Inertial Confinement Fusion and High-Energy-Density Physics Research Opportunities for External Users on OMEGA

University of Rochester
Laboratory for Laser Energetics

Summary

OMEGA provides unique opportunities for high-energy-density physics research

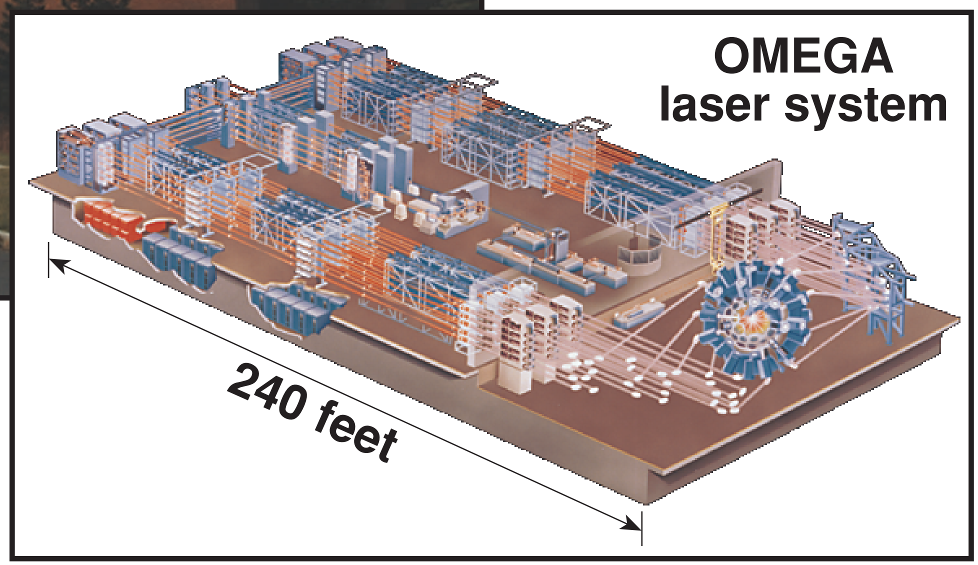
- Researchers from national laboratories, National Laser Users' Facility (NLUF), CEA, and AWE carry out increasingly complex direct- and indirect-drive experiments.

- NLUF and other external-user experiments on OMEGA provide opportunities for graduate and undergraduate education.

- The NLUF is a model for the larger-scale National Ignition Facility (NIF) users operations.

- LLE will enhance its users program and extend its capabilities in high-energy-density physic research with the construction of the multi-petawatt OMEGA EP laser facility.

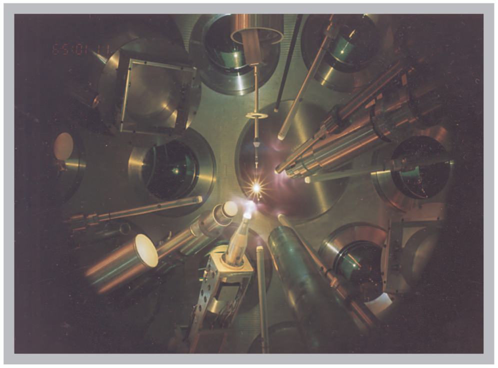
The Laboratory for Laser Energetics (LLE) was established in 1970



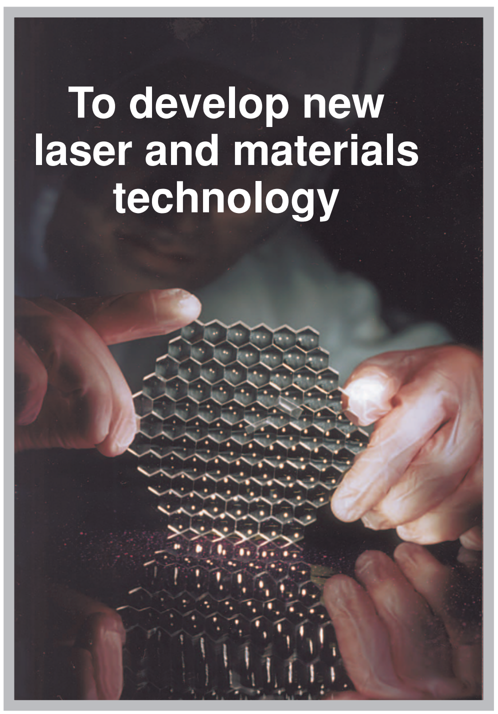
- Scientists & Faculty: 62
- Professional Staff: 201
- Graduate Students: 63
- Undergraduate Students: 64

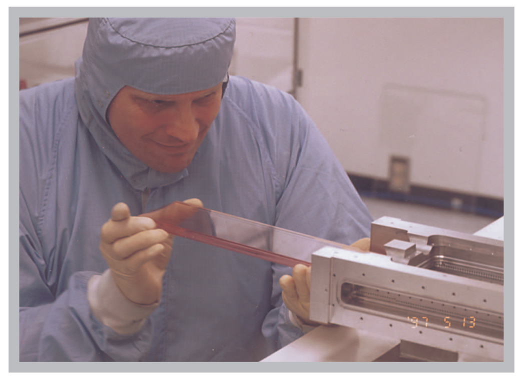
LLE's mission statement

To conduct implosion experiments and basic physics experiments in support of the National Inertial Confinement Fusion (ICF) Program.

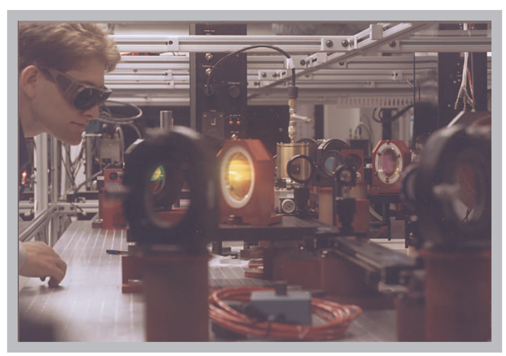


To operate the National Laser Users' Facility (NLUF).





To conduct research and development in advanced technology related to high-energy-density phenomena.



To provide graduate and undergraduate education in electro-optics, high-power lasers, high-energy-density physics, plasma physics, and nuclear fusion technology.

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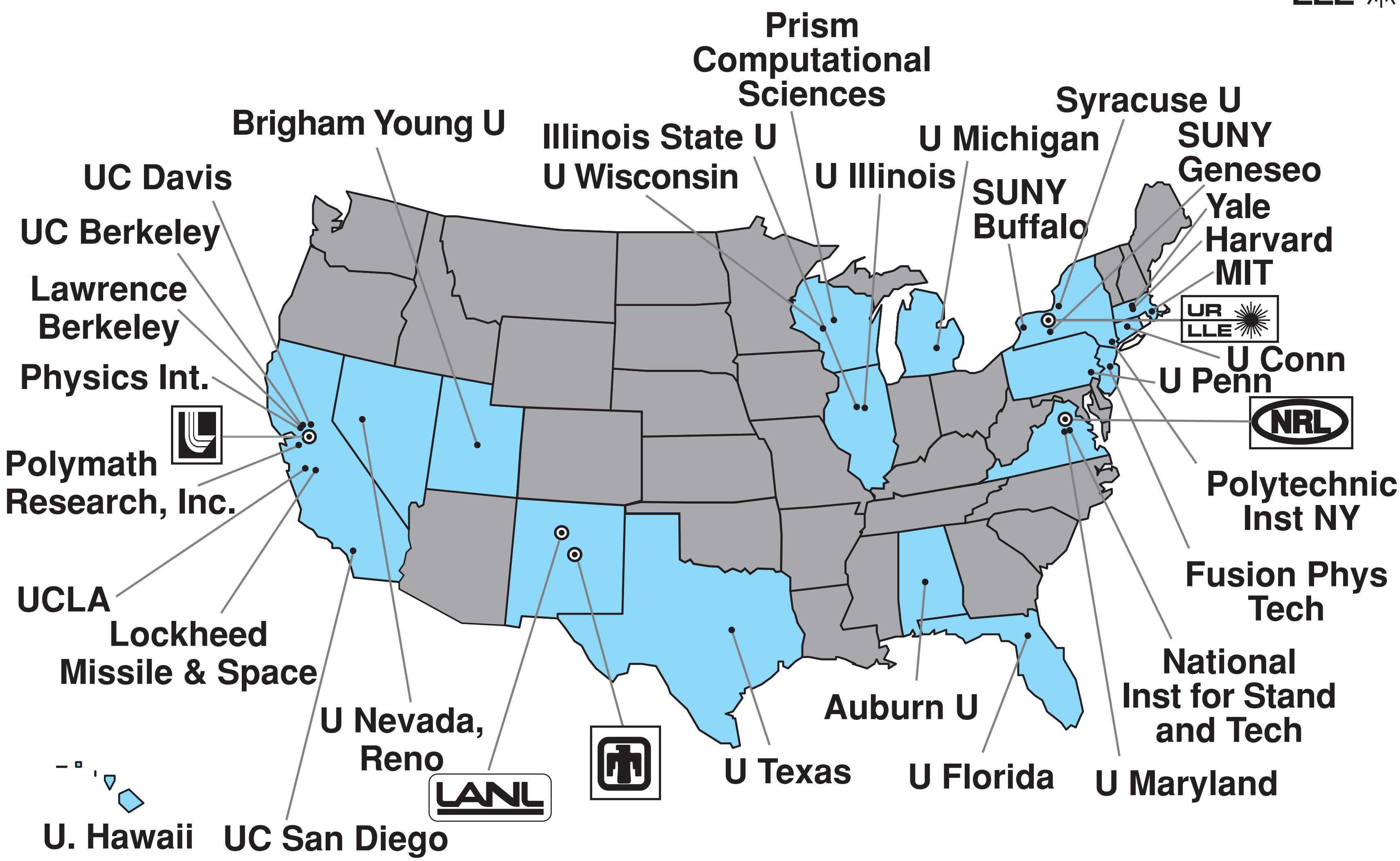
NLUF

The National Laser Users' Facility makes high-energy-density research facilities available to U.S. scientists (est. 1979)



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Principal investigators of approved NLUF experiments have come from industry, government, and university laboratories

UR LLE

- 32 accepted proposals from 5 government laboratories:
  - Lawrence Livermore National Laboratory
  - Los Alamos National Laboratory
  - Lawrence Berkeley Laboratory
  - National Institute of Standards and Technology
  - Naval Research Laboratory
- 6 accepted proposals from 5 industries:
  - Lockheed Missile and Space Company
  - Physics International
  - Fusion Physics and Technology
  - Polymath Associates
  - Prism Computational Sciences
- 85 accepted proposals from 25 university laboratories:
  - Brigham Young University
  - University of Illinois
  - University of Rochester
  - University of California, LA
  - University of California, San Diego
  - University of Maryland
  - University of Florida
  - University of Connecticut
  - University of Pennsylvania
  - Auburn University
  - Illinois State University
  - University of Texas
  - University of Hawaii
  - Yale University
  - University of Wisconsin, Madison
  - Polytechnic Institute NY
  - University of California, Davis
  - University of California, Berkeley
  - SUNY, Buffalo
  - SUNY, Geneseo
  - Syracuse University
  - Harvard University
  - University of Nevada at Reno
  - University of Michigan
  - Massachusetts Institute of Technology

NLUF

The National Laser Users' Facility (established in 1979) allows the University of Rochester's LLE facilities to be used by scientists from around the country

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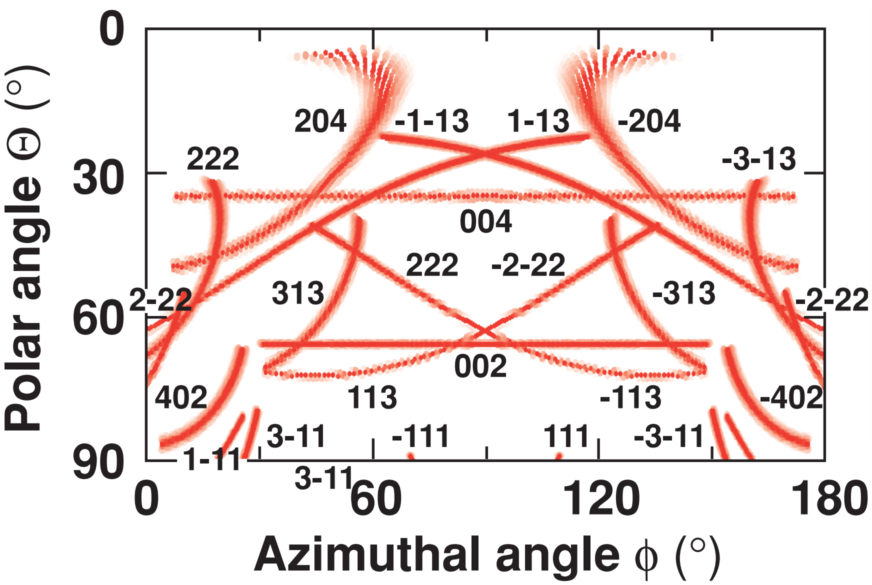
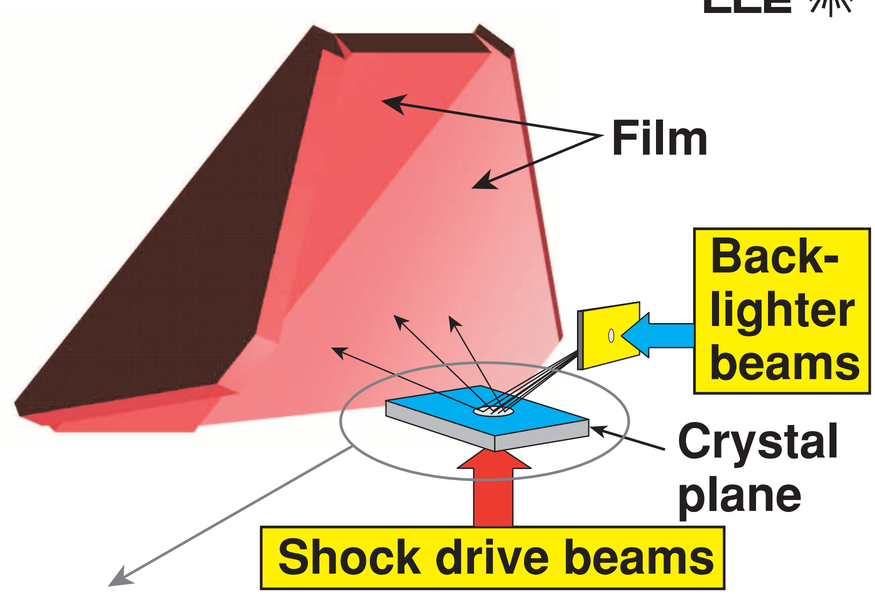
Objective: To make available high-energy-density physics research facilities to qualified scientists.

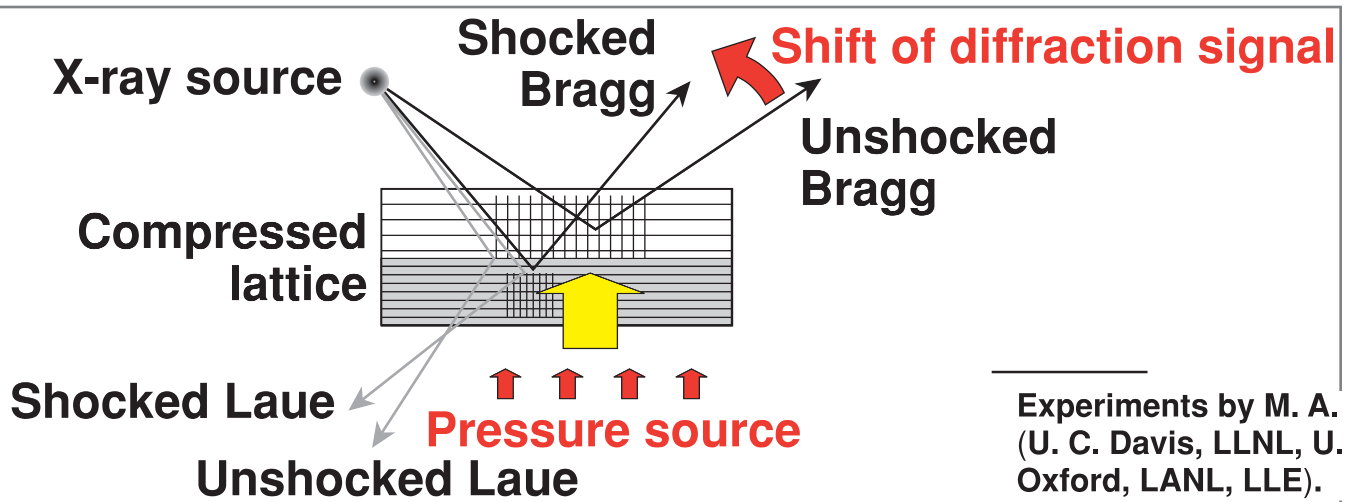
- There have been 248 submitted proposals.
- 123 of these have been approved.
- Scientists come from university, industrial, and government laboratories.
- 63 graduate students and 20 post-doctoral fellows have been funded by NLUF grants.
- Annual DOE support to users has ranged from \$400 K to \$1000 K.

Examples of NLUF experiments

Dynamic properties of crystals are investigated using x-ray diffraction







Experiments by M. A. Myers *et al.*
(U. C. Davis, LLNL, U. C. San Diego, Oxford, LANL, LLE).

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Dynamic properties of crystal are investigated using x-ray diffraction

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VOLUME 86, NUMBER 11 PHYSICAL REVIEW LETTERS 12 MARCH 2001

Anomalous Elastic Response of Silicon to Uniaxial Shock Compression on Nanosecond Time Scales

A. Loveridge-Smith,[1] A. Allen,[1] J. Belak,[2] T. Boehly,[3] A. Hauer,[4] B. Holian,[4] D. Kalantar,[2] G. Kyrala,[4] R. W. Lee,[2] P. Lomdahl,[4] M. A. Meyers,[5] D. Paisley,[4] S. Pollaine,[2] B. Remington,[2] D. C. Swift,[4] S. Weber,[2] and J. S. Wark[1]

[1]*Department of Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford, OX1 3PU, United Kingdom*
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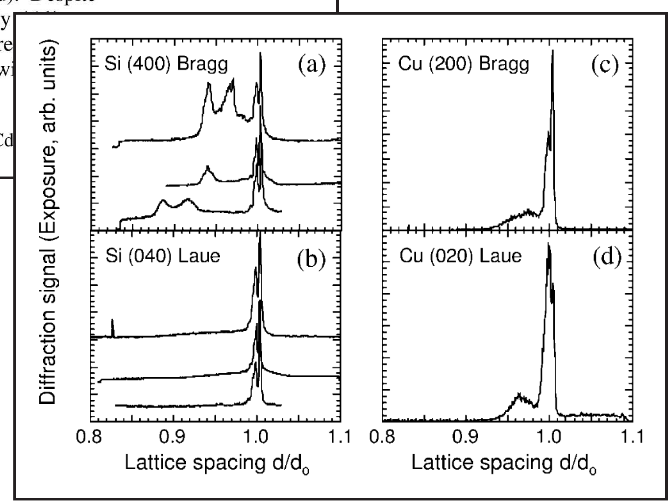
(Received 21 September 2000; revised manuscript received 16 January 2001)

We have used x-ray diffraction with subnanosecond temporal resolution to measure the lattice parameters of orthogonal planes in shock compressed single crystals of silicon (Si) and copper (Cu). Despite uniaxial compression along the (400) direction of Si reducing the lattice spacing by nearly observable changes occur in planes with normals orthogonal to the shock propagation dire contrast, shocked Cu shows prompt hydrostaticlike compression. These results are consistent wi estimates of plastic strain rates based on dislocation velocity data.

DOI: 10.1103/PhysRevLett.86.2349 PACS numbers: 62.50.+p, 46.40.Cd



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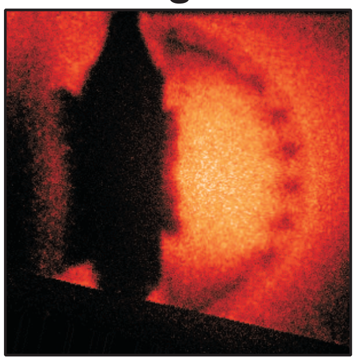
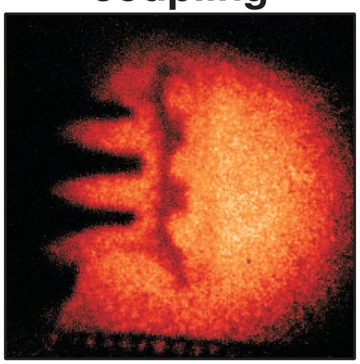
NLUF

A wide range of NLUF experiments on the OMEGA laser explore the physics of supernova explosions

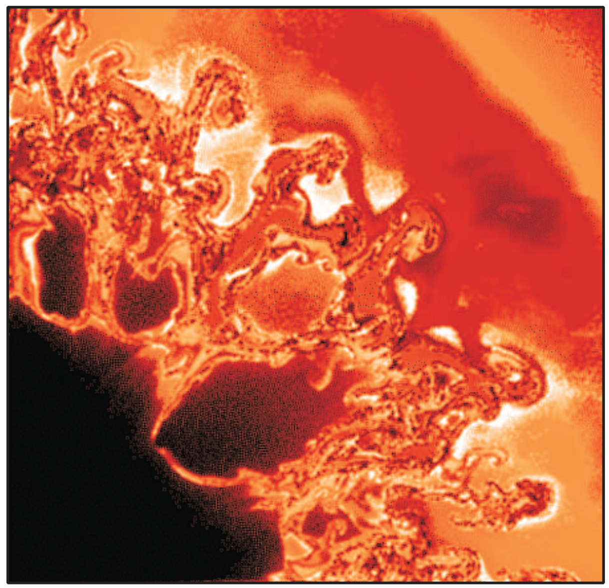
Spherical divergence



Multi-interface coupling

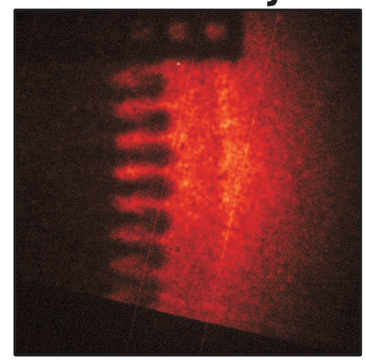


2-D simulation of supernova SN1987A

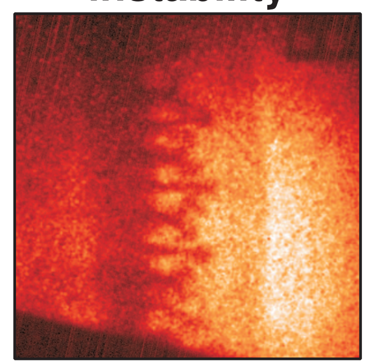


Muller, Fryxell, and Arnett (1991)

2-D versus 3-D instability



Multimode instability



H. F. Robey *et al.*, Phys. Plasmas 8, 2446 (2001).
R. P. Drake *et al.*, Astrophys. J. 564, 896–908 (2002).
Collaborators: U. Michigan, LLNL, U. Arizona, U. Colorado, U. Chicago, SUNY Stonybrook, U. Maryland, NRL, UR/LLE, U. Eastern Michigan, CEA Saclay

E11506a

OMEGA is a nexus for a variety of high-energy-density physics experiments

VOLUME 89, NUMBER 16 PHYSICAL REVIEW LETTERS 14 OCTOBER 2002

Observation of a Hydrodynamically Driven, Radiative-Precursor Shock

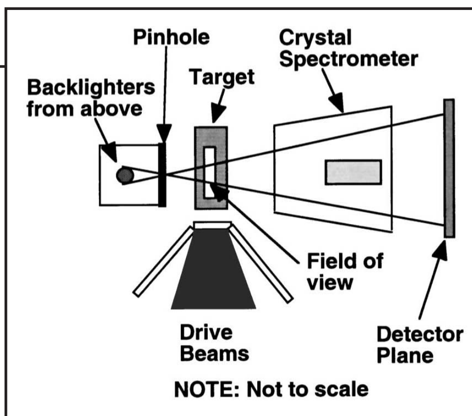
P. A. Keiter and R. P. Drake
University of Michigan, Ann Arbor, Michigan

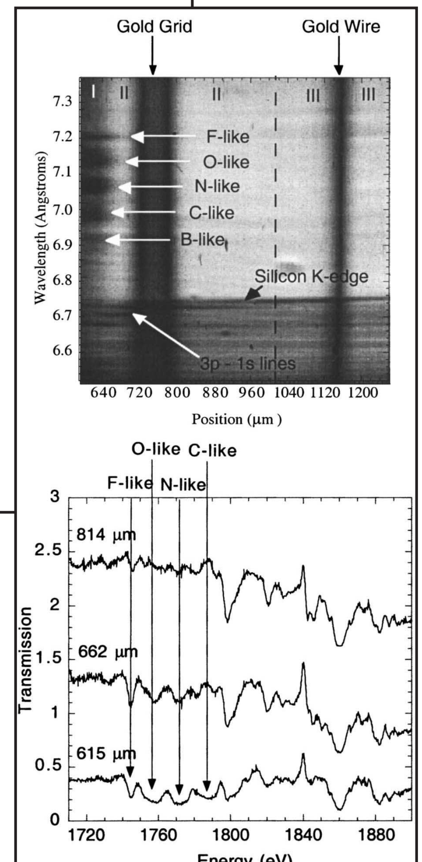
T. S. Perry, H. F. Robey, B. A. Remington, C. A. Iglesias, and R. J. Wallace
Lawrence Livermore National Laboratory, Livermore, California

J. Knauer
Laboratory for Laser Energetics, University of Rochester, Rochester, New York
(Received 11 December 2001; published 27 September 2002)

Observations of a radiative-precursor shock that evolves from a purely hydrodynamic system are presented. The radiative precursor is observed in low-density SiO_2 aerogel foam using x-ray absorption spectroscopy. A plastic slab, shocked and accelerated by high-intensity laser irradiation, drives the shock which then produces the radiative precursor. The length and temperature profile of the radiative precursor are examined as the intensity of the laser is varied.

PACS numbers: 52.35.Tc





NLUF experiments explore the use of spectroscopic diagnostics to determine implosion core gradients

VOLUME 88, NUMBER 4 PHYSICAL REVIEW LETTERS 28 JANUARY 2002

Spectroscopic Determination of Dynamic Plasma Gradients in Implosion Cores

I. Golovkin,[1] R. Mancini,[1,*] S. Louis,[2] Y. Ochi,[3] K. Fujita,[3] H. Nishimura,[3] H. Shirga,[3] N. Miyanaga,[3] H. Azechi,[3]
R. Butzbach,[4] I. Uschmann,[4] E. Förster,[4] J. Delettrez,[5] J. Koch,[6] R. W. Lee,[6] and L. Klein[7]

[1]*Department of Physics, University of Nevada, Reno, Nevada 89557*
[2]*Department of Computer Science, University of Nevada, Reno, Nevada 89557*
[3]*Institute of Laser Engineering, Osaka University, Osaka, Japan*
[4]*Institute of Optics and Quantum Electronics, Jena University, Jena, Germany*
[5]*Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623*
[6]*Lawrence Livermore National Laboratory, University of California, Livermore, California 94550*
[7]*Department of Physics and Astronomy, Howard University, Washington, D.C. 20059*
(Received 12 June 2001; published 10 January 2002)

The time-dependent gradient structure of a laser-compressed, high-energy-density plasma has been determined using a method based on the simultaneous analysis of time-resolved x-ray monochromatic images and x-ray line spectra from Ar-doped D_2 implosion cores. The analysis self-consistently determines the temperature and density gradients that yield the best fits to the spatial-emissivity profiles and spectral line shapes. This measurement is important for understanding the spectra formation and plasma dynamics associated with the implosion process. In addition, since the results are independent of hydrodynamic simulations, they are also important for comparison with fluid-dynamic models.

DOI: 10.1103/PhysRevLett.88.045002 PACS numbers: 52.57.Fg, 32.30.Rj, 52.50.Lp, 52.70.La

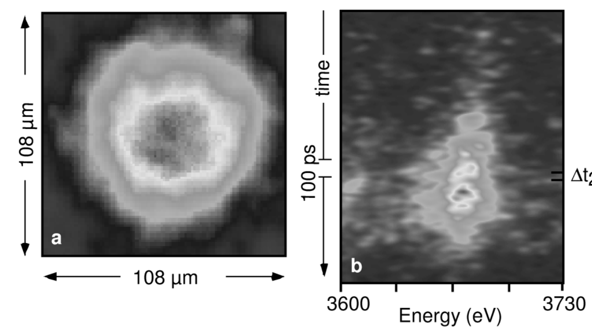


FIG. 1. (a) Ar Heβ monochromatic image frame, recorded in the interval $\Delta t_2 = 342-382$ ps; (b) time-resolved Ar Heβ spectra with the time interval Δt_2 marked on the time axis.

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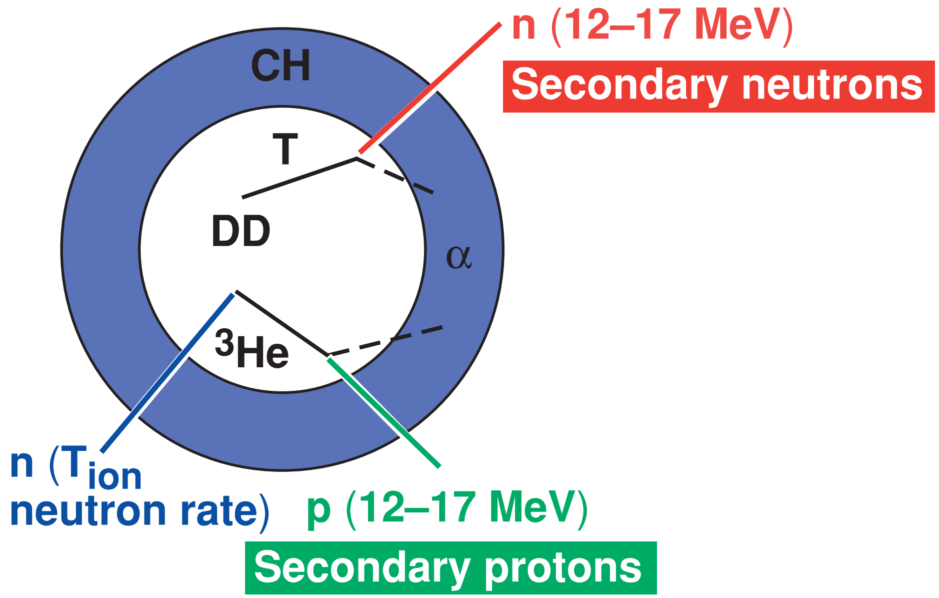
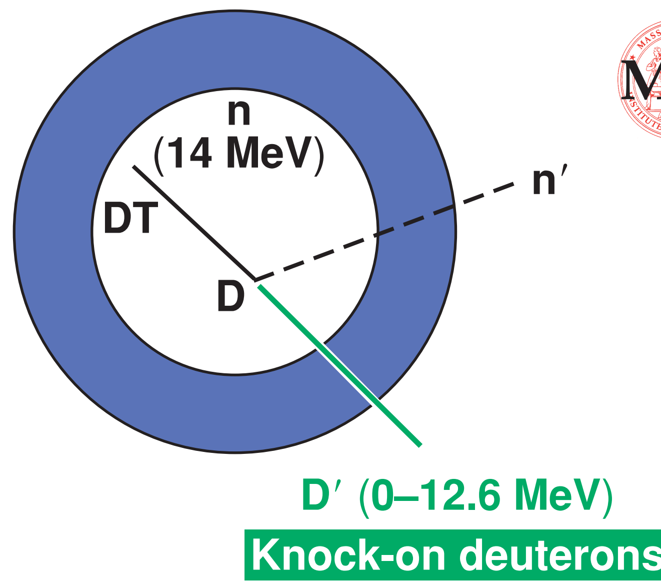
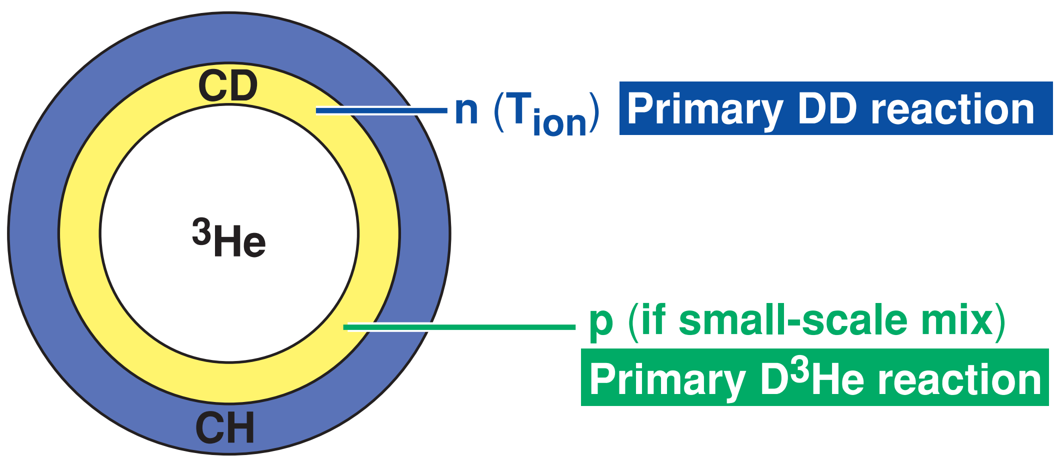
Implosion Diagnostics

Charged-particle spectroscopy has been developed and implemented on OMEGA by MIT-PSFC under NLUF







R. Petrasso *et al.*, Phys. Rev. Lett. 90 (13), 135002 (2003).

TC5724g

National Laboratory scientists use OMEGA to carry out HEDP experiments

- The experimental programs include
  - Testing of NIF target concepts
  - EOS of materials
  - Properties of shocked materials
  - Radiation flow and opacity
  - Hydrodynamic instabilities
  - Diagnostic development
  - Laboratory astrophysics

OMEGA serves as a test bed for NIF target concepts

PHYSICS OF PLASMAS VOLUME 10, NUMBER 6 JUNE 2003

Role of laser beam geometry in improving implosion symmetry and performance for indirect-drive inertial confinement fusion

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(Received 20 January 2003; accepted 28 March 2003)

The role of a high-Z radiation cavity or hohlraum in inertial confinement fusion is to convert laser energy into soft x-ray energy, in a highly spatially symmetric manner, so that a centrally located capsule containing deuterium and tritium can be uniformly imploded. In practice, however, the asymmetry introduced by the small number of high intensity laser beams can introduce significant perturbations in the drive uniformity. Experiments performed on Nova (10 beams) [J. T. Hunt and D. R. Speck, Opt. Eng. **28**, 461 (1989)] and Omega (using 40 beams) [J. M. Sources, R. L. McCrory, C. P. Verdon *et al.*, Phys. Plasmas **3**, 2108 (1996)] demonstrate a significant improvement in symmetry and target performance from a fourfold increase in the number of laser beams. [DOI: 10.1063/1.1576762]

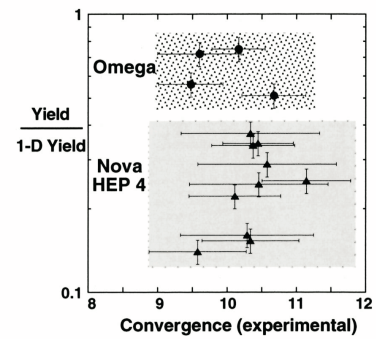

FIG. 4. Comparison of measured yield normalized to calculated 1D clean yield vs measured convergence ratio for implosions driven by single ring per side Nova (triangles) vs multiple ring per side Omega (circles) hohlraums.

VOLUME 89, NUMBER 16 PHYSICAL REVIEW LETTERS 14 OCTOBER 2002

Hohlraum-Driven High-Convergence Implosion Experiments with Multiple Beam Cones on the Omega Laser Facility

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(Received 21 March 2002; published 26 September 2002)

High-convergence implosion experiments have been performed on the Omega laser facility [T.R. Boehly *et al.*, Opt. Commun. **133**, 495 (1997)] using cylindrical gold hohlraums with 40 drive beams arranged into multiple cones. These experiments make use of improved hohlraum radiation symmetry conditions [T.J. Murphy *et al.*, Phys. Rev. Lett. **81**, 108 (1998)] to demonstrate near predicted primary (2.45 MeV) neutron production from single-shell implosions with measured deuterium fuel convergence ratios exceeding 20 at an ignition-relevant hohlraum case-to-capsule ratio ≈ 3.

DOI: 10.1103/PhysRevLett.89.165001 PACS numbers: 52.57.–z, 52.50.Jm

OMEGA serves as a test bed for NIF target concepts (cont'd)

VOLUME 82, NUMBER 19 PHYSICAL REVIEW LETTERS 10 MAY 1999

Inertial Confinement Fusion with Tetrahedral Hohlraums at OMEGA

J. M. Wallace, T. J. Murphy, N. D. Delamater, K. A. Klare, J. A. Oertel, G. R. Magelssen, E. L. Lindman, A. A. Hauer, and P. Gobby

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J. D. Schnittman, R. S. Craxton, W. Seka, R. Kremens, and D. Bradley

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S. M. Pollaine, R. E. Turner, and O. L. Landen

Lawrence Livermore National Laboratory, Livermore, California 94551

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InterScience, Germantown, Maryland 20875-0659

J. J. MacFarlane

University of Wisconsin, Madison, Wisconsin 53706

(Received 2 November 1998)

l confinement fusion will require for ignition a highly symmetric x-ray flux this end, the "tetrahedral hohlraum," spherical in shape with four laser entrance ertices of a tetrahedron, has been proposed. The first experimental test of OMEGA laser, is reported here. Drive symmetry was probed using capsule which varied qualitatively as expected with hohlraum dimensions. Modeling s time-averaged flux asymmetries as low as 1% rms over a 2.2-ns laser pulse. 8]

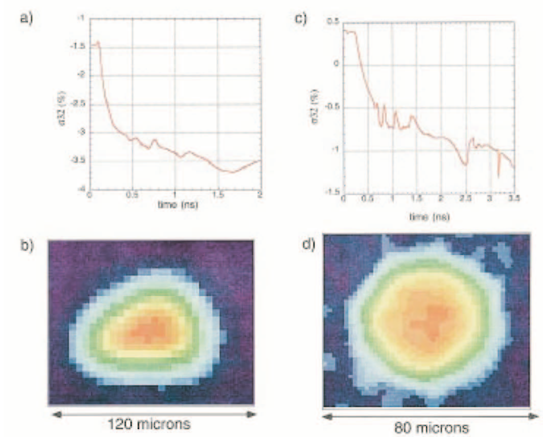

FIG. 3(color). Comparison between two different tetrahedral-hohlraum designs: the 1150/450 target with the 1-ns pulse on the left and the 1400/350 target with the shaped pulse on the right. Plots (a) and (c) show σ_{32}, the predicted time-dependent rms flux-asymmetry component. $\sigma_{32} < (>) 0$ indicates a hole-cold (hole-hot) configuration. The lower part of the figure shows the corresponding x-ray images for the two capsule implosions. Image (b), obtained with the smaller hohlraum, shows a triangular pattern having $d = 1.16$ with the lobes pointing toward the three opposite LEHs (not shown). Image (d), obtained with the larger hohlraum, is more nearly round, $d = 0.96$, and is consistent with the more symmetrical flux distribution predicted by the view-factor calculations.

OMEGA serves as a testbed for NIF target concepts (cont'd)

PHYSICS OF PLASMAS VOLUME 8, NUMBER 5 MAY 2001

National Ignition Facility scale hohlraum asymmetry studies by thin shell radiography*

S. M. Pollaine,† D. K. Bradley, O. L. Landen, R. J. Wallace, O. S. Jones, P. A. Amendt, L. J. Suter, and R. E. Turner
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(Received 24 October 2000; accepted 20 February 2001)

A necessary condition for igniting indirectly driven inertial confinement fusion (ICF) capsules on the National Ignition Facility (NIF) is controlling drive asymmetry to the 1% level [S. W. Haan, S. M. Pollaine, J. D. Lindl *et al.*, Phys. Plasmas **2**, 2480 (1995)]. Even flux-asymmetry modes (e.g., Legendre modes P_2, P_4, P_6, and P_8) must be reduced by hohlraum design and laser beam pointing. Odd flux-asymmetry modes (e.g., Legendre modes P_1, P_3, P_5, etc.) are theoretically removed by reflection symmetry across the hohlraum midplane [S. M. Pollaine and D. Eimerl, Nucl. Fusion **38**, 1523 (1998)], but will be produced by power imbalance, laser beam pointing errors, and target fabrication errors. An experimental campaign is now being conducted on the University of Rochester's Omega laser to measure higher order (P_4 and high
hohlraums that approximate the conditions of a NIF hohlraum d
[S. W. Haan, S. M. Pollaine, J. D. Lindl *et al.*, Phys. Plasmas **2**,
use a new point-projection backlighting technique [O. L. Landen
et al., Rev. Sci. Instrum. **72**, 627 (2001)] to cast high quality 4.
diameter Ge-doped CH shells designed to enhance sensitivity to
the position of the limb of the shells resulting primarily from driv
accuracy of 2 μm. The linearity and sensitivity of thin implodin
it possible to achieve this degree of accuracy, which is sufficient
The promising results to date permit the comparison of measured
inference, drive asymmetries for the first eight asymmetry mode
Physics. [DOI: 10.1063/1.1364514]

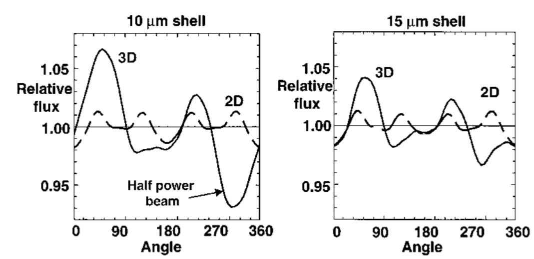

FIG. 12. View factor simulations using the actual power in each of the 42 beams that went into the hohlraum for shots 19082 (left) and 19083 (right). The 2D dashed curves were made by azimuthally averaging each laser beam.

Complex multi-target assemblies are routinely fielded on OMEGA

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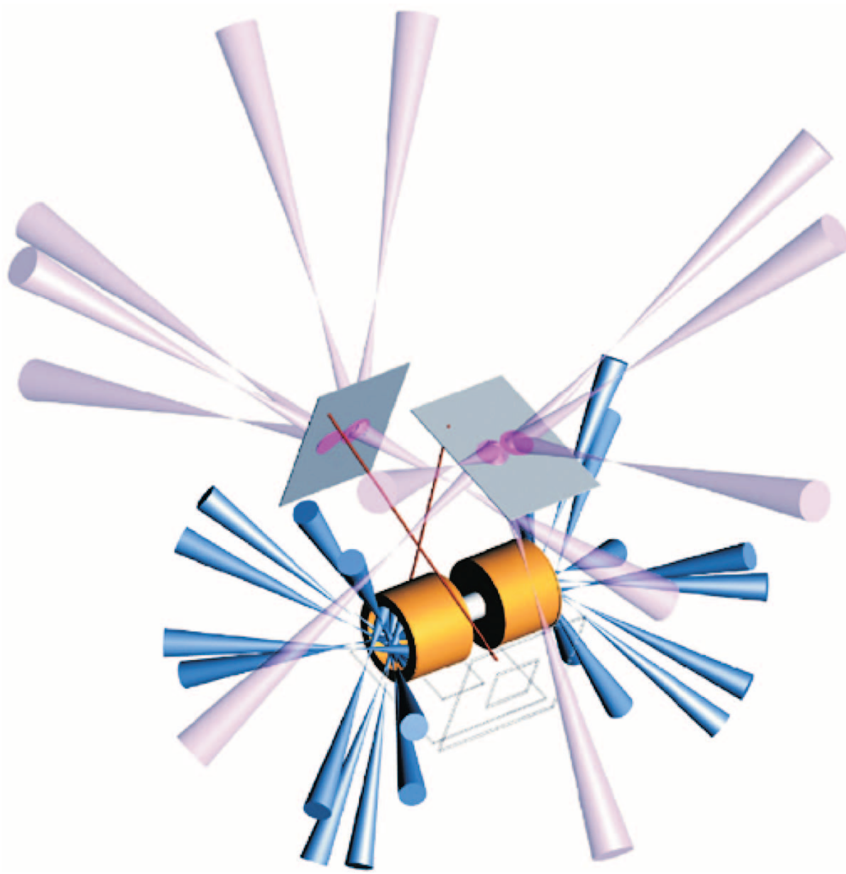

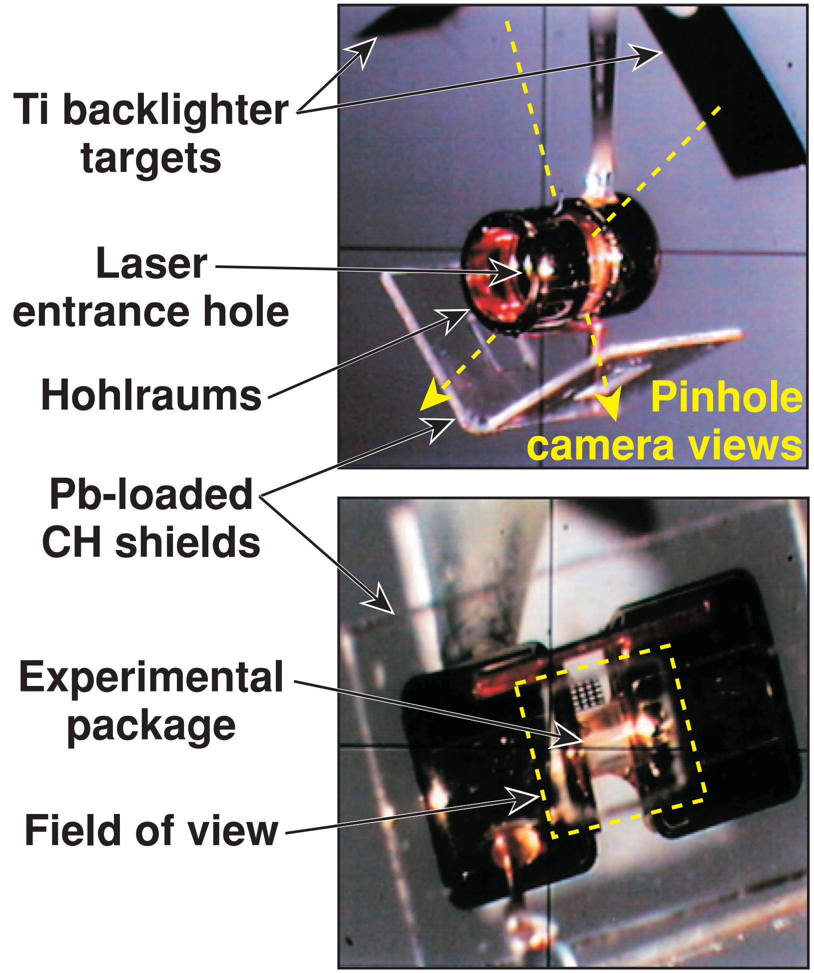

- The experimental configuration provides two orthogonal pinhole-camera views, synchronous or sequential in time.

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Supersonic jet experiments provided high-quality benchmark data for code comparisons

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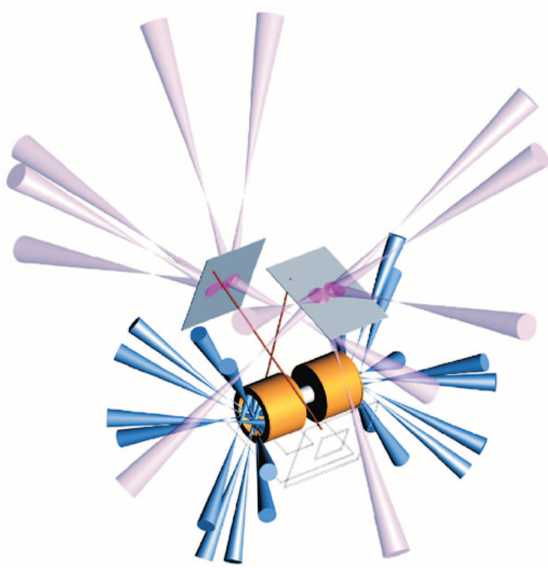
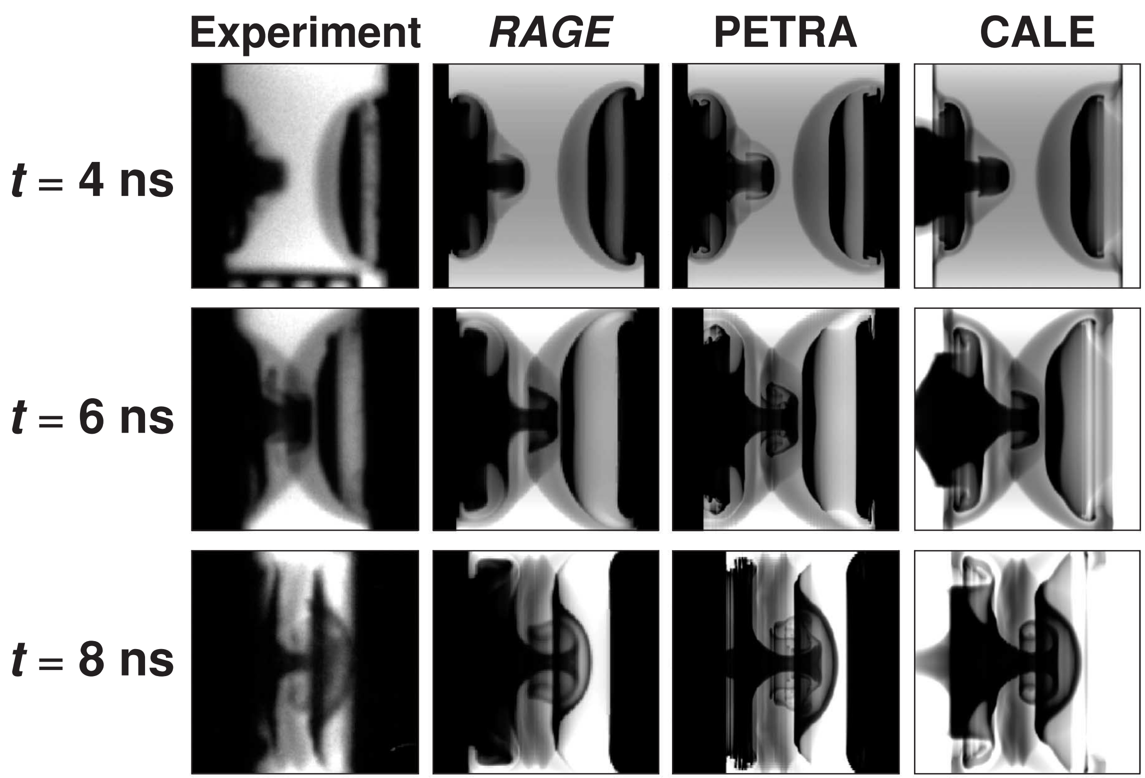
Los Alamos
AWE

AWE jets



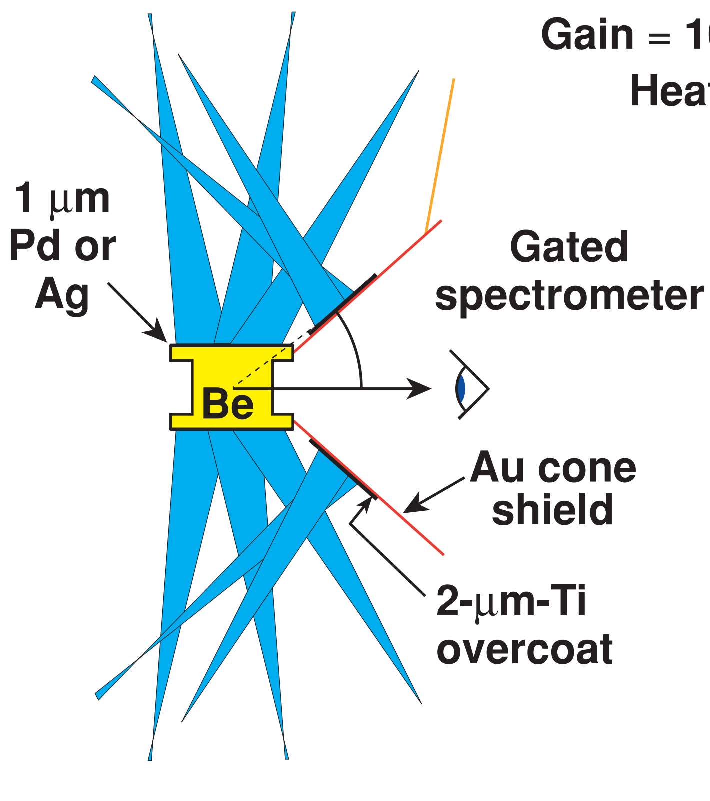


J. Foster, et al. Phys. Plasmas 9 225 (2003).

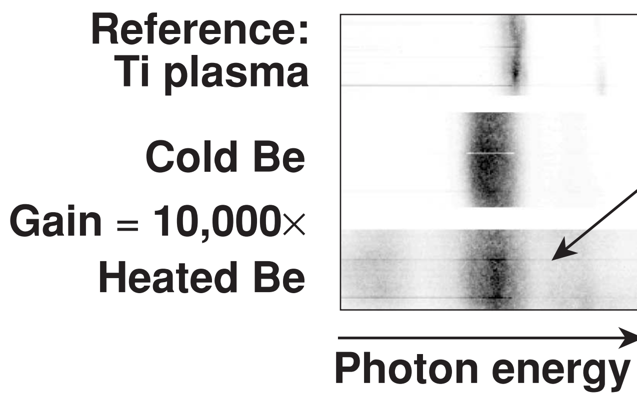
National Laboratory Program

First demonstration of x-ray Thomson scattering as a high-density temperature and density diagnostic

OMEGA proof-of-principle experiment geometry



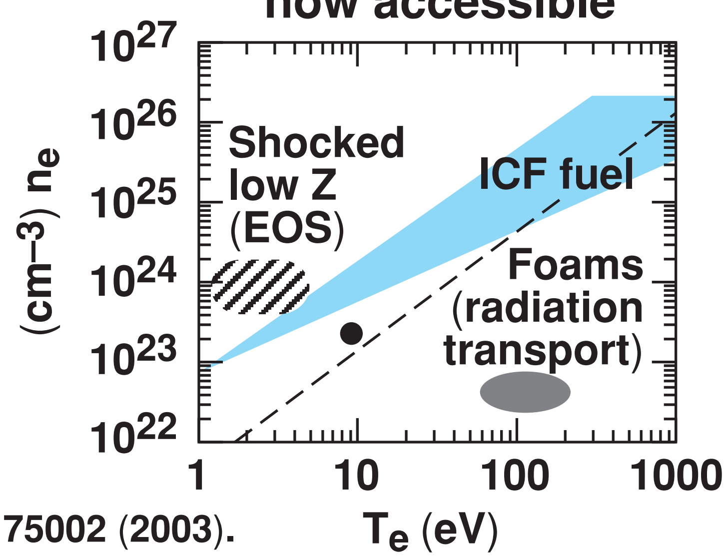
X-ray spectra



XRTS/EOS/ Cap.Dev.

Compton-downshifted and Doppler-broadened Thomson spectrum observed as expected

High-density regimes now accessible



U300a S. H. Glenzer *et al.*, Phys. Rev. Lett. 90 (17), 175002 (2003).

OMEGA is used to develop and test NIF target diagnostics

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REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 74, NUMBER 3 MARCH 2003

CVD diamond as a high bandwidth neutron detector for inertial confinement fusion diagnostics

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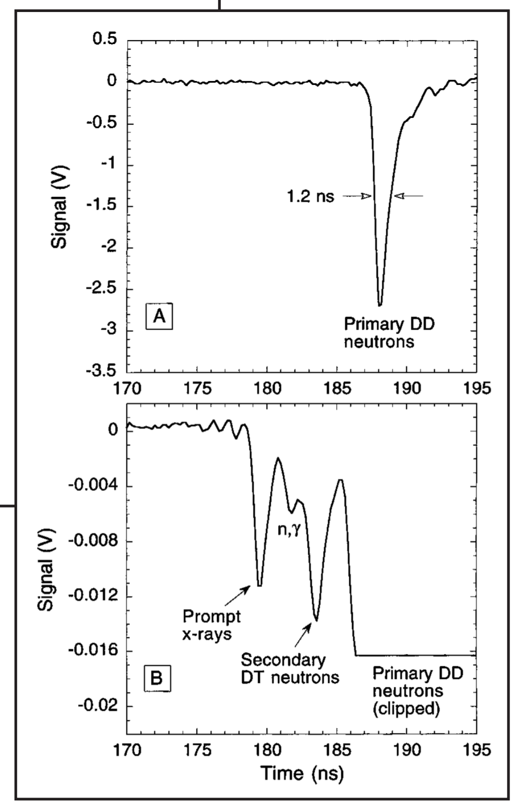
Lawrence Livermore National Lab, University of California, Livermore, California 94550

V. Yu. Glebov, T. C. Sangster, and C. Stoeckl
Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623-1299

(Presented on 9 July 2002)

We characterize the response of chemical vapor deposition (CVD) diamond detectors to inertial confinement fusion (ICF) neutrons generated at the OMEGA laser fusion facility in Rochester, NY. Four detectors are tested: three utilizing ‘‘optical grade’’ CVD diamond, and one utilizing ‘‘electronic grade’’ CVD diamond. Using a 50 Ω measurement system, we find that the optical grade wafers, biased to 1000 V/mm, have an average sensitivity of 0.24 μV ns/n for 2.5 MeV (DD fusion) neutrons and 0.62 μV ns/n for 14.0 MeV (DT fusion) neutrons. At the same E field, the electronic grade wafer has a sensitivity of 0.56 and 1.43 μV ns/n for 2.5 and 14 MeV neutrons, respectively. Linear dynamic range for the optical grade material is shown to be at least 10^5. Average full width at half maximum response times, as measured with pulsed laser and 3 GHz scope, are 376 and 880 ps for optical and electronic grades, respectively. These characteristics make CVD diamond suitable for ICF applications such as neutron time-of-flight spectroscopy, bang time measurements, and ion temperature measurements. [DOI: 10.1063/1.1534899]



OMEGA is used to develop and test NIF target diagnostics (cont'd)

REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 74, NUMBER 5 MAY 2003

First results of pinhole neutron imaging for inertial confinement fusion

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(Received 8 July 2002; accepted 2 March 2003)

Results are presented for the first implementation of pinhole imaging of inertial confinement fusion-produced neutrons. Raw images are shown, together with mathematical reconstructions of the source objects, for both spherical and asymmetric implosions. These reconstructions are considerably sharpened with respect to the raw images. They rely on the accurate calculation of the point-spread function, including neutron penetration into the material defining the pinhole. Proton recoil in the scintillator material and irregularity in scintillator fiber packing must be considered. The statistics of the system are inferred, which allows the use of simulations to demonstrate the robustness of the reconstructions to noise.
[DOI: 10.1063/1.1569407]

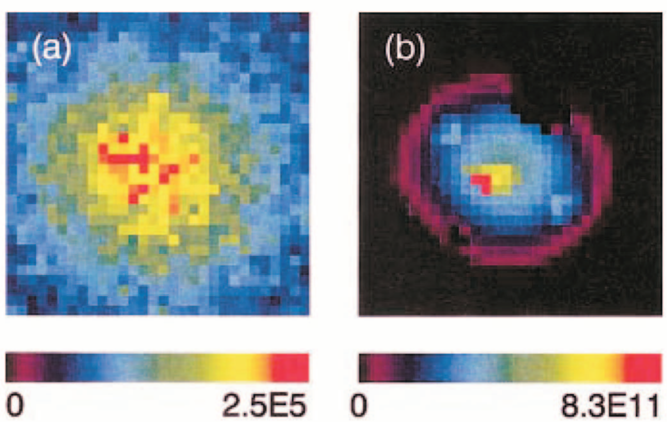

FIG. 6. (Color) Reconstruction for shot 23 710. (a) Binned data (1.53 cm wide). (b) Reconstruction (189 μm wide).

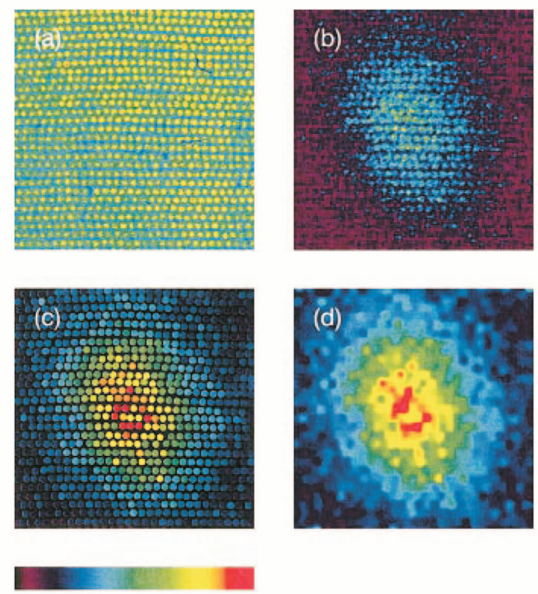

FIG. 4. (Color) Data processing for shot 26 665 (prolate drive). (a) Raw data from a flat-field shot. (b) Raw data from shot 26 665. (c) Data have the dark-field signal subtracted, are divided by flat-field signal, and are summed over fibers. (d) A smooth function is fit to match the data over the areas of fibers. 1.53 cm per plot.

National Laboratory Programs

Direct-drive cylindrical implosions demonstrate mix in convergent, compressible plasma

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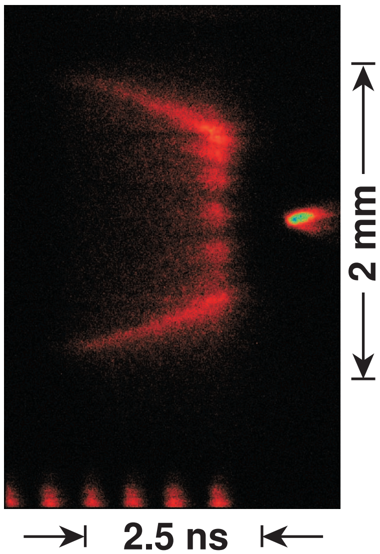
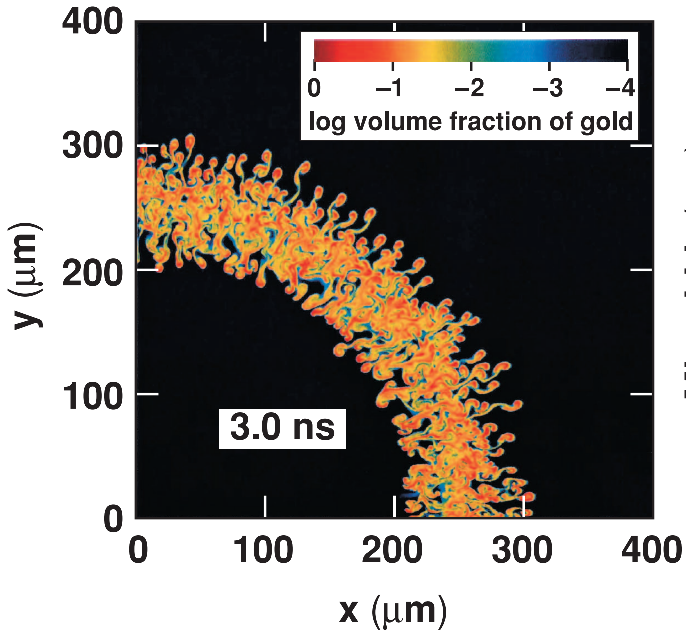
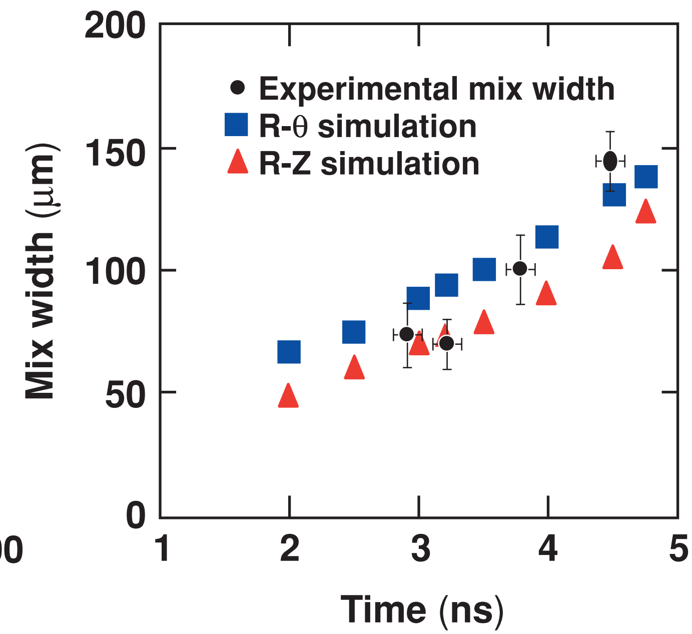


Imaging x-ray streak camera image of cylindrical implosion. Spikes of an imposed m = 14 perturbation burnthrough just before the end of the 2.5-ns drive pulse.



RAGE simulation of the volume fraction of a gold marker in a direct-drive cylindrical mix implosion



Comparison of experimental measurements of mix width in time with *RAGE* simulation

U308

C. W. Barnes *et al.*, Phys. Plasmas 9, 4431 (2002).

The first ICF ablator burnthrough data in halfraums were obtained in SNL/LANL/LLNL/LLE experiments

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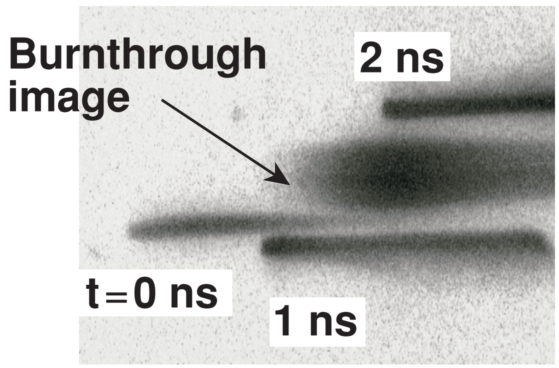
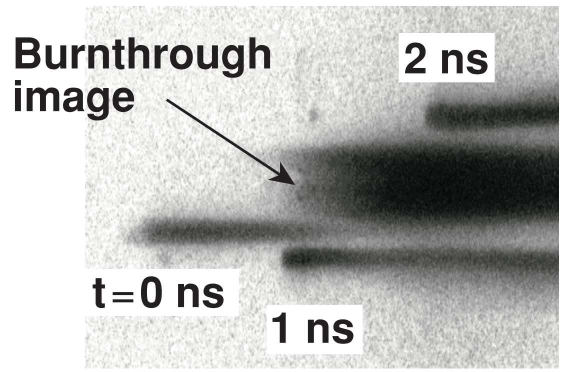
WBS 3 Ablator

IDI 3.2.1: Perform integrated ablator experiments in OMEGA halfraum geometry

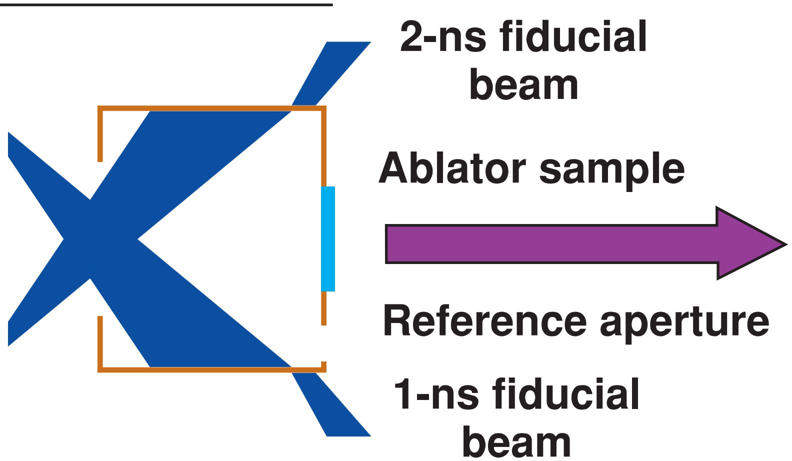
Polyimide



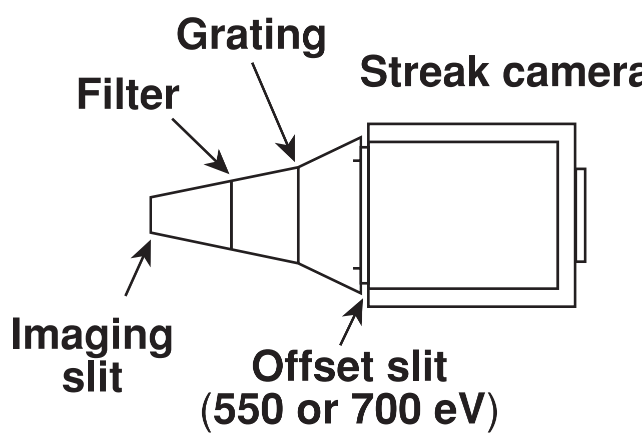
Beryllium



OMEGA Halfraum



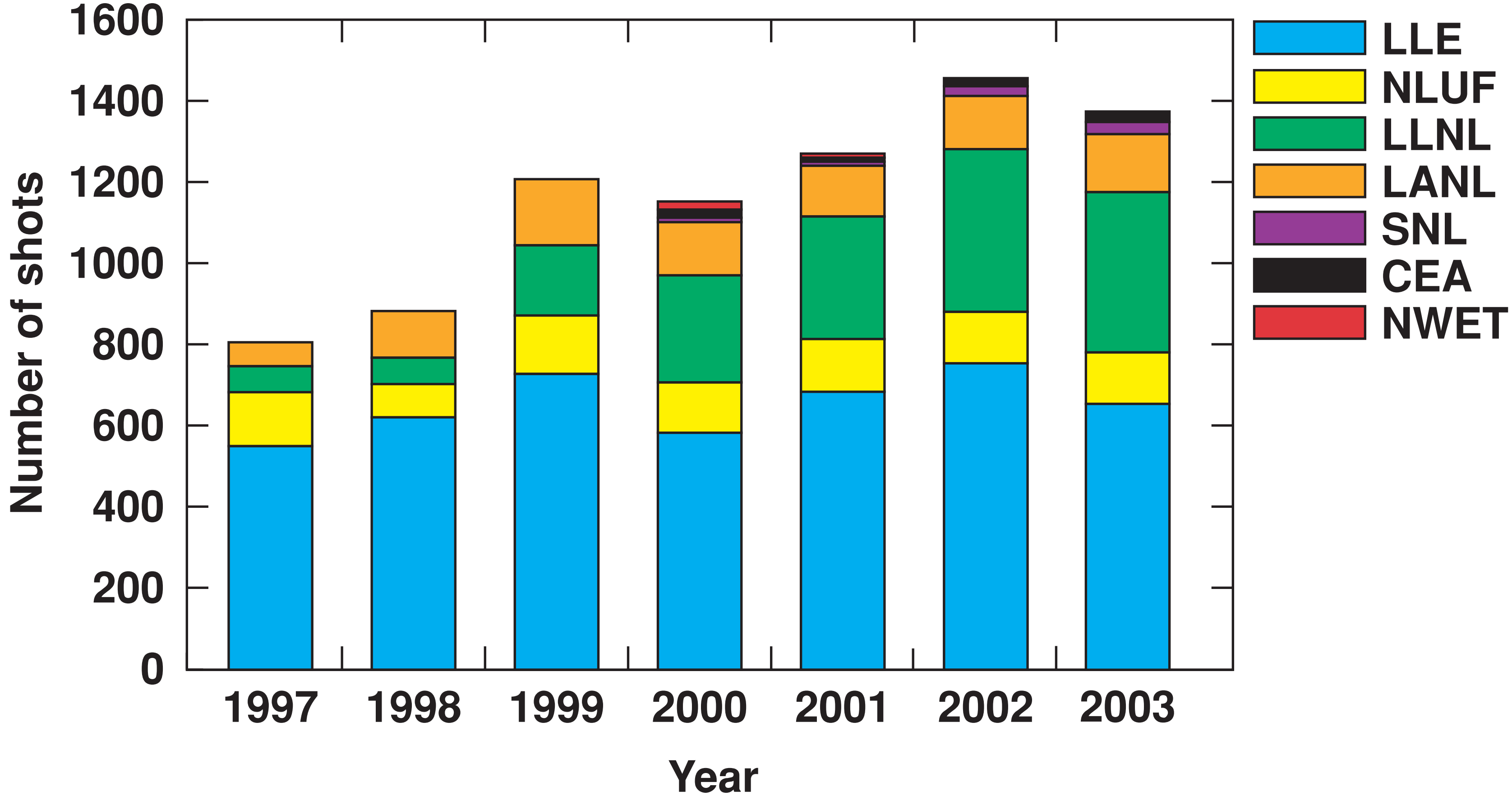
LLNL Streaked X-Ray Imager (SXI)



U301

Sandia National Laboratories

OMEGA operations have been increased to support external users program requirements

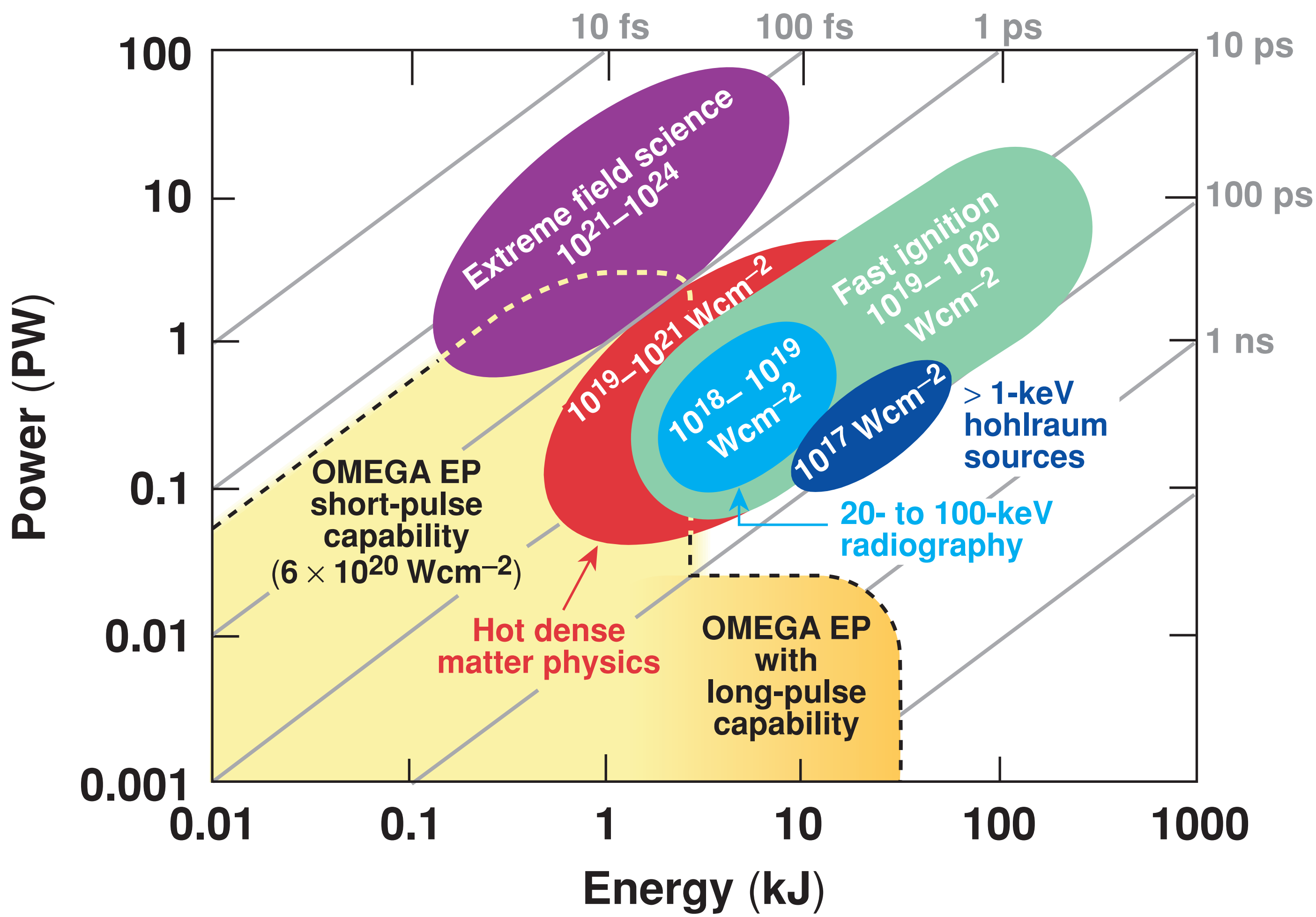


M204e

OMEGA EP

To enhance the nation's high-energy-density science capabilities, LLE will build a multi-petawatt laser

UR LLE

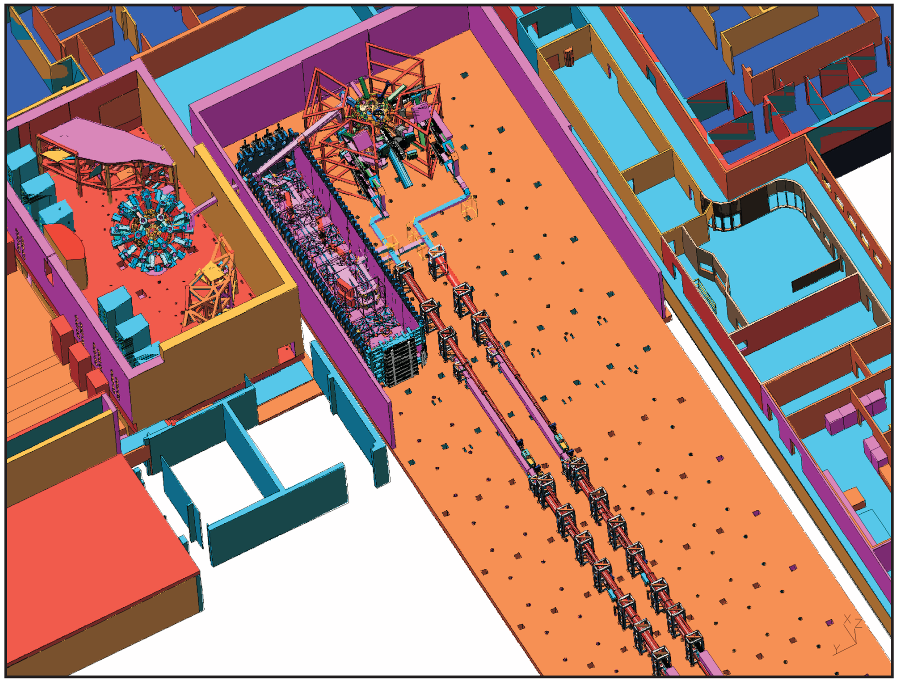


E11703f

LLE will extend its HED physics capabilities by constructing OMEGA EP (extended performance)

UR LLE

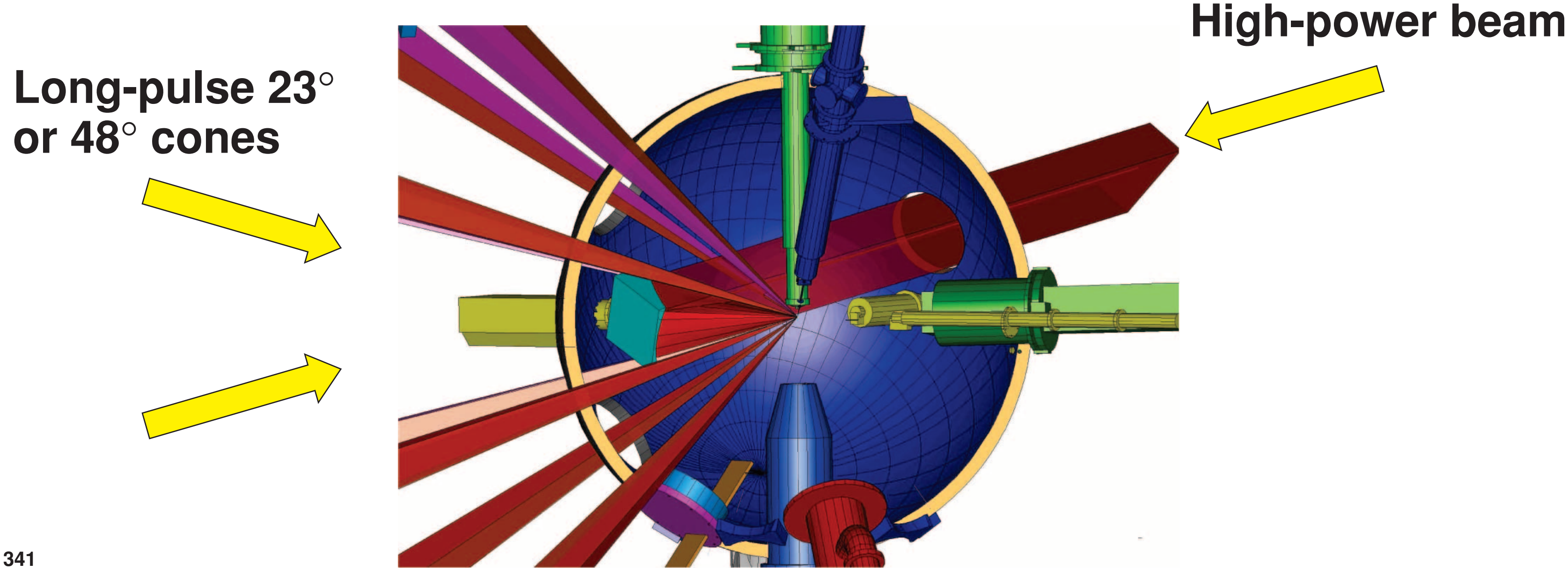
- OMEGA EP will add two short-pulse, 2- to 3-PW, 2.6-kJ beams to OMEGA.
- Two high-energy, high-power laser beams can be routed into the OMEGA target chamber or a dedicated OMEGA EP chamber.
- Co-location of high-energy, high-power lasers with HED facilities maximizes their utility.
- Status:
  - CD0 – May 2003
  - CD1/3A – September 2003
  - Building construction start – August 2003



Many flexible configurations will be possible on OMEGA EP

- OMEGA EP will allow
  - Significant advances in radiographic capabilities for HED experiments
  - Development of diagnostics and diagnostic techniques for the NIF
  - Studies of the fast ignition concepts
  - Additional precision HED physics experiments
  - Studies of ultrahigh-intensity laser–matter interactions
  - Maximizing the optimal use of the NIF

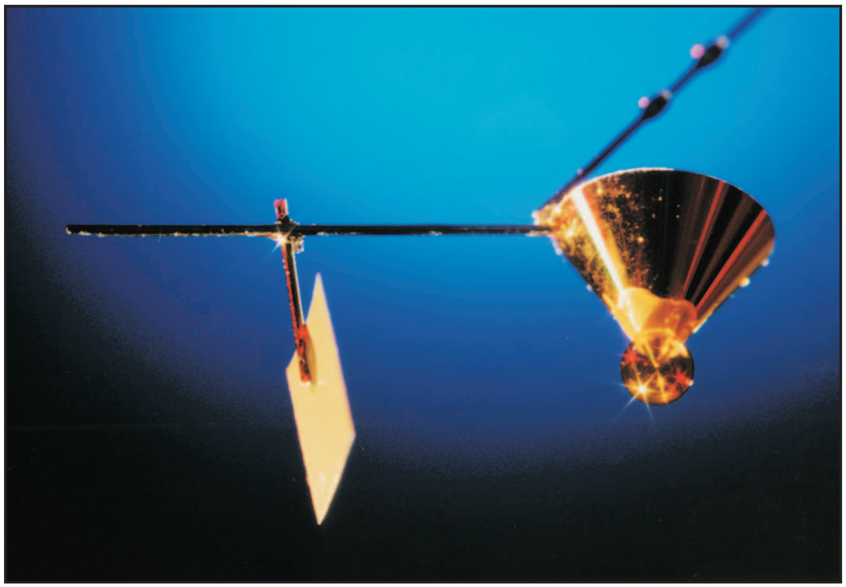
OMEGA EP target chamber

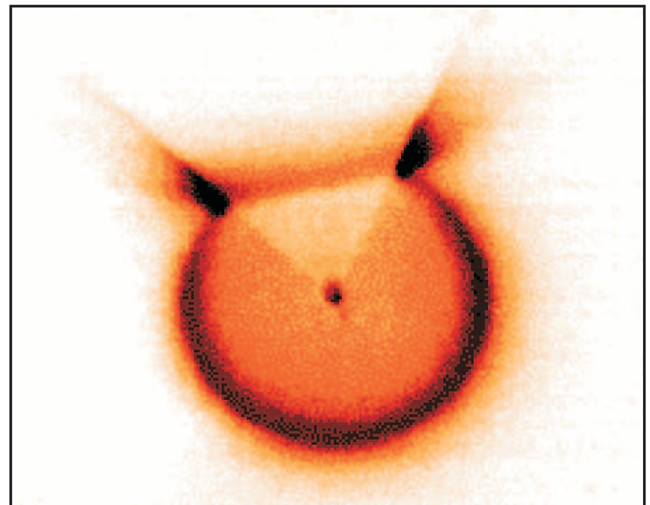


I1341

Fuel assembly experiments with cone-focused targets have begun on OMEGA

Direct-drive cone targets shot on OMEGA in FY03 (LLNL, GA, ILE)




Pin-hole camera (H8)

E11959b

Construction of the OMEGA EP building began in August 2003

Summary/Conclusions

OMEGA provides unique opportunities for high-energy-density physics research

UR LLE

- Researchers from national laboratories, National Laser Users' Facility (NLUF), CEA, and AWE carry out increasingly complex direct- and indirect-drive experiments.
- NLUF and other external-user experiments on OMEGA provide opportunities for graduate and undergraduate education.
- The NLUF is a model for the larger-scale National Ignition Facility (NIF) users operations.
- LLE will enhance its users program and extend its capabilities in high-energy-density physic research with the construction of the multi-petawatt OMEGA EP laser facility.

U298b