AMO 2010: *Controlling the Quantum World*

A Decadal Assessment and Outlook Report on Atomic, Molecular and Optical Science
(Part of Physics 2010)

Philip Bucksbaum, Co-Chair
Robert Eisenstein, Co-Chair

Briefing for the NRC Plasma Science Committee
October 1, 2006

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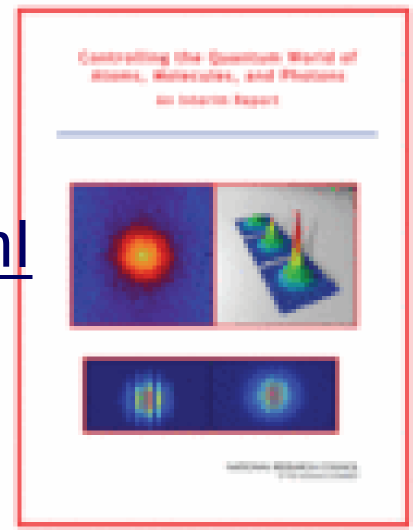
Want to know more?

http://www.nap.edu/catalog/11705.html
AMO 2010 report (preliminary version)

http://books.nap.edu/catalog/11482.html
Interim report (November 2005)



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Want to know even more?

Go to http://www.stanford.edu/~phbuck/amo2010/

- The briefing to CMMP 2010: “AMO 2010: Lessons Learned,” (a step-by-step guide for producing a Physics 2010 report)

- The AMO 2010 pre-release briefing

- A summary talk prepared for an AIP meeting

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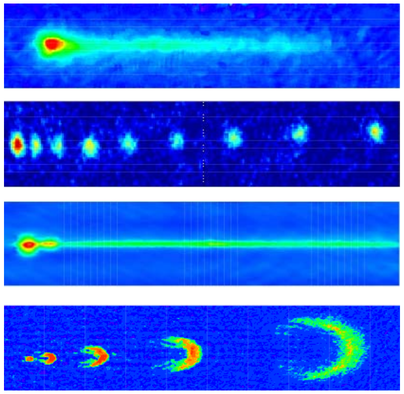
Atom laser
Quantum degenerate gases



AMO 2010 Charge:

- Review the field of AMO science, emphasize recent accomplishments, and identify new opportunities and compelling scientific questions.
- Identify the impact of AMO science on other scientific fields, emerging technologies, and national needs.
- Identify future workforce, societal and educational needs for AMO science.
- Make recommendations on how the US research enterprise might realize the full potential of AMO science.

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Committee Membership

Philip H. Bucksbaum, Co-chair University of Michigan/Stanford University **Robert Eisenstein**, Co-chair Gordon A. Baym, University of Illinois C. Lewis Cocke, Kansas State University Eric A. Cornell, University of Colorado / JILA E. Norval Fortson, University of Washington Keith Hodgson, Stanford Synchrotron Radiation Laboratory Anthony M. Johnson, University of Maryland Baltimore County Steven Kahn, Stanford University Mark A. Kasevich, Stanford University	Wolfgang Ketterle, Massachusetts Institute of Technology Kate Kirby, Harvard-Smithsonian Center for Astrophysics Pierre Meystre, University of Arizona Christopher Monroe, University of Michigan Margaret M. Murnane, University of Colorado / JILA William D. Phillips, National Institute of Standards and Technology Stephen T. Pratt, Argonne National Laboratory K. Birgitta Whaley, University of California, Berkeley Consultants: Neal F. Lane, Rice University Neil Calder, SLAC

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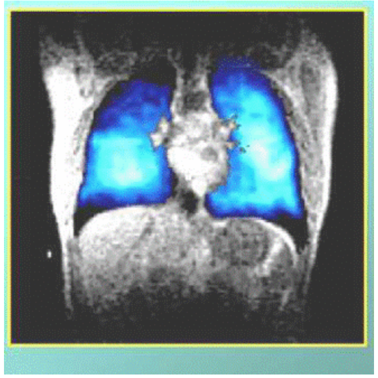
Medical imaging
via optical pumping and spin-exchange



Project Timeline

- Committee formed beginning of 2005
- First meeting – Washington DC – April 4/5, 2005
- Data requested from Federal agencies – August, 2005
- Interim Report – November, 2005
- Report finalized and review begun – March, 2005
- Briefing in Washington – July 10, 2006
- Report (prepublication) release – July 24, 2006
- Print version release – Sometime this fall

amo2010 Structuring the main report around science

- Structure of the main report
  - Central chapters organized around our **Science** conclusions
  - Funding and human resources in a separate chapter at the end
  - Three tiers (see below)
- The "three-tier" document
  - Executive Summary
  - Chapter 1 becomes extended Exec Summary, a condensation of Ch. 2-8, like a "Micropedia."
  - Ch. 2-7 are the main science chapters.
  - Ch. 8 contains policy issues, and data collected from funding agencies.

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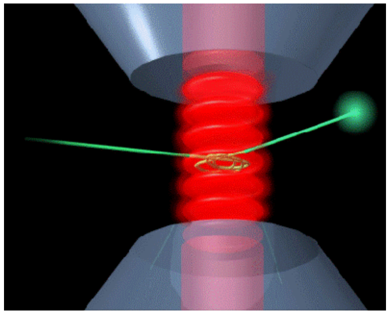

Cavity-enhanced atom-photon interactions

Main conclusions: Six Compelling Research Questions For AMO Science

- What is the nature of physical law?
- What happens at the lowest temperatures in the Universe?
- What happens at the highest temperatures in the Universe?
- Can we control the inner workings of a molecule?
- How will we control and exploit the nanoworld?
- What is the future of quantum information science?

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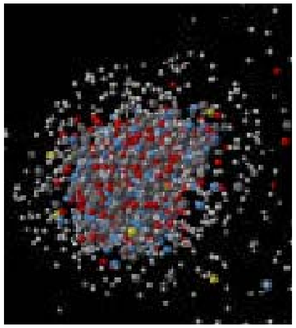
Nanoplasma created by exploding a virus at the LCLC X-ray free electron laser (simulation)



What happens when light is pushed to extremes?

- Lasers in the next decade will have powers exceeding a petawatt, focused fields up to 1000 atomic units
- The electric fields at a focus will induce exotic plasmas usually found only in stars, hydrogen bombs, or particle accelerator collisions.
- There are applications in HED science and laser accelerator science.
- New brilliant x-ray lasers will be able to heat or illuminate plasma processes with femtosecond resolution.

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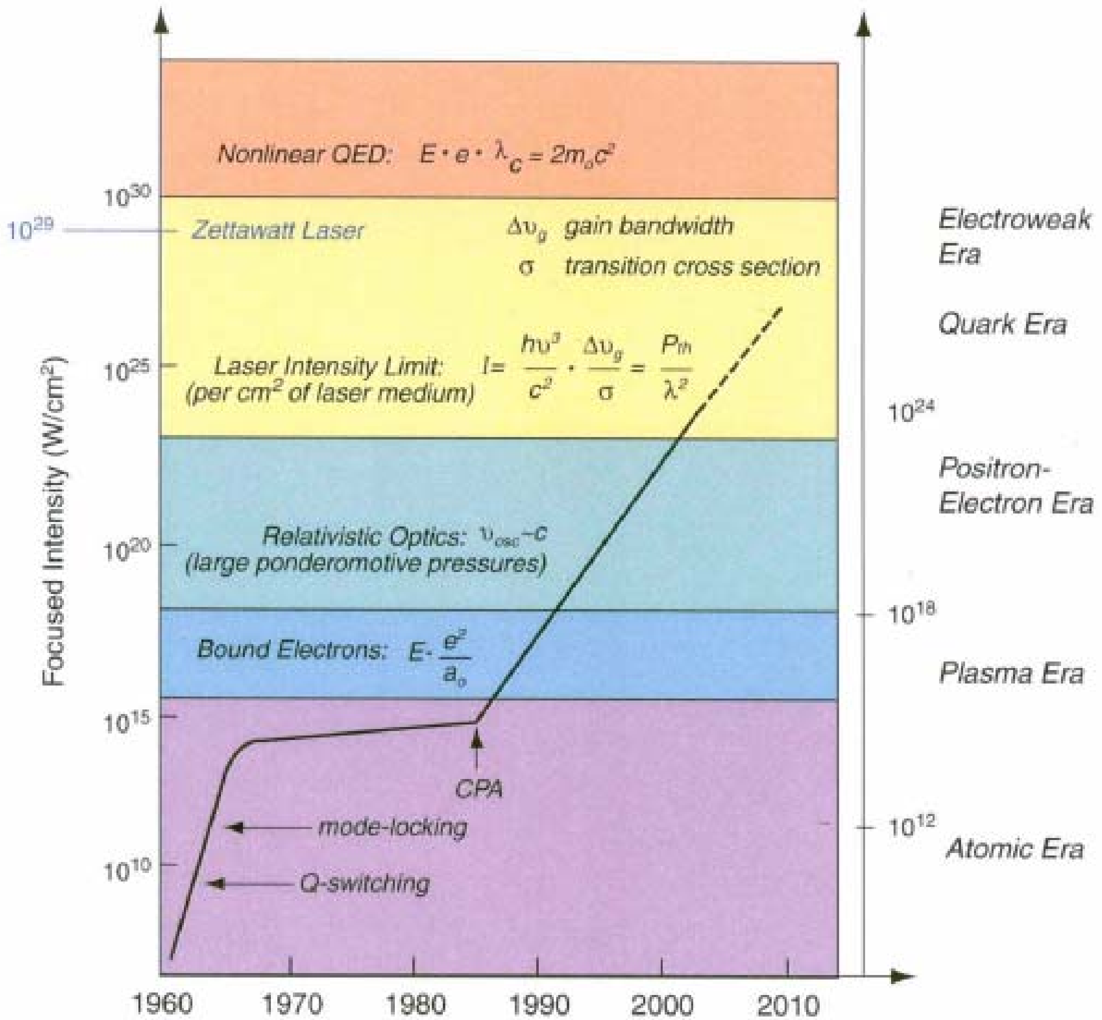
High-powered lasers in 2010



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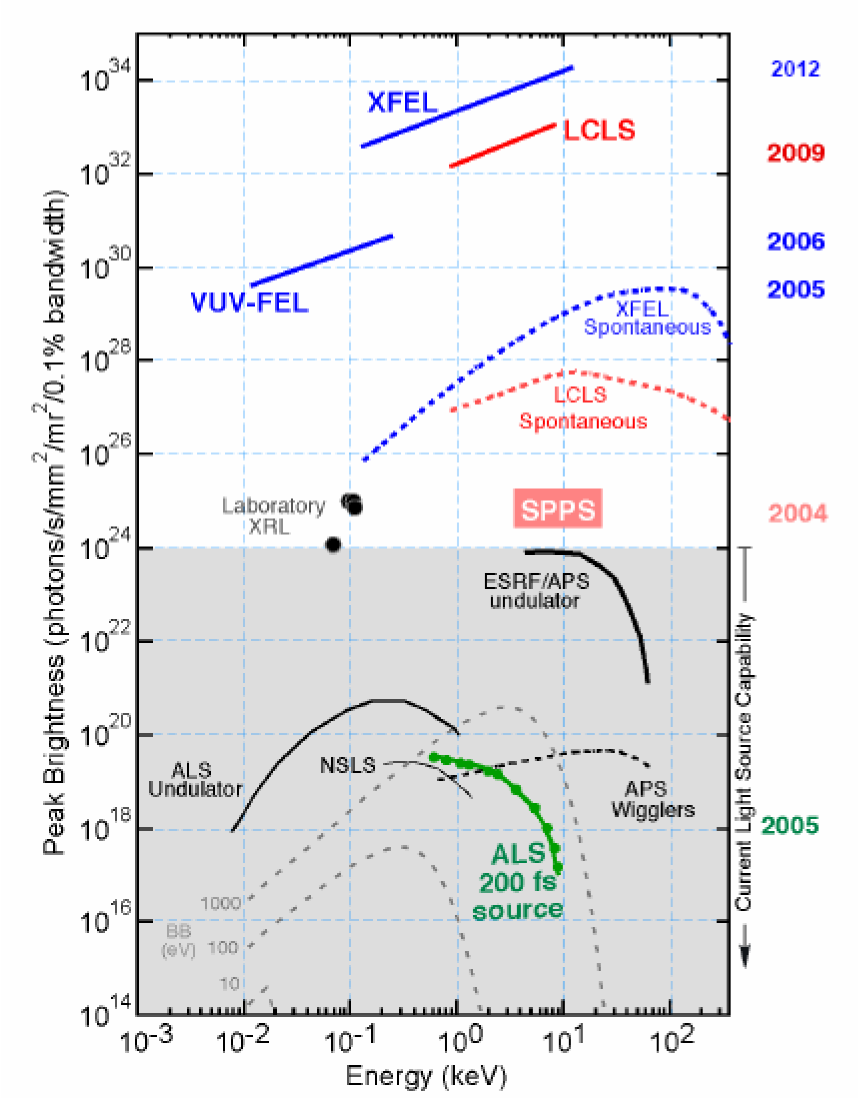

[X-ray lasers in 2010]

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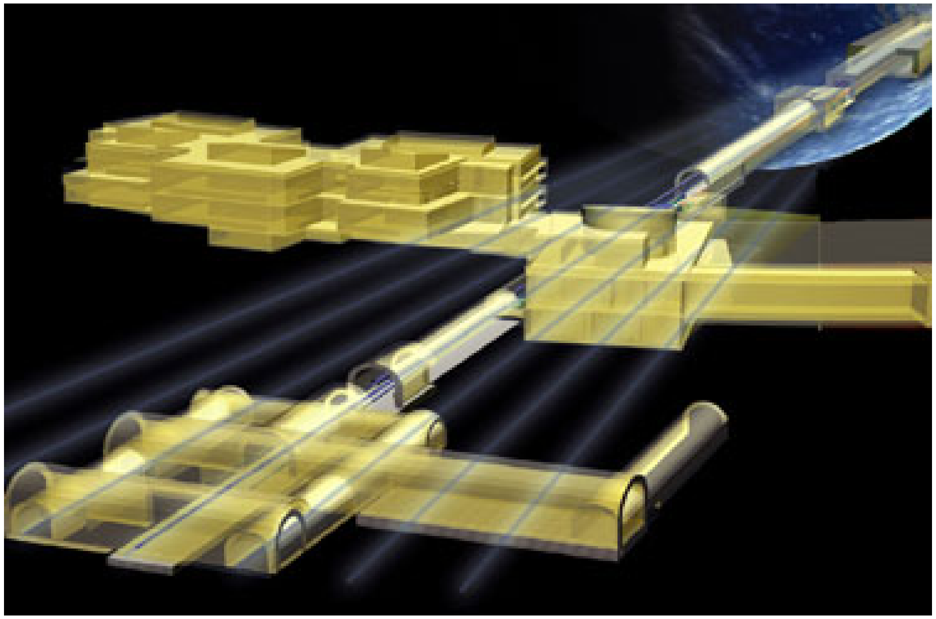
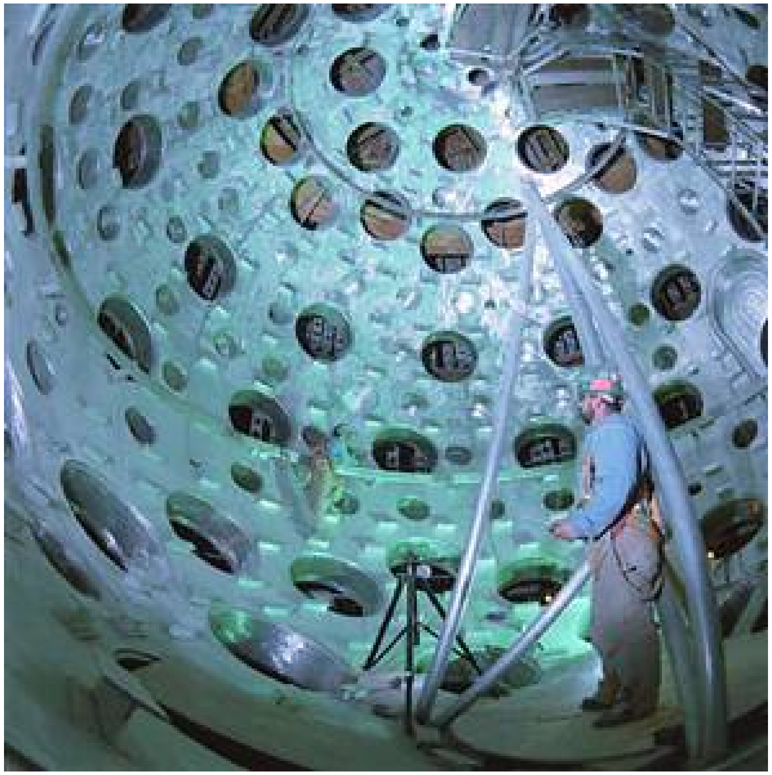
Extreme Light will have many connections to plasma physics

X-ray lasers



LCLS, planned to start operations in 2009, showing the underground labs and the path of the x-ray FEL beam.

Megajoule lasers



NIF Target Chamber

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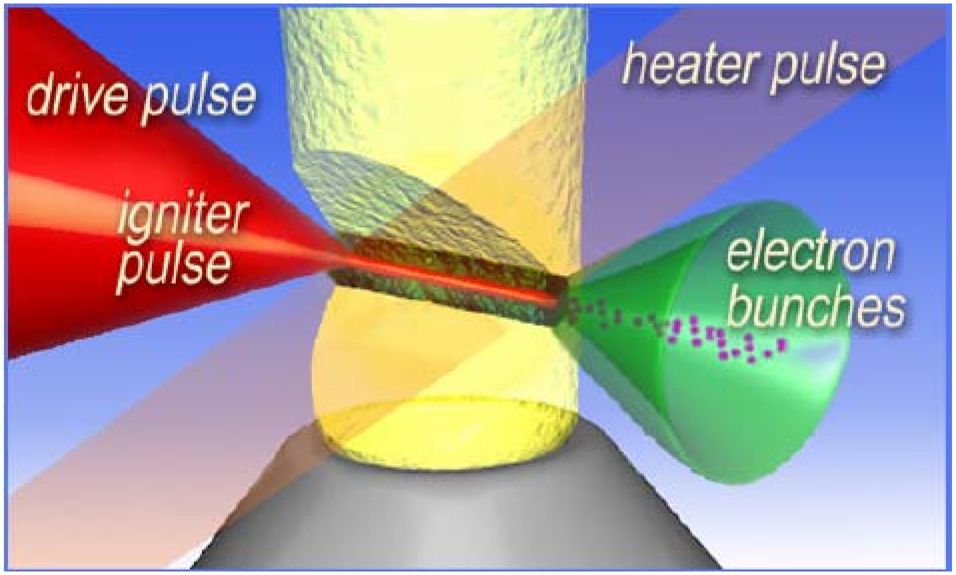
Laser-driven plasma accelerators

- Plasma wakefield acceleration may hold the key to advanced ultra-high energy electron accelerators in th future
- The diagram represents an experiment in which a plasma channel driven an 8-9 TW laser achieved average accelerating gradients near 50 gigaelectronvolts per meter.
- The electron energy spread is at the percent level.



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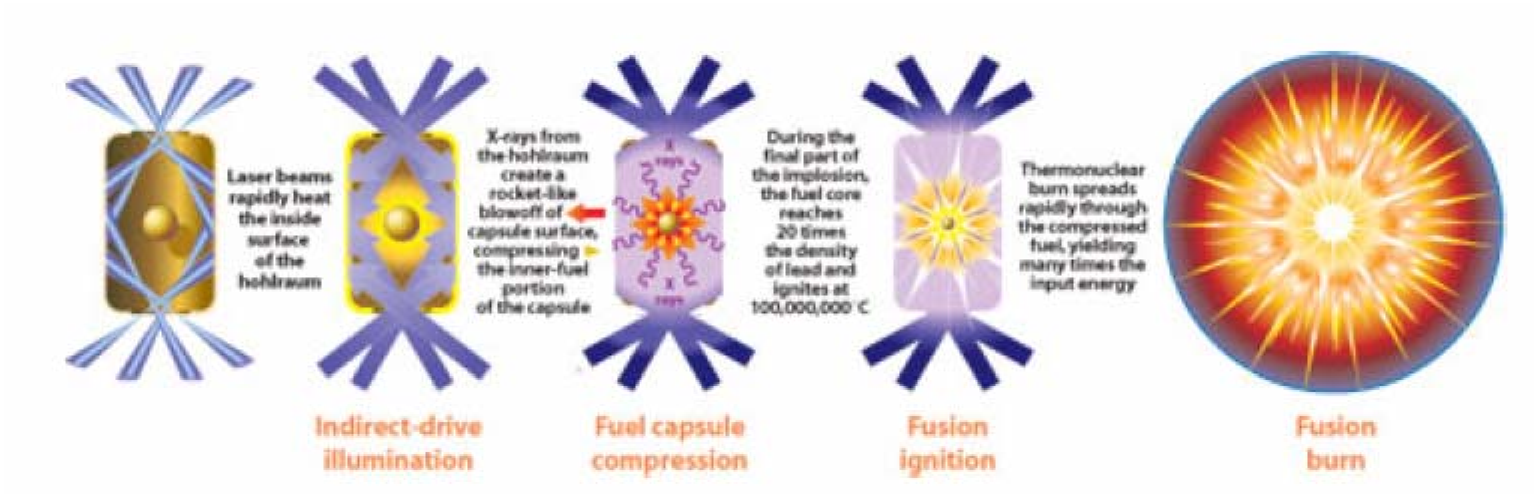
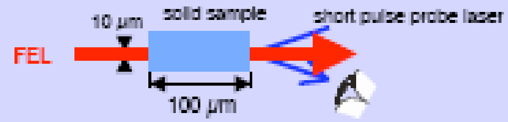
Laser-driven ICF

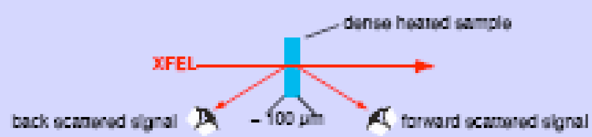


amo2010 HEDS proposed for XFELs will cover a range of WDM experiments

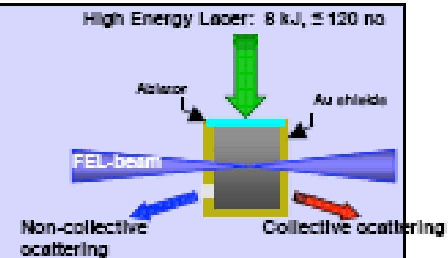
- **Creating Warm Dense Matter**
  - Generate ~ 10 eV solid density matter
  - Measure the equation of state



- **Probing dense matter with Thomson Scattering**
  - Perform scattering from solid density plasmas
  - Measure n_e, T_e, <Z>, *f*(v)

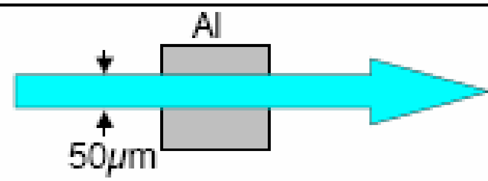


- **Probing High Pressure phenomena**
  - Use high energy laser to create steady high pressures
  - Produce shocks *and* shockless high pressure systems
  - Study high pressure matter on time scales < 1 ps
  - Diagnostics: Diffraction, SAXS, Diffuse scattering, and Thomson scattering

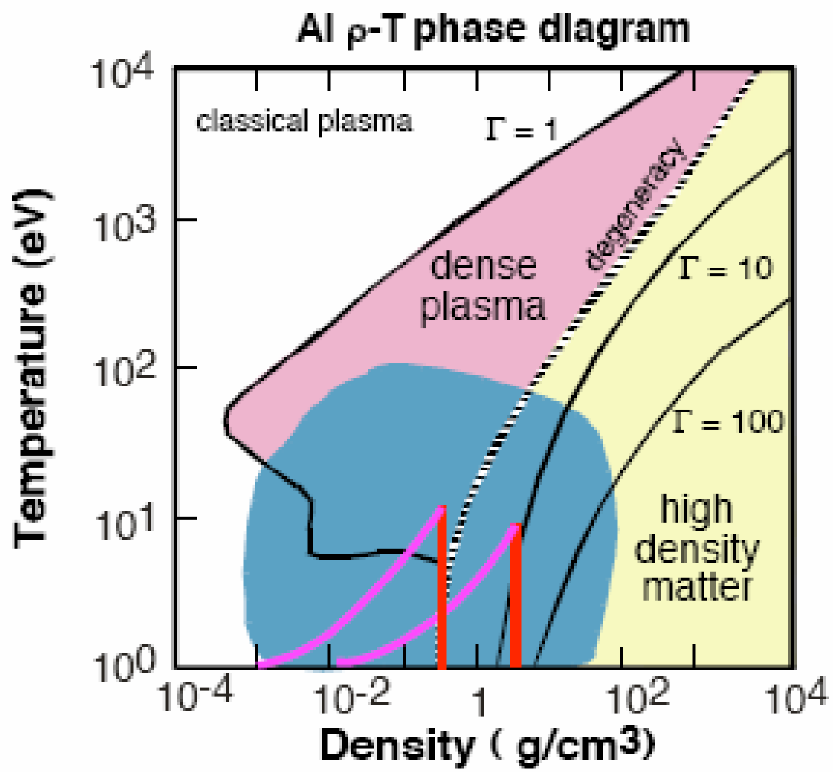


amo2010 WDM created by isochoric heating will isentropically expand sampling phase space

- Concept is straightforward



- XFEL can heat matter rapidly and uniformly to create:
  - Isochores (constant ρ)
  - Isentropes (constant entropy)
- Using underdense foams allows more complete sampling
  - Isochores (constant ρ)
  - Isentropes (constant entropy)



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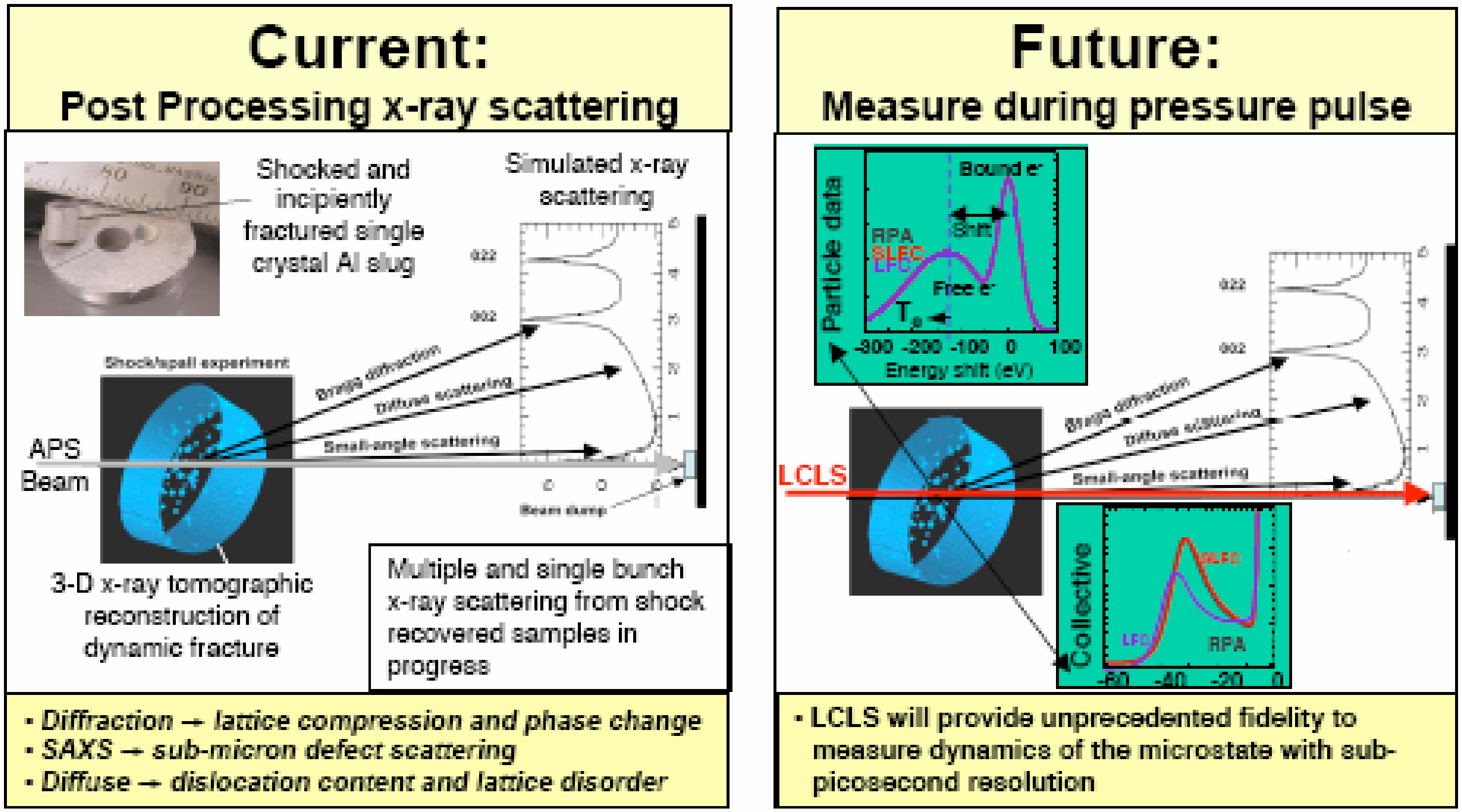
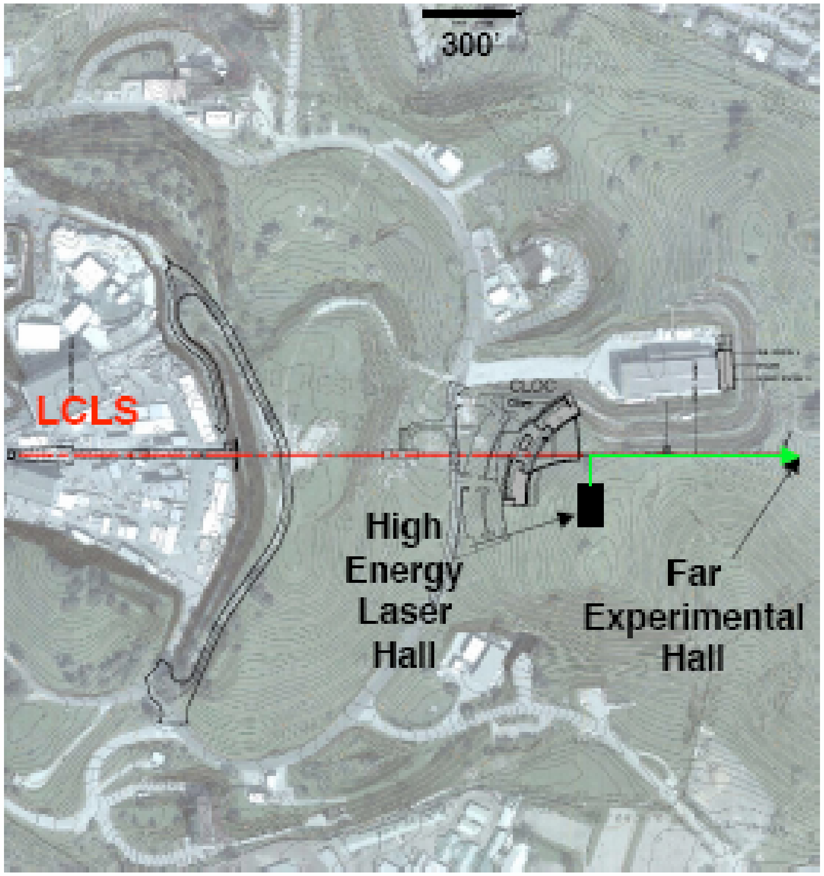
High pressure studies: material strength, spall and phase transitions



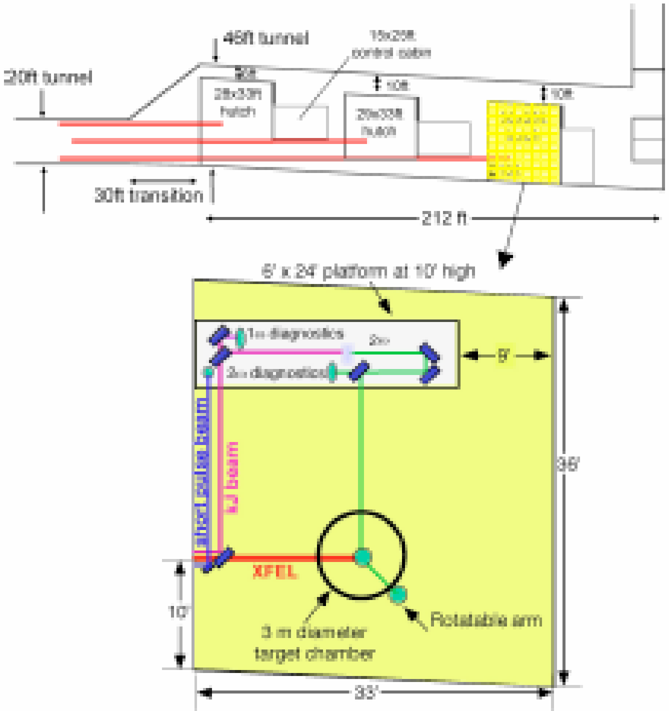
• **LCLS with HEDS end station: sufficient signal to noise for measurements during the high pressure phase**

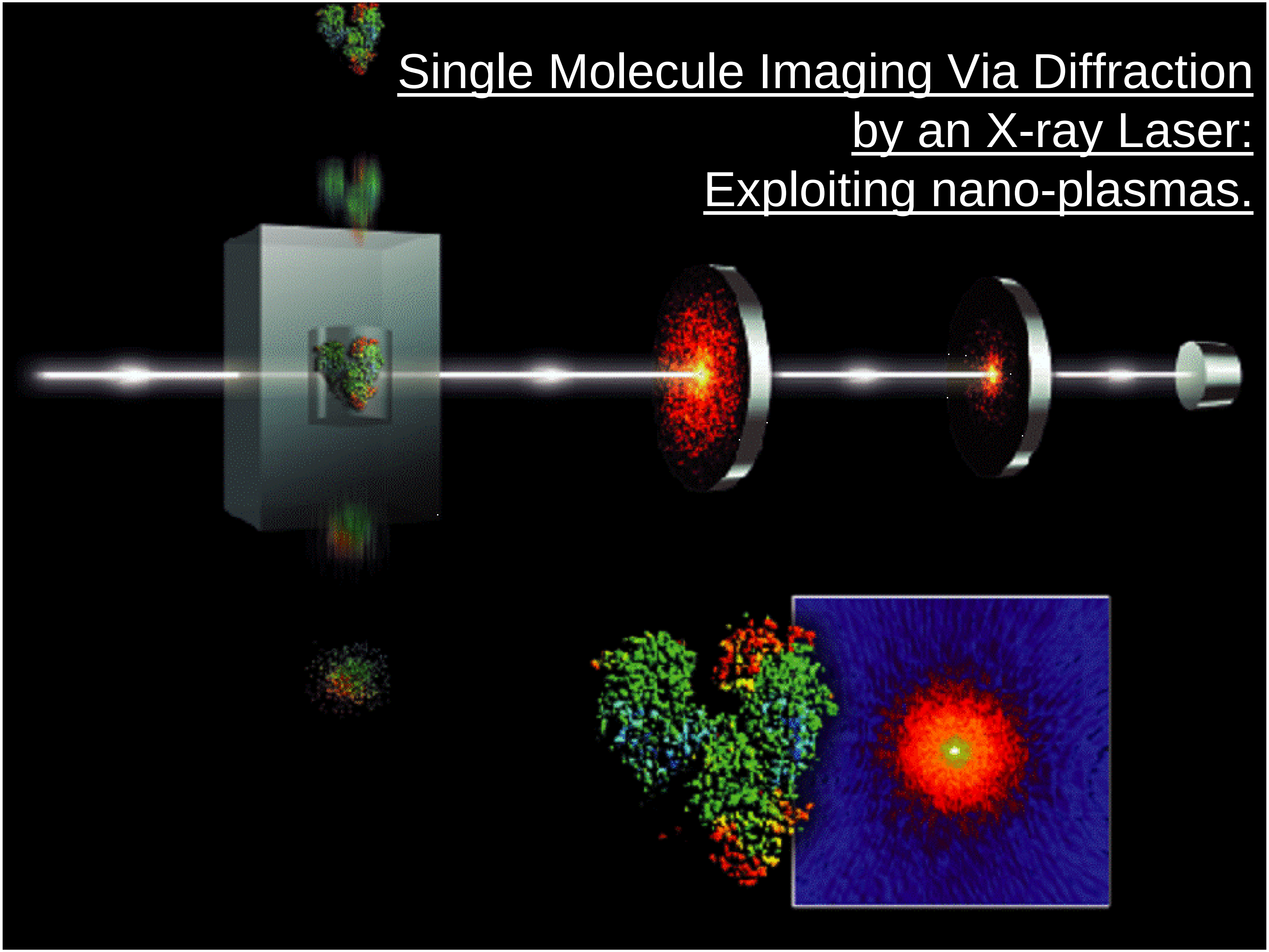
amo2010 Possibilities for HEDS at LCLS



Aerial view of SLAC site

- Transport is efficient over long distances
- Lasers can be transported to Far Experimental Hall




Single Molecule Imaging Via Diffraction
by an X-ray Laser:
Exploiting nano-plasmas.

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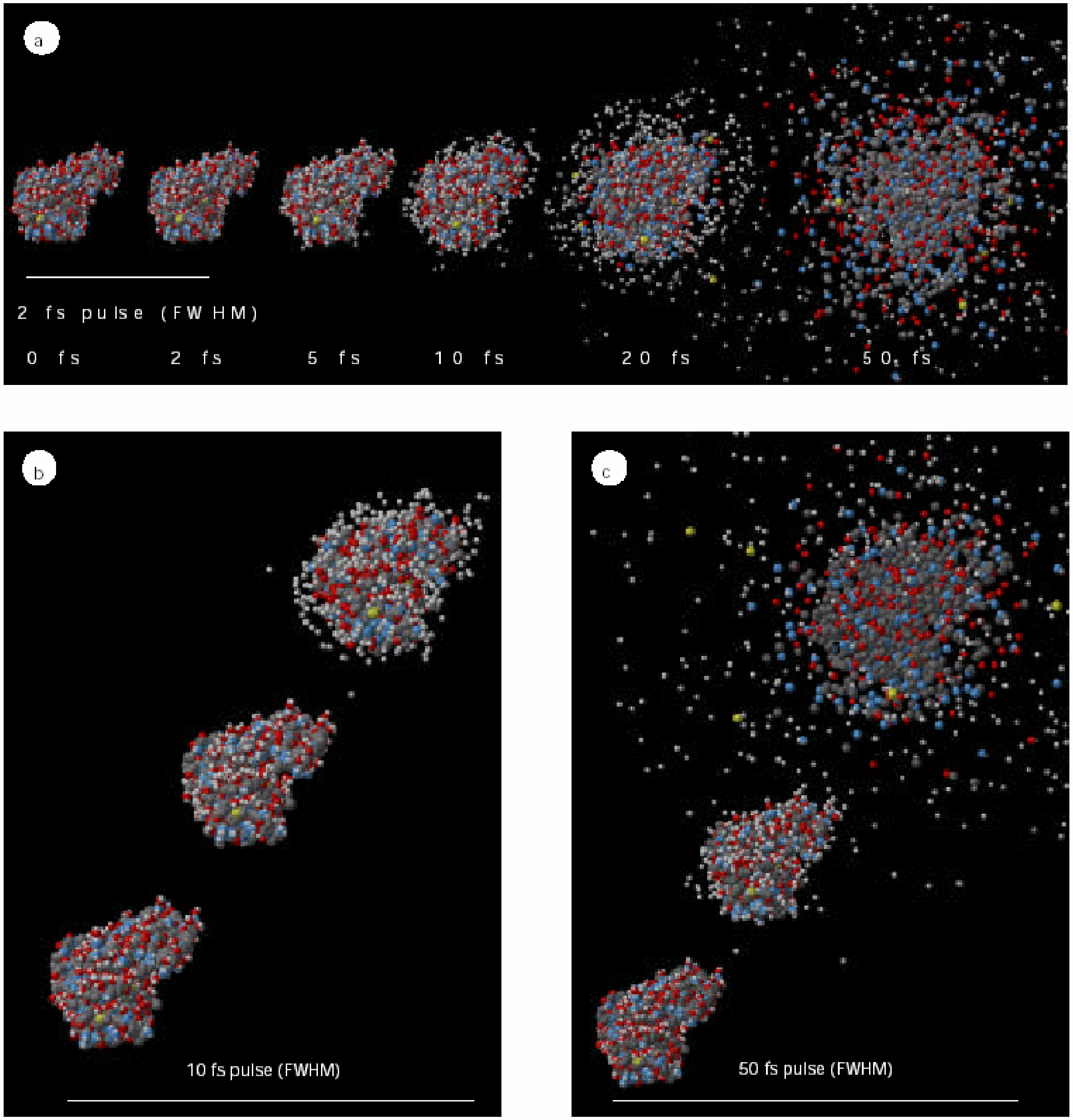
[Cluster Explosions at an XFEL]



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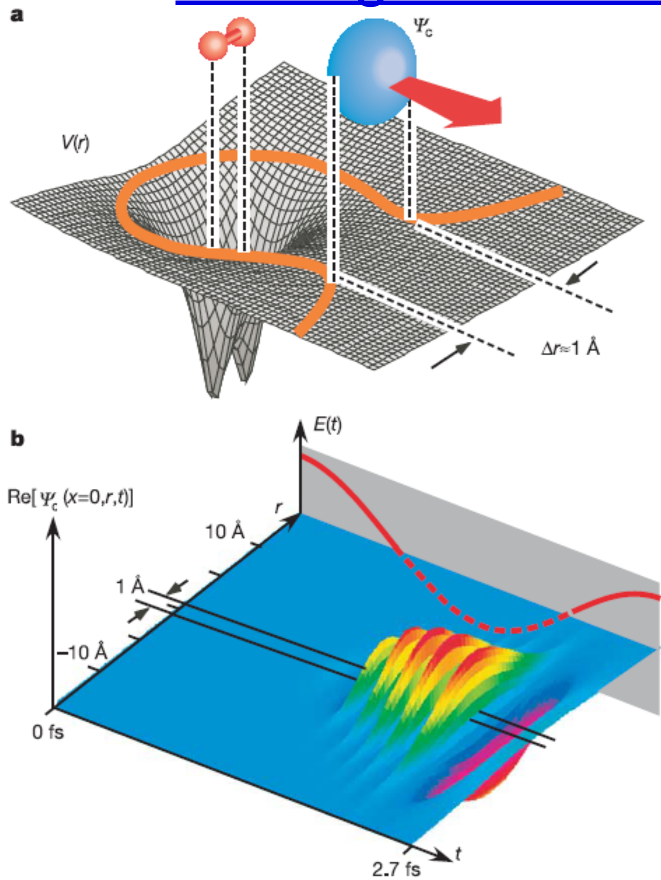
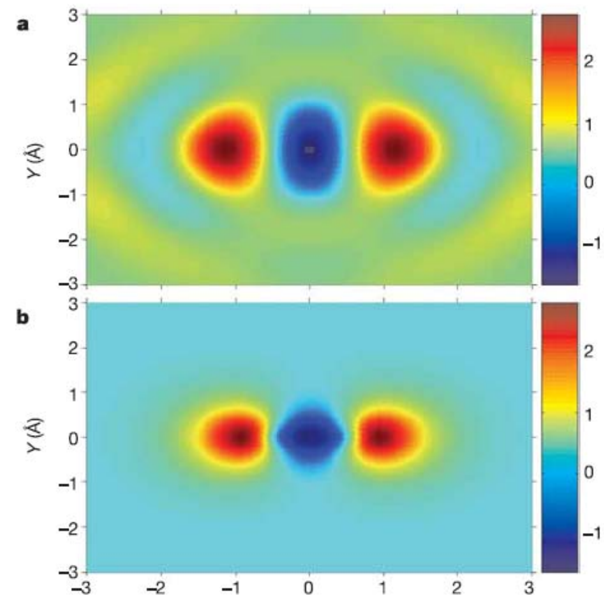
Attosecond time scales: viewing the Inner Workings of a Molecule





A snapshot image of a molecule
obtained from field ionization and electron-molecule recollision in <2fs

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Conclusions, Findings, and Recommendations

- In science prioritization, picking winners is far more important than identifying losers.
- Tell the government what the field needs, rather than how the agencies should do their jobs.

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AMO Science and National Policy: Conclusions

- Benefits of different funding styles
- Importance of breadth of agency support
- Prognosis for continued advances in AMO science
- Critical importance of investing in research
- Strong connections to defense
- The "science inflator" makes CPI adjusted budgets actually shrink
- Importance of theory
- Importance to astrophysics
- Too few Americans choosing to study science
- Continued access to foreign scientists and technology is essential

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AMO Science and National Policy: Recommendations

- Improve education in the physical sciences and mathematics at all levels and significantly strengthen the research effort.
- Support programs in AMO science across disciplinary boundaries and through a multiplicity of agencies.
- Reverse recent declines in support for 6.1 research in DOD.
- Budgets must take into account the science inflator.
- Rebalance AMO theory funding.
- Implement incentives to encourage more American students, especially women and minorities, to study the physical sciences and take up careers in the field.
- Continue to strongly encourage the best foreign-born students to pursue scientific careers in the United States.

amo2010 The roll-out:

- Pre-publication briefing
  - Went to Washington two weeks before release of the doc
  - Brought along Bill Phillips. (Nobelists and similar types on the committee have special credibility)
  - Spoke to everyone we could: NSF, DOE, DOD, NIST, NASA, OSTP, OMB, House Science Committee staff.
  - Brought paper copies of the presentation, but with a memory stick just in case.

Press release

NEWS

THE NATIONAL ACADEMIES
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Read Full Report

Date: July 24, 2006
Contacts: Patrice Pages, Media Relations Officer
Megan Petty, Media Relations Assistant
Office of News and Public Information
202-334-2138; e-mail <news@nas.edu>

FOR IMMEDIATE RELEASE

U.S. Should Reinforce Its Commitment to Research in Atomic, Molecular, and Optical Science

WASHINGTON -- The federal government should reinforce its commitment to research in atomic, molecular, and opt science -- the study of atoms, molecules, and light, and related technologies such as lasers and fiber-optic communic new report from the National Academies' National Research Council. The report, which highlights six main "challeng that could directly impact the technology and economy of the future, also stresses the importance of research and ed physical sciences.

"During the past century, U.S. research in AMO science has benefited our country enormously through the developm

- This is not automatic for NRC reports.
- Wrote the draft ourselves, and reviewed the NRC rewrite carefully well in advance. VERY IMPORTANT!

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Business World | September 2006

US Commitment Lags in Atomic, Molecular and Optical Sciences

by Anne L. Fischer

The US government must deepen its commitment to research in atomic, molecular and optical sciences to maintain a leadership role in these areas, according to a report released by the Washington-based National Research Council of the National Academies.

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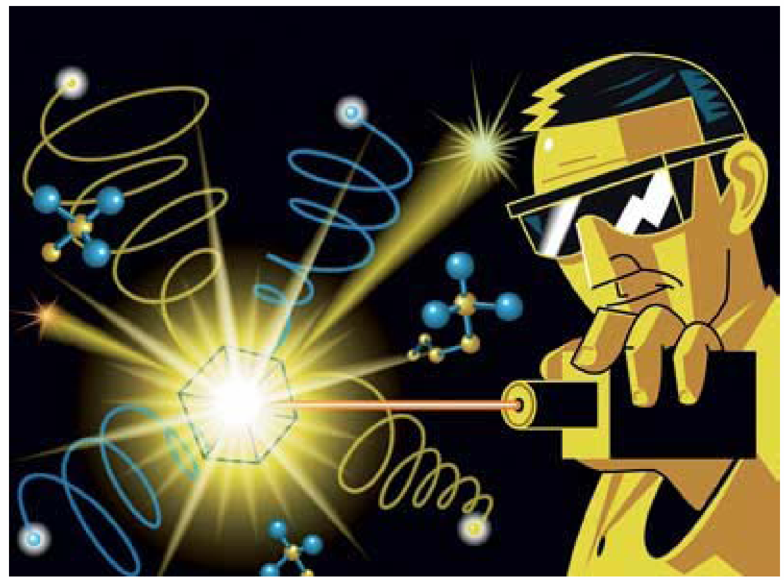
The fast show

Aug 31st 2006

From *The Economist* print edition

Extremely short laser pulses can illuminate electrons in motion



ON THE atomic scale, things move mind-bogglingly quickly. Electrons jump betwe orbits or escape the nucleus altogether in attoseconds—that is, million, million, millionths of a second. Indeed, one attosecond is to one second what one second the age of the universe. Seeing such acrobatics takes wit and ingenuity, but it is

amo2010 So, how did it go?

- We've had lots of good feedback from the physics community (cheers from a friendly crowd, of course.)
  - FYI article
  - Mentions in PT, Physics World, OPN, and so on.
- Some favorable comments from agencies
  - amo2010 figured prominently in a recent BESAC "grand challenges" presentation.
- Affect on science policy?
  - Too early to tell…