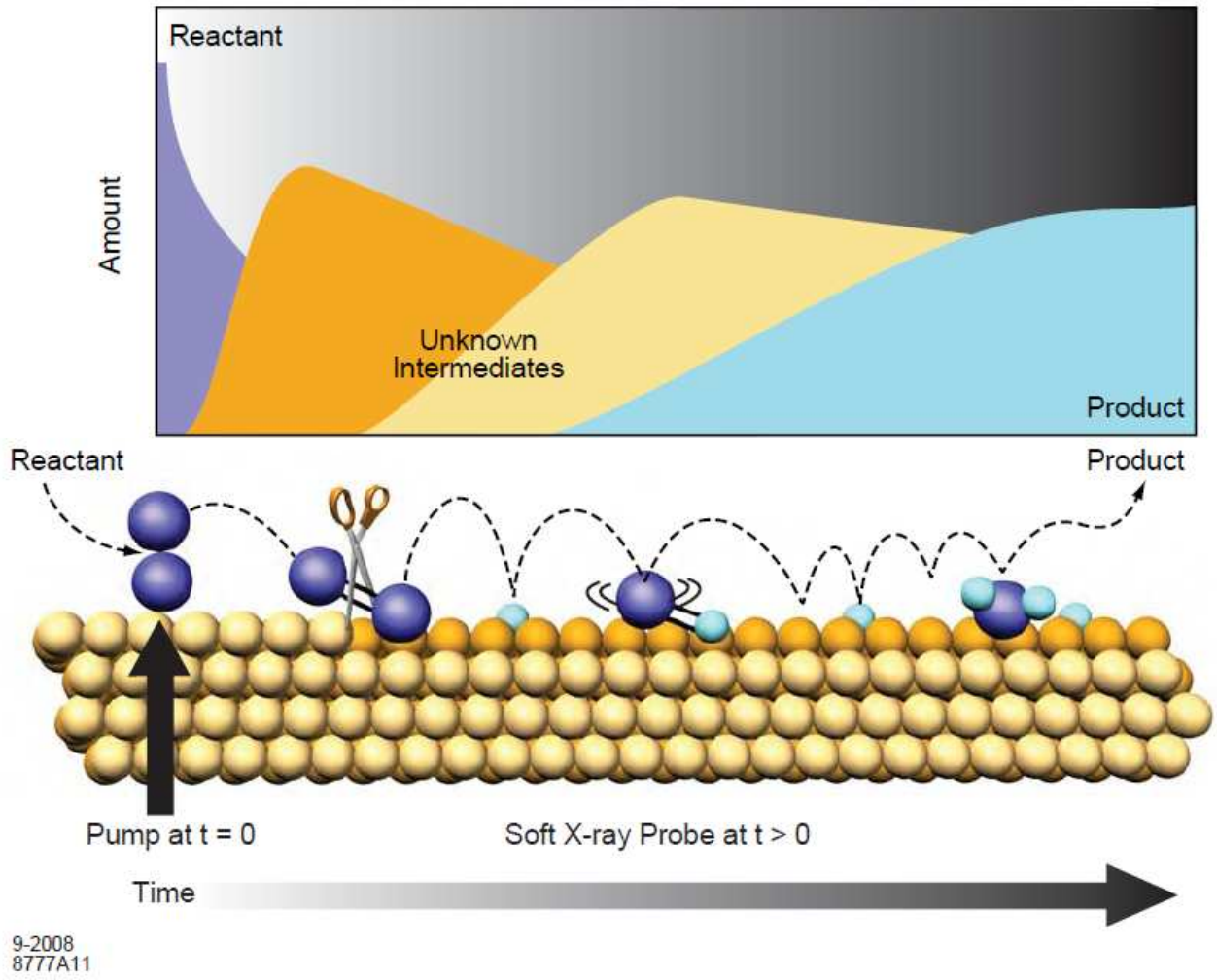
Real-Time Catalysis and Surface Chemistry



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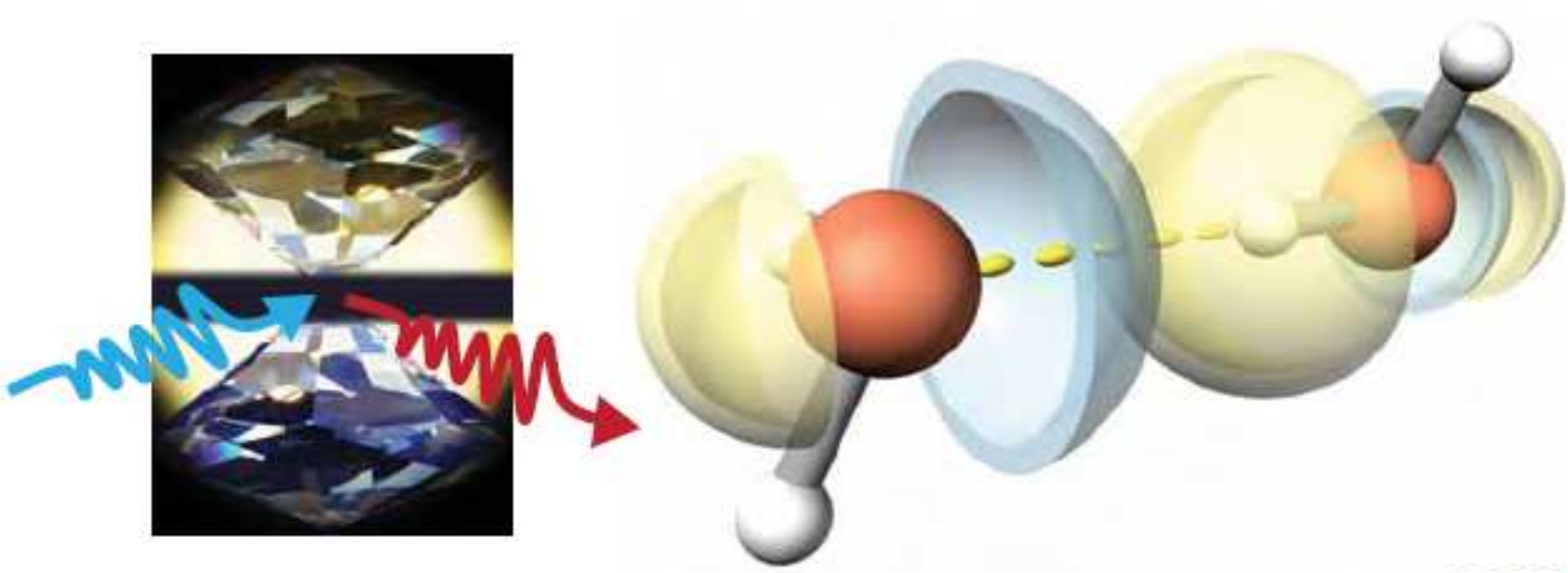
Novel Materials by Design and Materials Behavior under Extreme Conditions



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Novel Materials by Design and Materials Behavior under Extreme Conditions

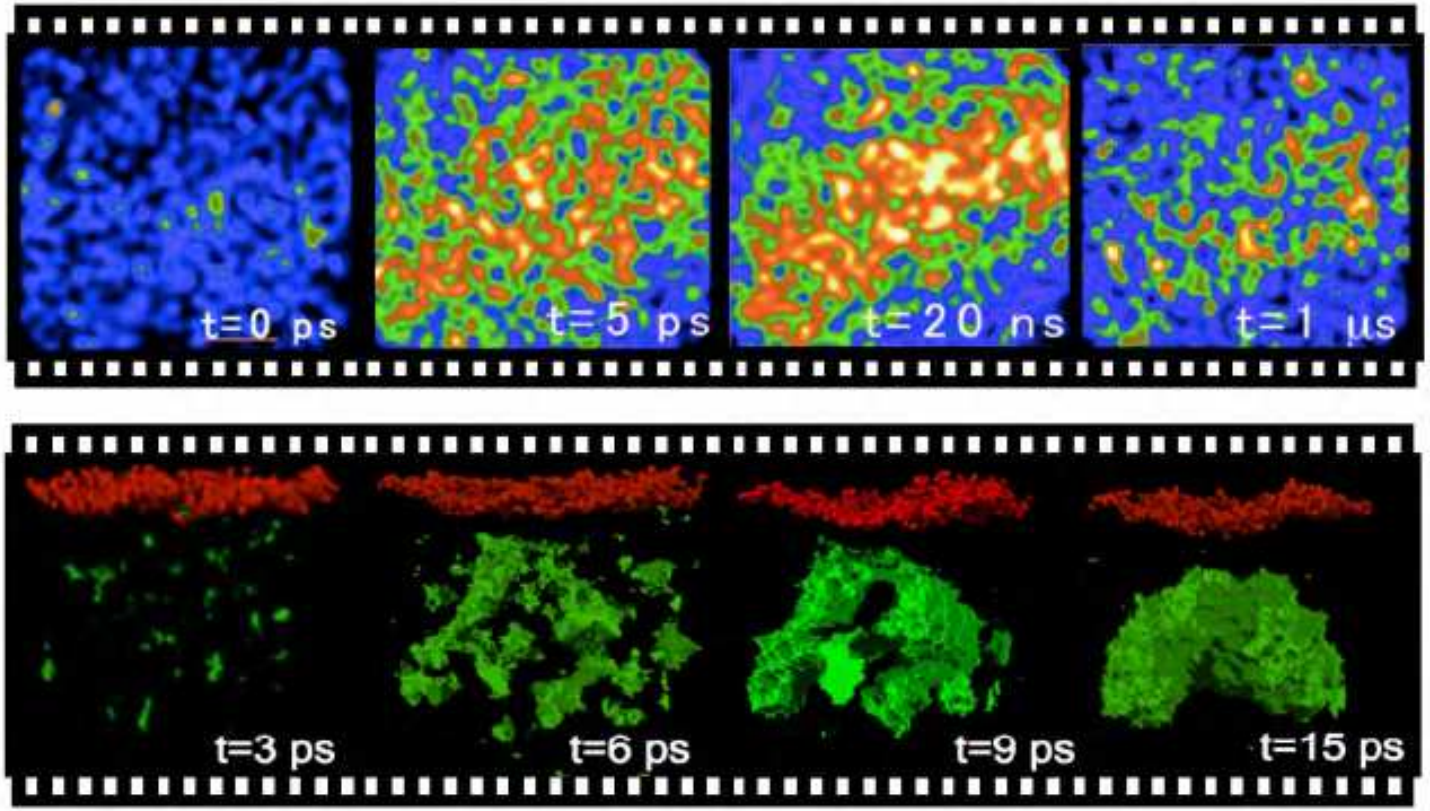

Figure 3.18. Top: Raw x-ray diffuse scattering measurements capturing the nucleation of nanoscale voids in optically excited semiconductors in real time. Bottom: molecular dynamics (MD) simulations showing the formation of nanoscale voids beneath the surface, supported by the experimental data. [Source: A. Lindenberg]

Movies of Folding Proteins

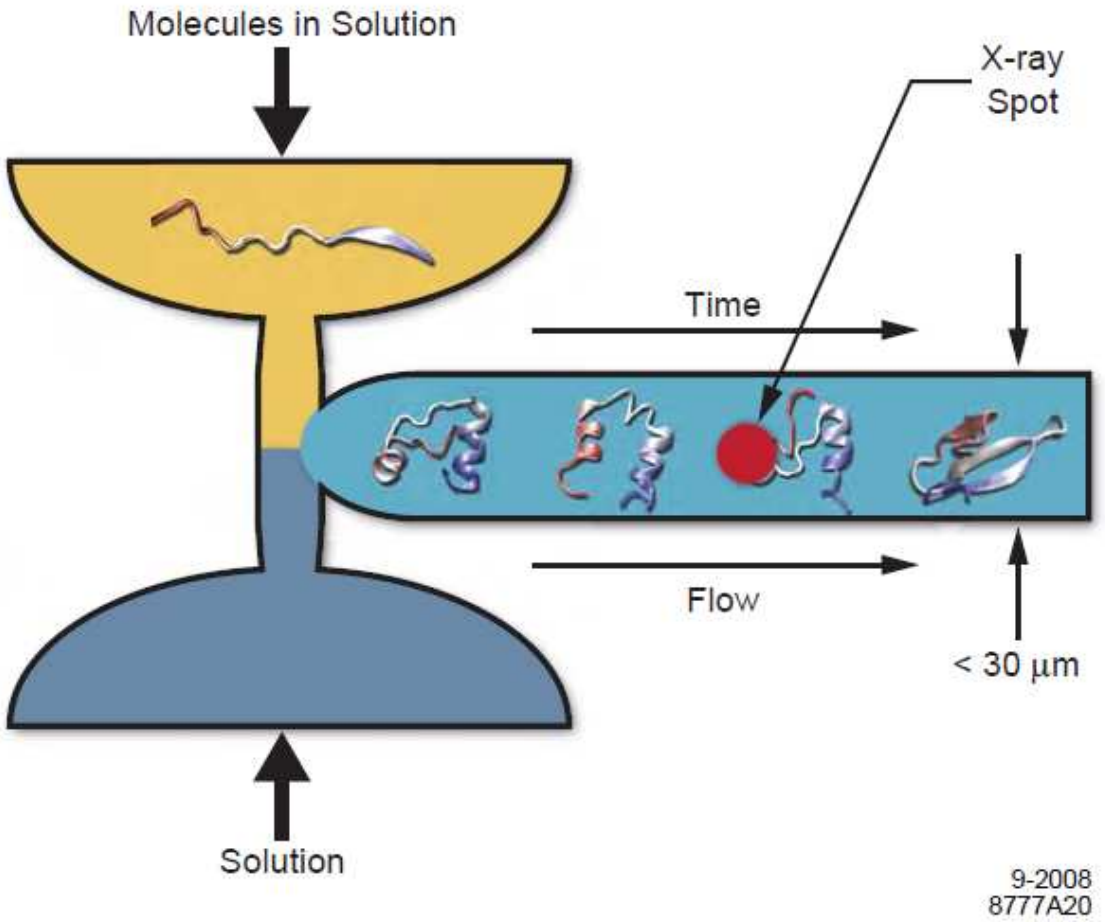

Figure 3.20. Schematics of a time-resolved x-ray scattering experiment using a nano-fluidic continuous-flow mixer [Matsumoto *et al., JACS* **129**, 3840 (2007)]. An unfolded-protein solution (top) is mixed with a second solution (bottom) that promotes folding. The x-ray beam interacts with the solution jet at different distances from the mixing point, corresponding to different time points in the protein folding process [The folded protein models adopted from an MD simulation by Freddolino *et al.,. Biophys. J.* **94**, L75 (2008)].

Understanding Light-Induced Catalysis —Learning from Nature

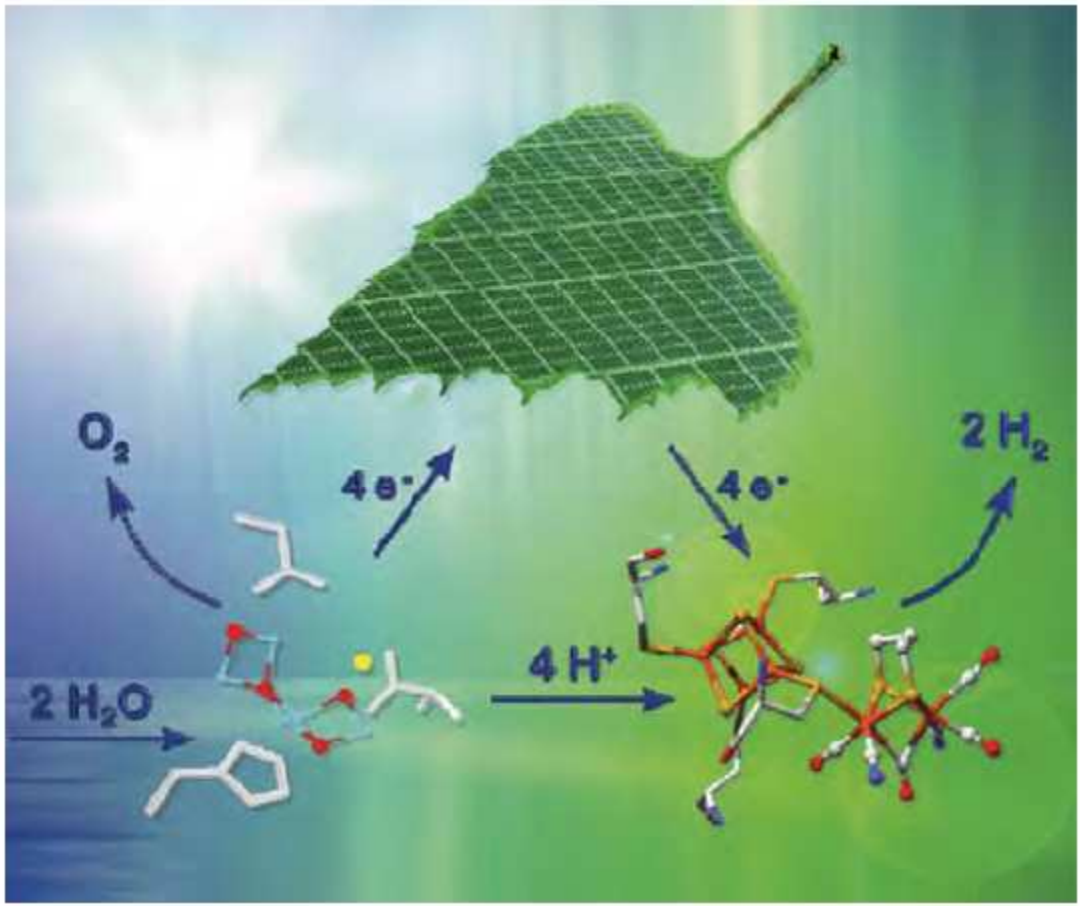

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Figure 3.3. Photosynthetic water splitting and a hydrogenase powered by a light-harvesting antenna complex. [Source: W. Lubitz, E.J. Reijerse and J. Messinger, *Energy Environ. Sci.* **1**, 15 (2008)]

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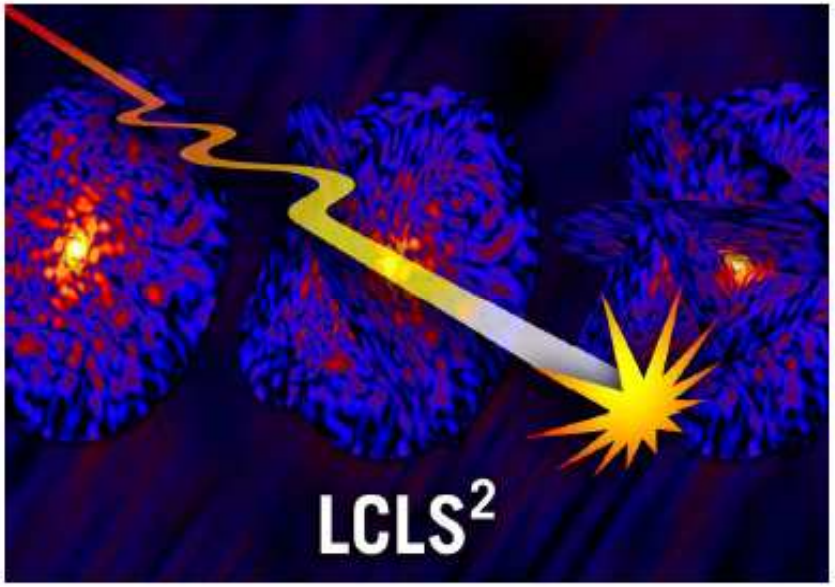
LCLS-II proposal submitted to DOE

Linac Coherent Light Source II
(LCLS-II) Proposal



DEPARTMENT OF ENERGY
SLAC NATIONAL ACCELERATOR LABORATORY

May 2010

SLAC-R-946

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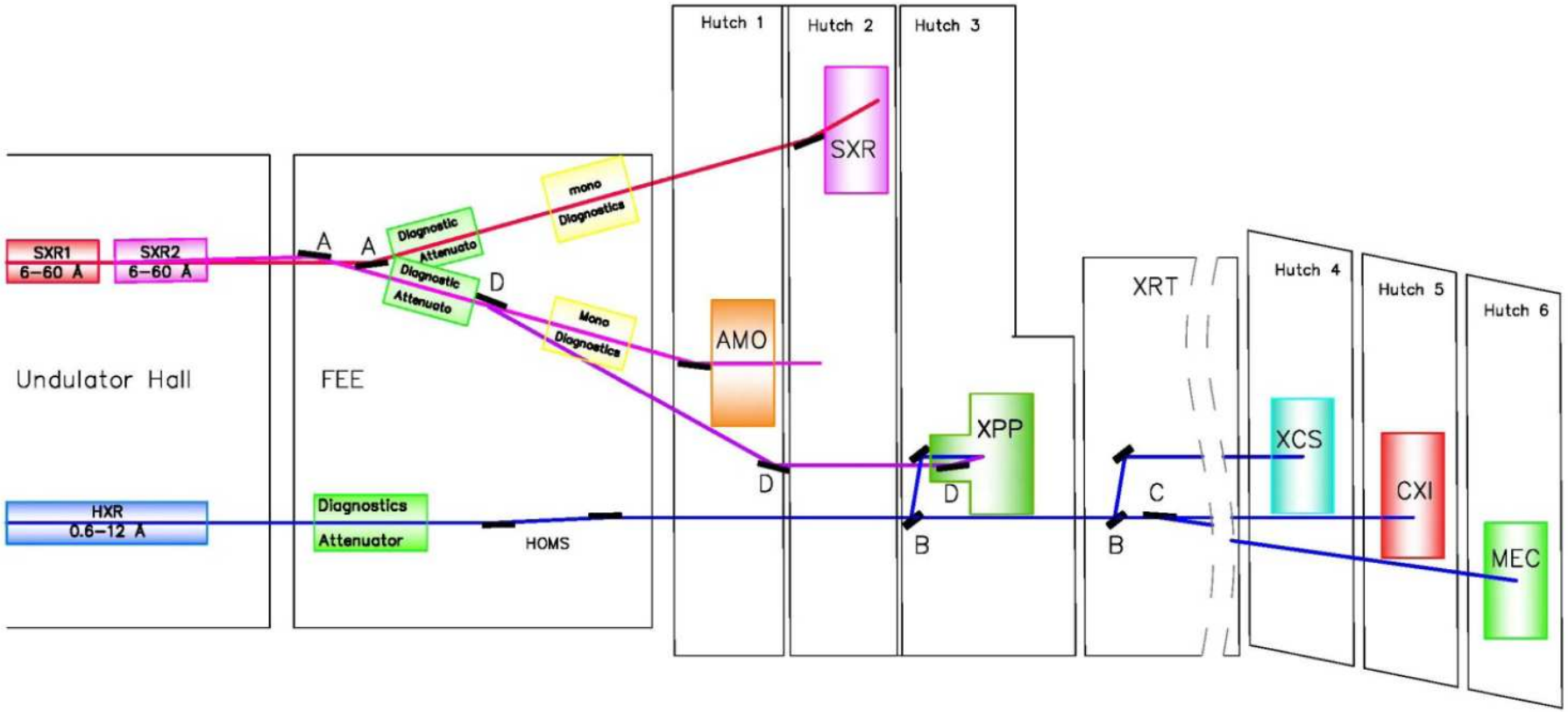
Schematic Overview of Undulators and Photon Beamlines for LCLS-II



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THANK YOU

The future is

ain’t what it used to be

Yogi Berra, 1947

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