High Energy Density Physics Workshop

May 24, 2004
Gaithersburg, MD

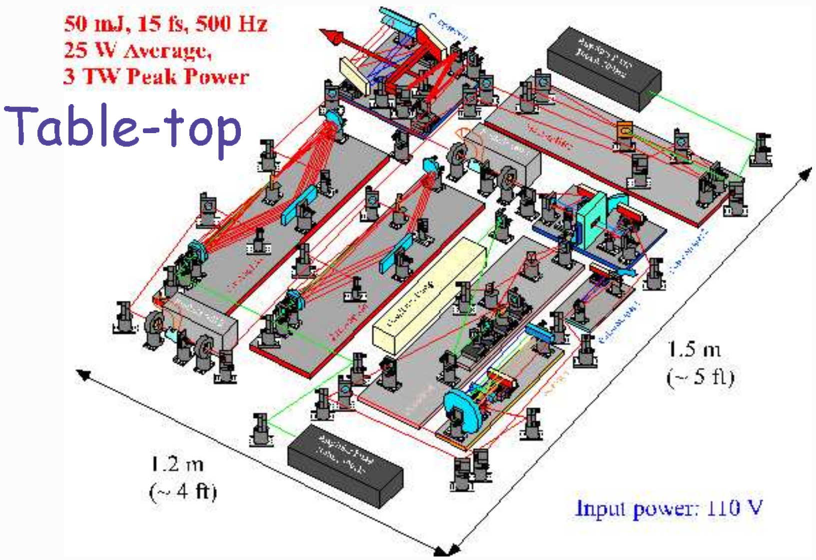
Report on HED with Ultra-Short-Pulse Lasers II

Louis DiMauro
BNL & Ohio State University

BROOKHAVEN NATIONAL LABORATORY

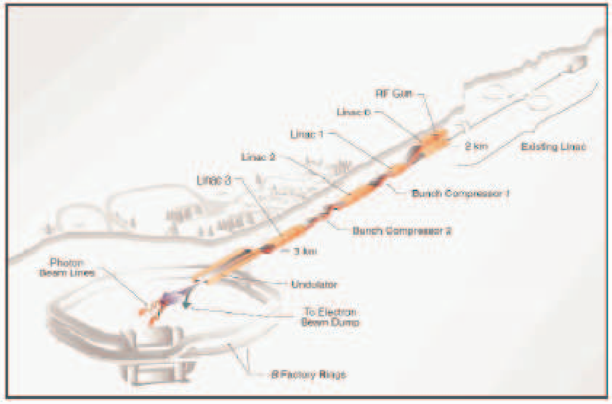
UUL physics tools

- intense, ultra-short lasers
  terawatt power
  few-cycle duration (few fs)
  long wavelength sources
  control of amplitude & phase
  arbitrary shaping techniques
  laboratory tabletop



- large-scale facilities
  X-FELs
  petawatt-class lasers
  collocation at accelerators

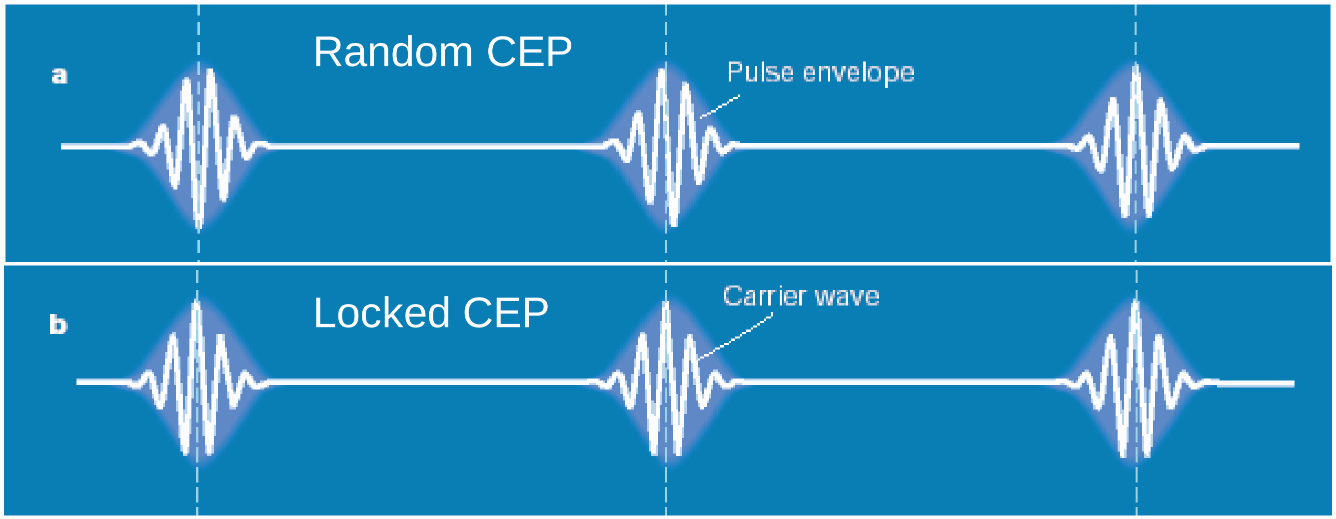
SLAC project
Linac Coherent Light Source (LCLS)



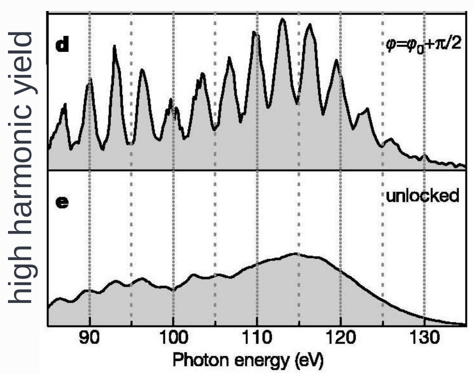
BROOKHAVEN NATIONAL LABORATORY

UUL physics tools

- modern technology enables the exquisite sculpting of the laser-matter interaction



"attosecond control of electronic processes by intense light fields"
Baltuska A, Krausz F *et al*., Nature **421**, 611 (2003).



nonlinear electronic processes, e.g. harmonic generation, can be controlled with sub-cycle precision.

BROOKHAVEN NATIONAL LABORATORY

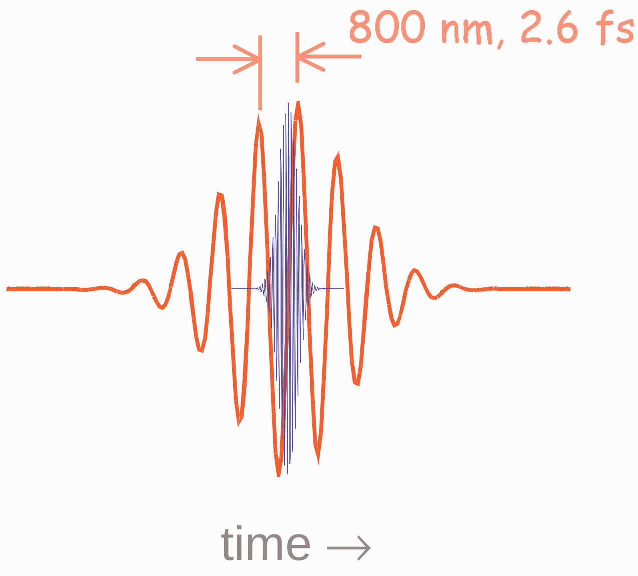
attophysics thrust: grand challenge

✓ *can physical and chemical processes be controlled with man-made light pulses that possess both the intrinsic time- (attoseconds, 10^{-18} s) and length- (x-rays, 1 Å) scales of all matter?*

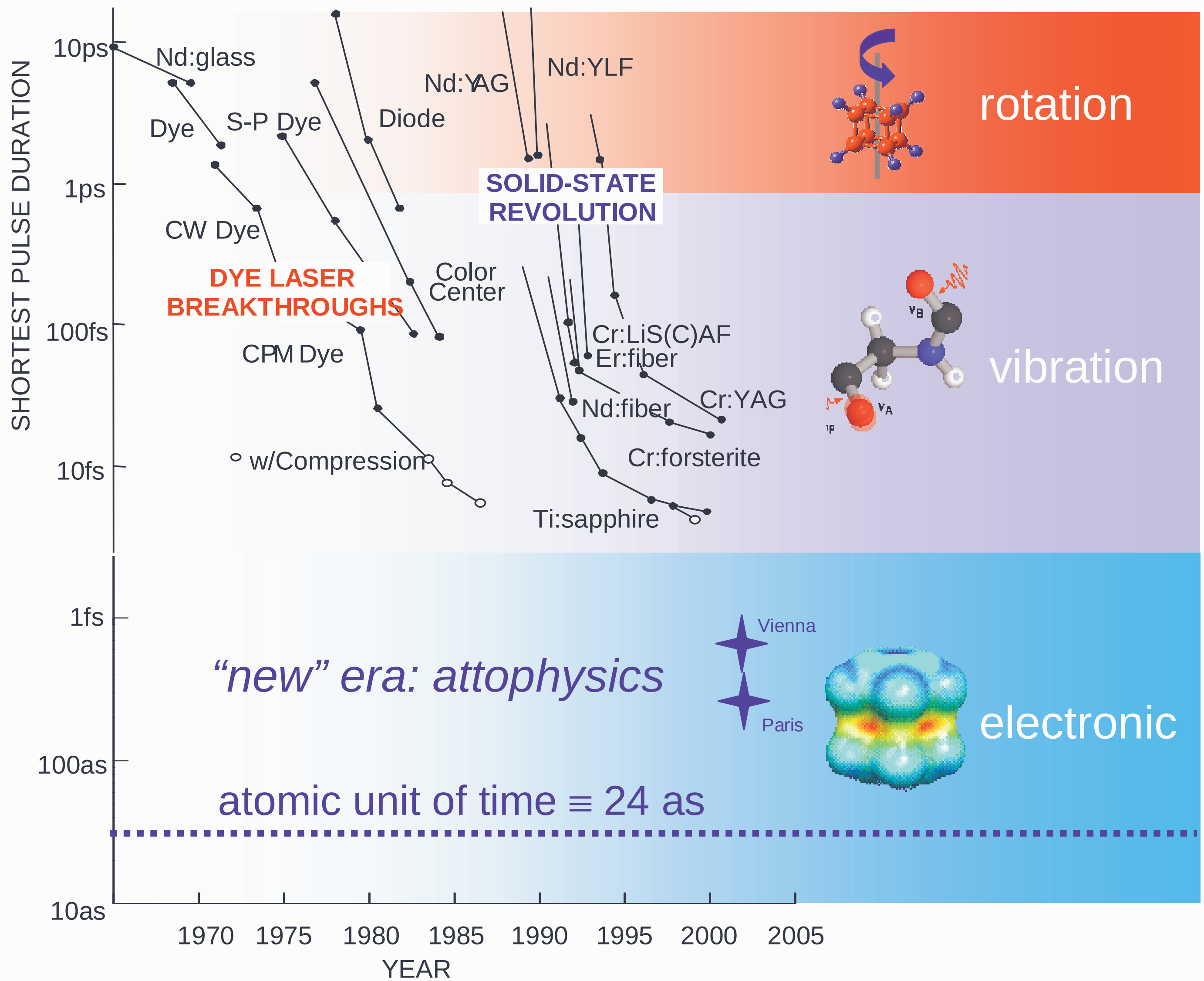
attosecond duration

⬇

short wavelengths (XUV, x-rays)



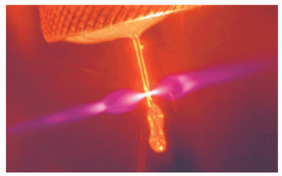
attophysics thrust: physical timescale



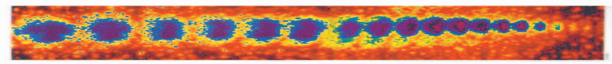
attophysics thrust: generation

✓ extreme nonlinear optics

- high harmonic generation



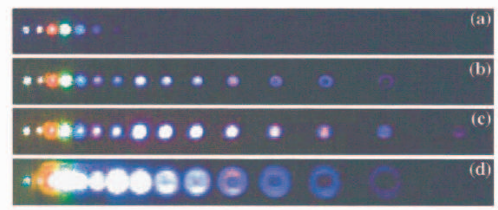
HHG orders 27–61



← wavelength (nm)

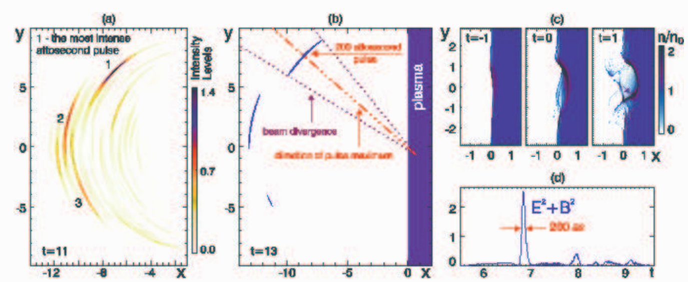
spatial and temporal coherent

- molecular Raman modulation
  S. E. Harris, A. Kaplan

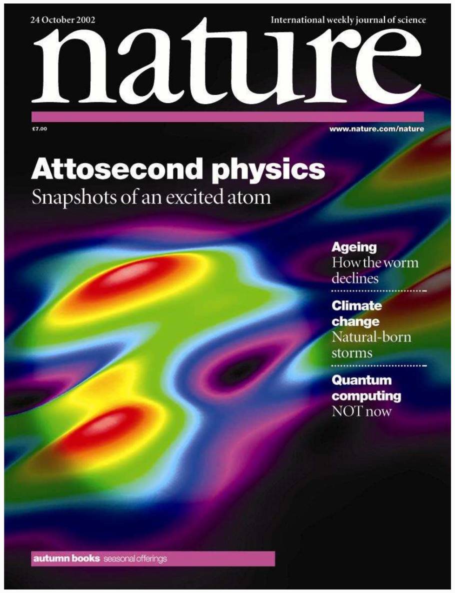


✓ relativistic plasma wave front

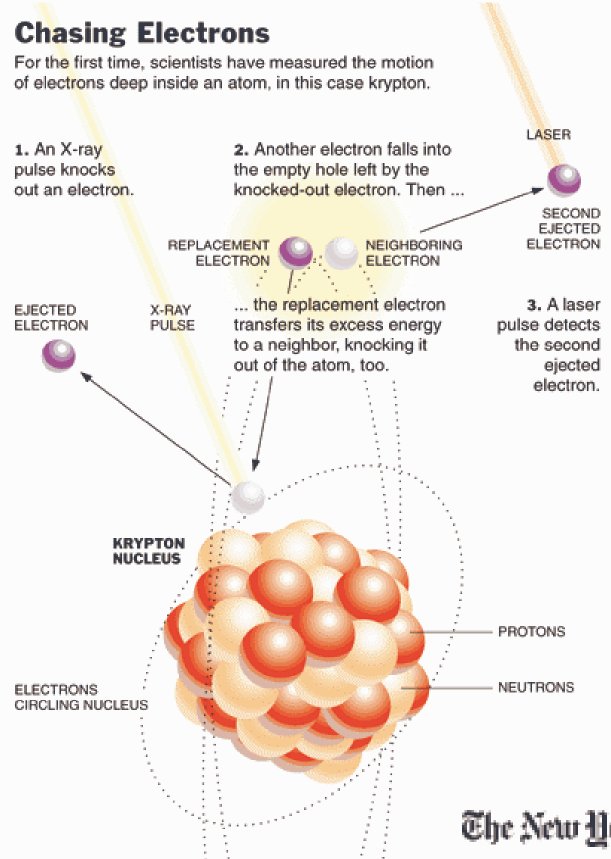
PIC simulations in λ^3 regime
Mourou *et al*., PRL **92**, 063902 (2004).



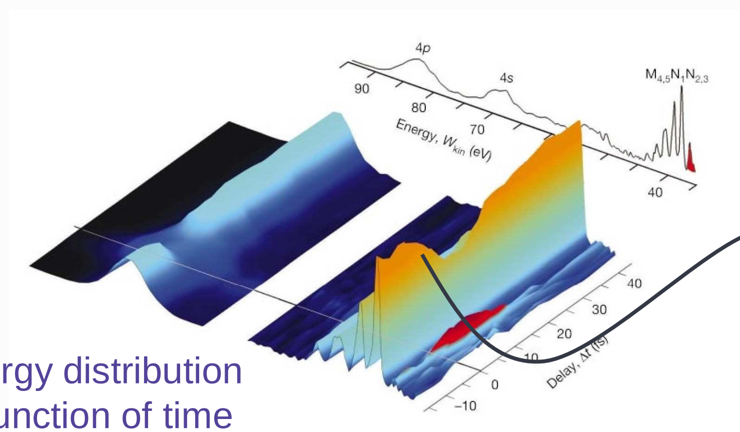
attophysics thrust: first experiment



"time-resolved atomic inner-shell spectroscopy"
Drescher M, Krausz F *et al*. Nature **419**, 803 (2002).



The New York Times



900 attosecond
time resolution

photoelectron energy distribution
as a function of time

BROOKHAVEN
NATIONAL LABORATORY

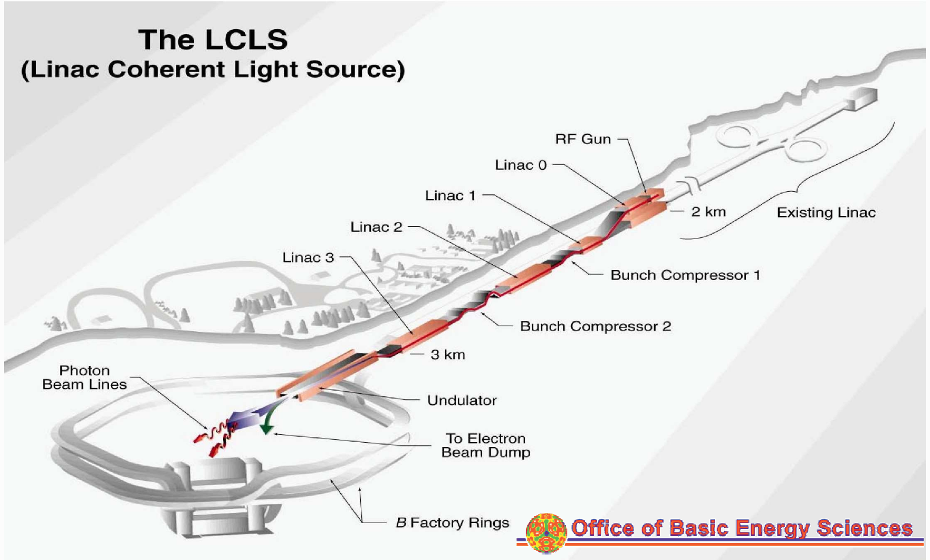
attophysics thrust: recommendations

Center requirements:
- high average powered, terawatt laser systems
- petawatt-class systems for relativistic drivers
- collocation of centers at existing DOE light sources

Interagency opportunities:
- NSF, DOE/BES, DOD (AFOSR, ARO)

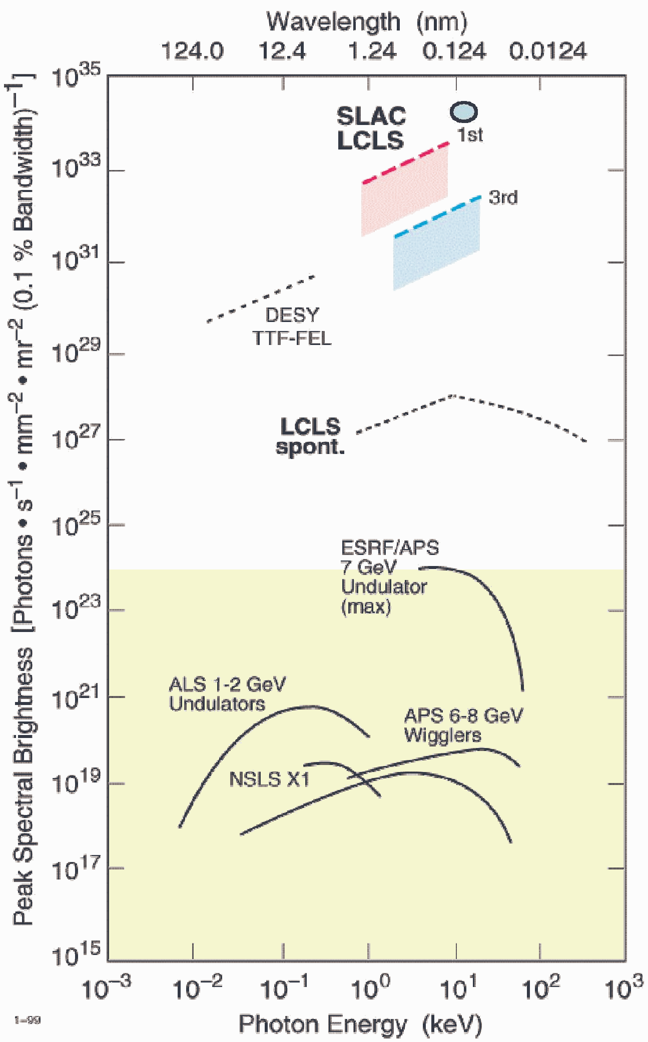
x-ray thrust: grand challenge

- ✓ *can intense, ultra-fast x-ray become a routine tool for imaging the structure and motion of "single" complex bio-molecules that are the constituents of all living things?*
- ✓ *can nonlinear optics be applied as a powerful, routine probe of matter in the XUV/x-ray regime?*



4th generation light sources produce x-rays with unprecedented peak power.

x-ray thrust: LCLS an extraordinary tool



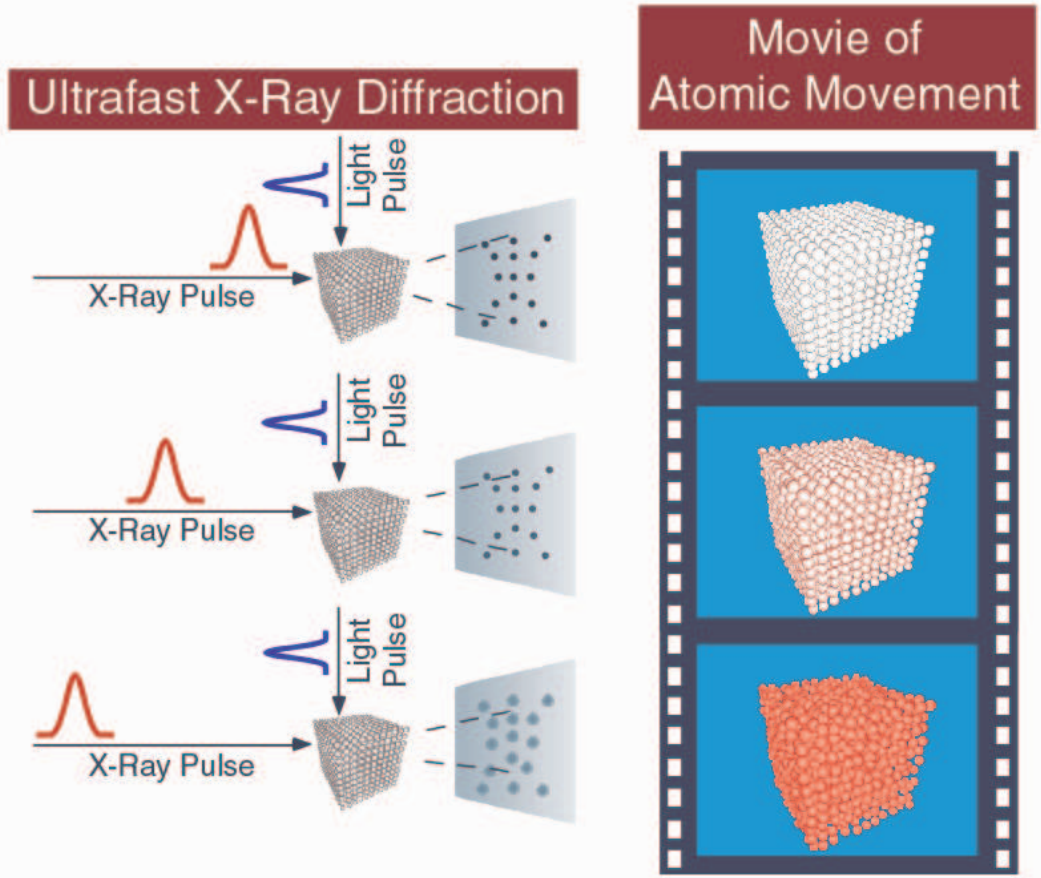
Baseline performance:

- 15-1.5 Angstrom
- 10 GW peak power
  larger by 10^9 to current sources
- ultra-short, 200 fs - ???
  exceeds 3rd generation by $\geq 10^3$
- coherent
  large degeneracy factor $\geq 10^9$

BROOKHAVEN NATIONAL LABORATORY

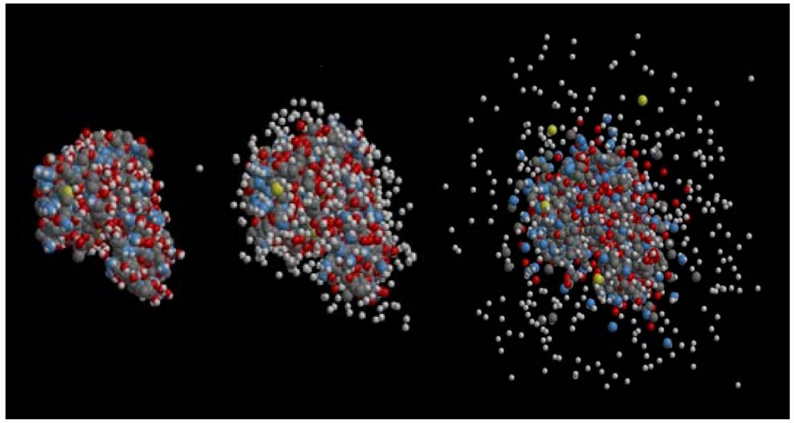
x-ray thrust: ultra-fast dynamics

x-rays can probe structure
ultra-fast x-rays can watch it move: dynamics

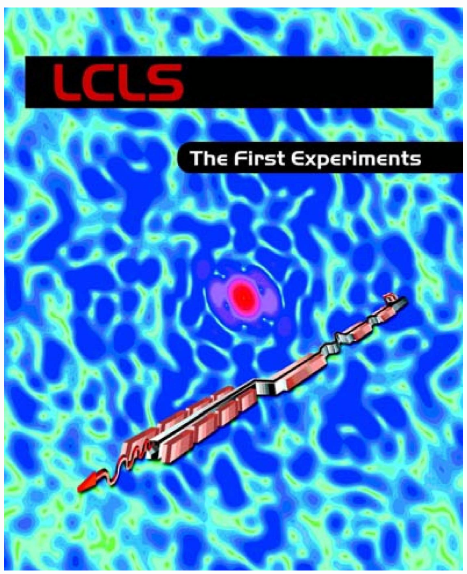


stuff starts moving in picoseconds

x-ray thrust: single molecules imaging



"potential for biomolecular imaging with femtosecond x-ray pulses"
Neutze R, Hajdu J *et al*., Nature **406**, 752 (2000).



Other 1st experiments:

- high-frequency, strong-field atomic physics
- plasma & WDM
- femtochemistry
- nanoscale complex dymanics

BROOKHAVEN NATIONAL LABORATORY

x-ray thrust: roadmap for the 4th generation

- Over the next ten years can expect to see the next (4th) generation of linac-based light sources come on-line
- Other variants of linac-based light sources (*e.g*. ERLs) are also likely to be developed

~2011

TESLA XFEL

2008

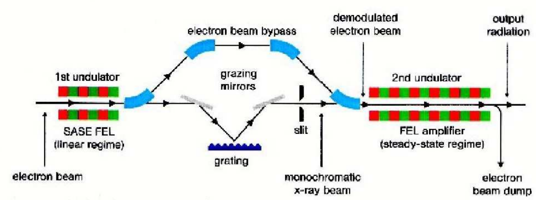
First XFEL

15 GeV Electrons LCLS 1.5 Å X-Ray

Linac Coherent Light Source

2003-2007

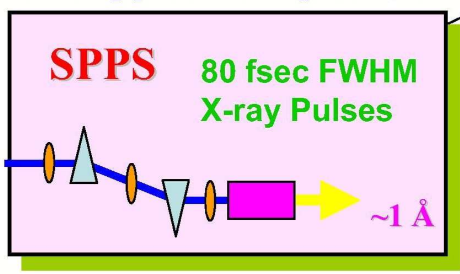
R&D, seeding, harmonic generation
Applns. of soft x-ray FELs



TESLA FEL

2003-2006

Short pulse characterization
Beam dynamics
Pump-probe studies on strongly scattering samples



BROOKHAVEN NATIONAL LABORATORY

x-ray thrust: recommendations

Center requirements:

- multi-terawatt-class long wavelength ($\geq$ 0.8 μm) drivers
- laser Centers collocated at 4th generation venues
  e.g. high-powered drivers for HEDP studies

Interagency opportunities:

- NSF, DOE/BES, DOE/NNSA, DOE/OFES, DOD

SAUUL recommendations

- **It is imperative that a new mode of organization be developed in this research field (UULs) to maintain its vitality in the USA and to make available the facilities and infrastructure needed to exploit current opportunities.**

SAUUL report 2003

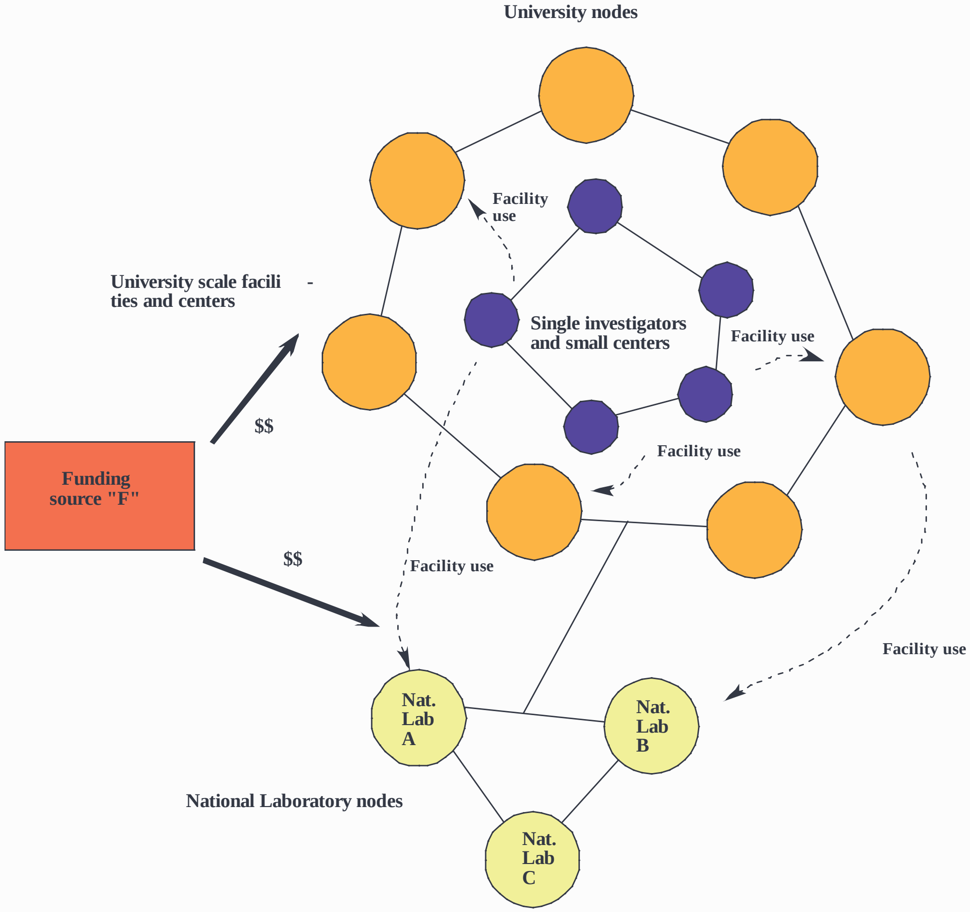
- SAUUL report was the outcome of a workshop held in DC during June 17-19, 2002.
- A broad scientific community interested in UUL physics were represented by the 44 workshop participants plus federal agency representatives.

BROOKHAVEN NATIONAL LABORATORY

SAUUL: a plan for organization

Plan for establishment of a UUL network:

1) formation of a funded cross agency body (CAB)
2) the CAB would hold nation-wide competition for the formation of network nodes.
3) the network would include three kinds of nodes:
   (a) facilities at national labs and existing large scale laboratories.
   (b) centers at universities.
   (c) single investigator efforts
4) single Investigators are a key component: will have access to the facilities at the network nodes
5) network will be a dynamic entity with a recurring competition for new and existing nodes. Can also sunset nodes.



Nodes have scientific thrust themes.