Summary

Research in high-energy-density (HED) physics and inertial fusion energy (IFE) is ripe for exploitation

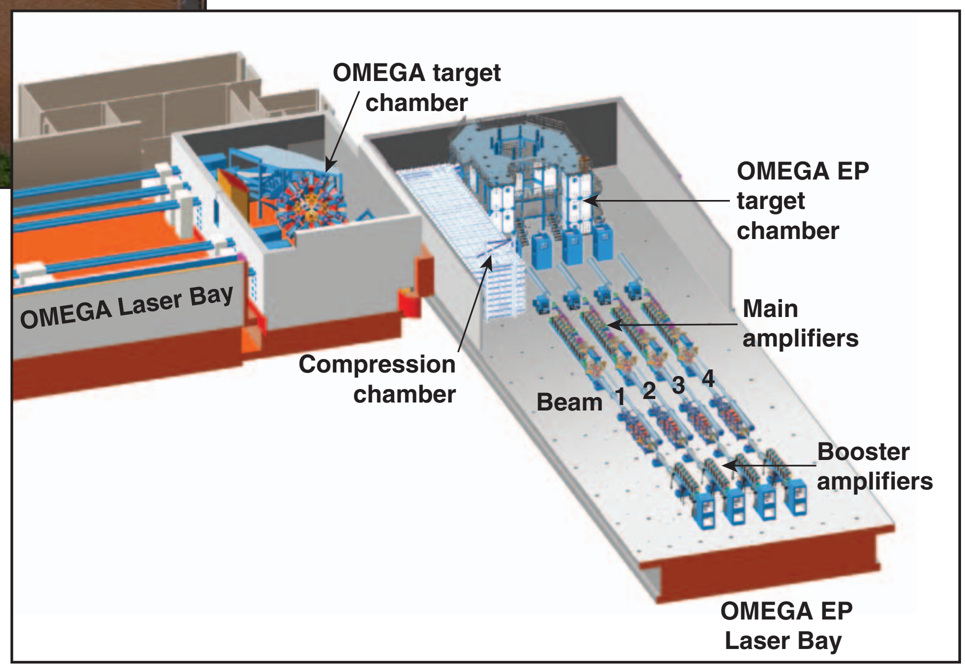
- HED basic science and IFE have been the subject of numerous favorable panel reports
- NNSA built and operates HED facilities for mission-driven and basic science research—ICF ignition is expected on the NIF in the next few years
- Budget pressures limit the facility operations, squeezing basic science
- LLE was founded in 1976
  - operates the Omega Laser Facility as a National Users' Facility
  - research program, currently focused on ICF research, supports ignition on the NIC (National Ignition Campaign)
    - only facility worldwide performing cryogenic target implosions
  - development of technologies supporting the ICF program
- Basic Science Users have access through the National Laser Users' Facility (1979) and Laboratory Basic Science (2008)
  - parallel tracks for University/Business and National Laboratories
- The Omega Laser Facility is ideal for testing Advance Ignition Concepts

There are significant research opportunities in high-energy-density physics on OMEGA.

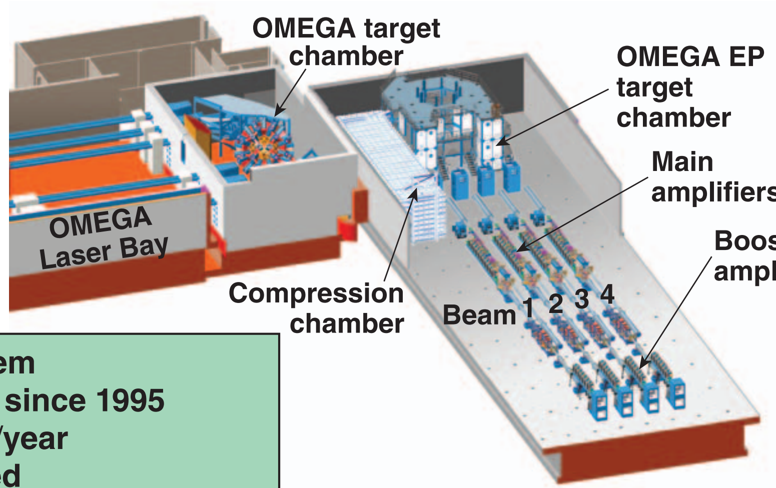
Laboratory for Laser Energetics

Total square footage: 310,000 ft^2

- **Faculty equivalent staff: 96**
- **Professional staff: 172**
- **Associated faculty: 26**
- **Contract professionals: 12**
- **Graduate and undergraduate students: 123**



LLE operates the Omega Laser as a National Users' Facility for NNSA



OMEGA Laser System
- Operating at LLE since 1995
- Up to 1500 shots/year
- Fully instrumented
- 60 beams
- >30-kJ UV on target
- 1% to 2% irradiation nonuniformity
- Flexible pulse shaping
- Short shot cycle (1 h)

OMEGA EP Laser System
- Construction complete 25 April 2008
- Adds four NIF-like beamlines; 6.5-kJ UV (10 ns)
- Two beams can be high-energy petawatt
  - 2.6-kJ IR in 10 ps
  - Can propagate to the OMEGA or OMEGA EP target chamber.

- The OMEGA Users' Group
  - founded in 2008 to facilitate communication among the users, the Omega facility, and the broader scientific community
  - annual OMEGA Laser Facility Users Group Workshop—to be held 29–30 April 2010
  - >160 members

Shot time on OMEGA is divided between NNSA missions and basic science

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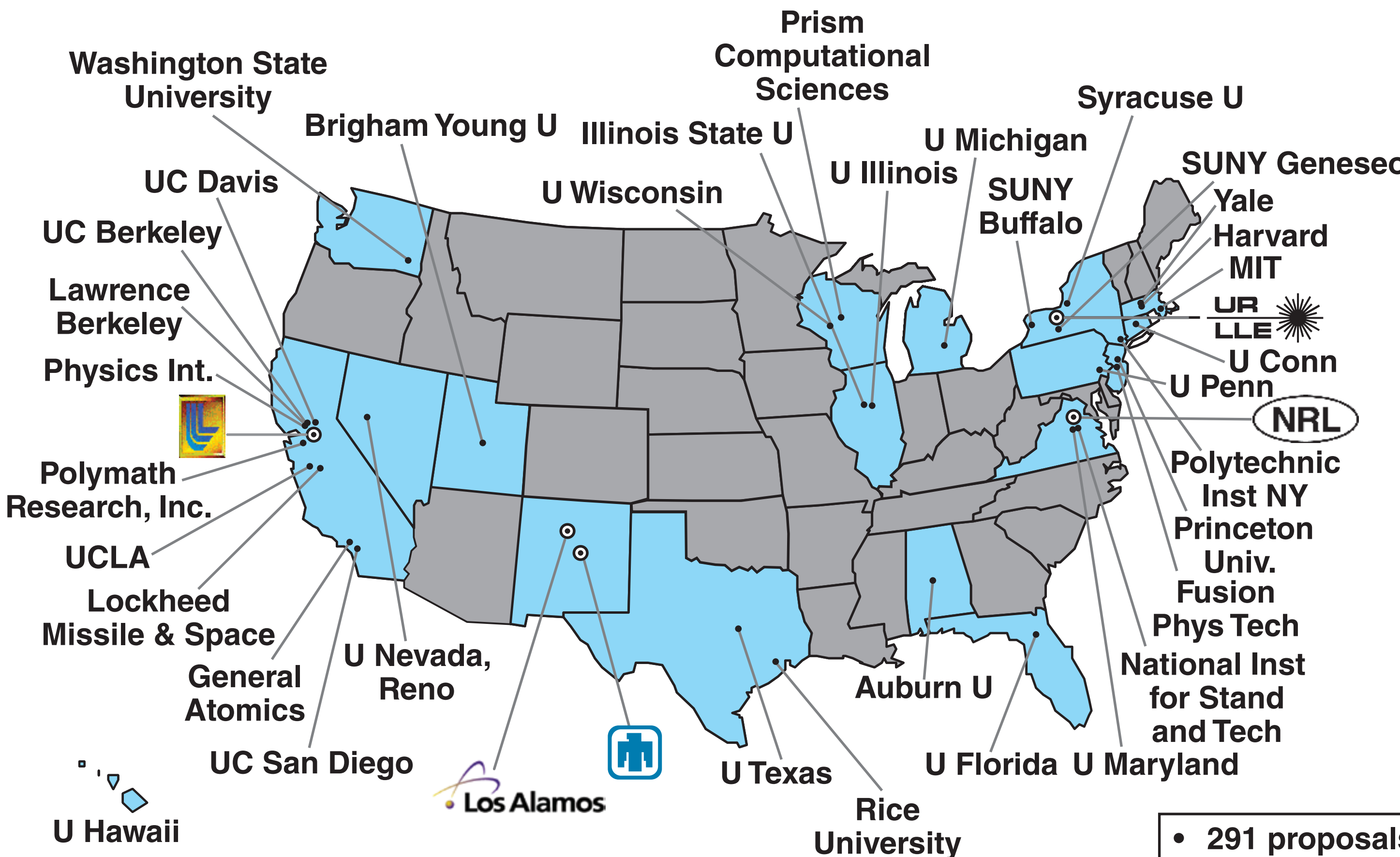
- Mission driven (~70%)
  - Inertial confinement fusion—National Ignition Campaign (NIC)
  - Weapons physics–HED
- Basic Science (~25%)
  - University/Industrial users–NLUF
  - Weapons Laboratories and LLE–Laboratory Basic Science
- In the scheduling process, mission-related programs
  - are integrated plans
  - priorities have been reviewed
  - the Omega Scheduling Committee considers relative priorities
- The two basic science categories are externally peer reviewed with rankings presented to the Scheduling Committee

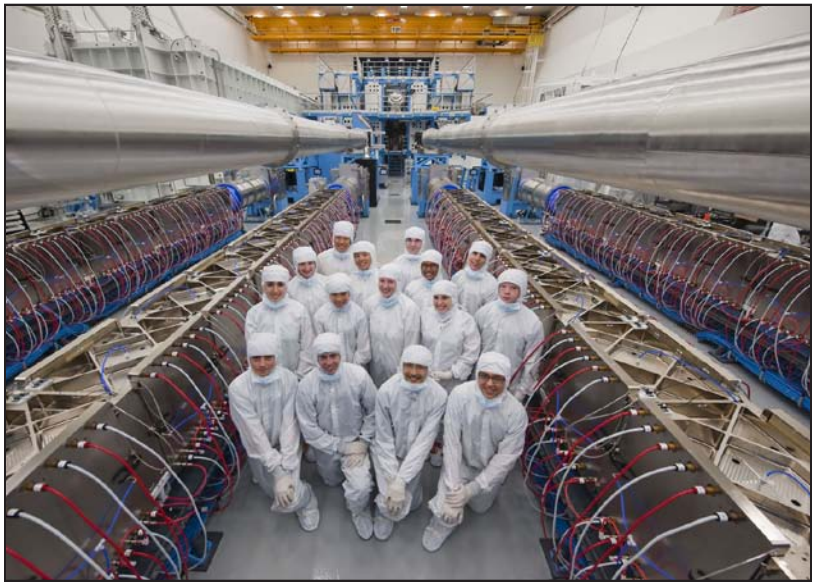
LLE's National Laser Users' Facility (begun in 1979) provides peer-reviewed access to the Omega Laser Facility for university researchers



- 291 proposals
- 154 approved
- >100 Ph.D. students

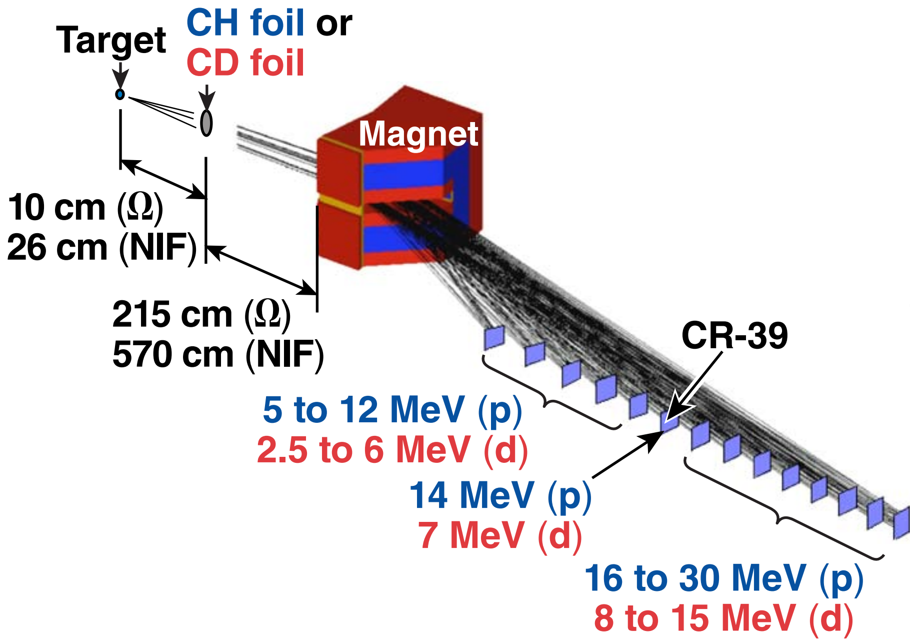
One of LLE's primary missions is the education and training of students

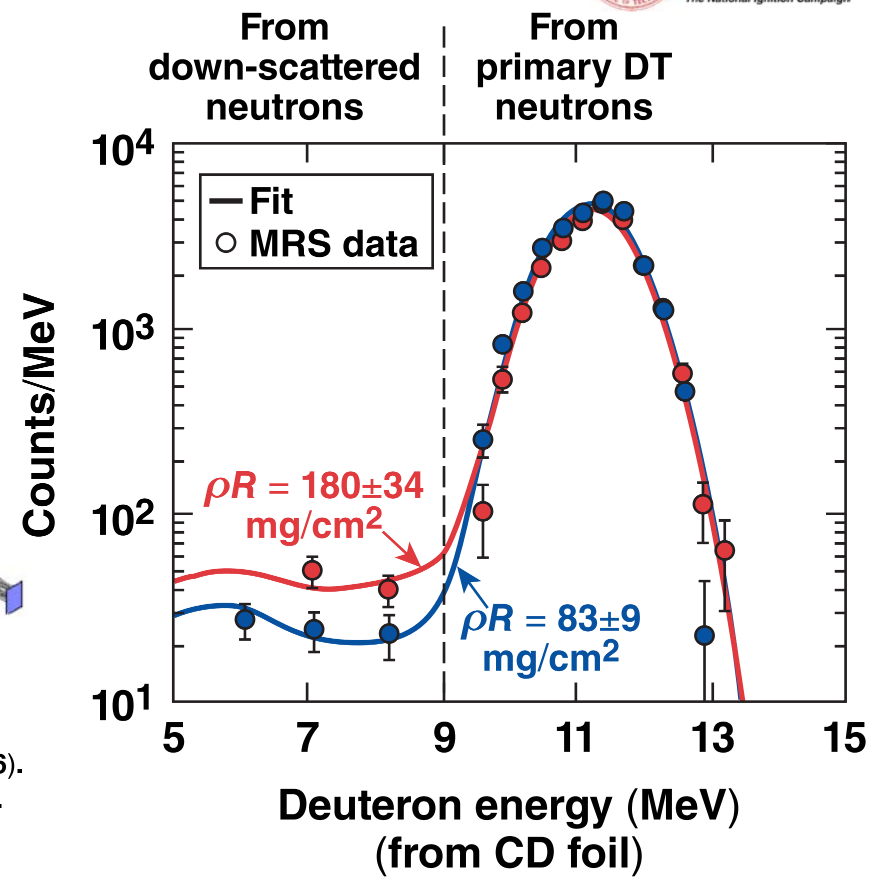
- **26** collaborating faculty members from five departments.
- **82** graduate students are currently pursuing Ph.D.'s.
- **191** students have completed Ph.D. degrees since LLE's founding.
- **39** Ph.D. students are directly funded by LLE through the Horton Fellowship Program.
- **61** undergraduate students are currently employed at LLE.
- LLE operates a summer research program for high school students (**16** students in 2009).
  - **28** Intel Science Talent Search semifinalists (**4** finalists)



Conventional ICF

A magnetic recoil spectrometer (MRS) is used to infer the areal density in OMEGA cryogenic-DT implosions





J. A. Frenje *et al*., NIF MRS System Design Review (April 2006).
J. A. Frenje *et al*., to be published in Rev. Sci. Instrum. (2008).

The MRS has been used on ~20 cryogenic DT implosions and measured areal densities from <100 mg/cm^2 to ~300 mg/cm^2.

Advanced ignition concepts separate compression (ρR) and heating (T_i)—two-step ignition

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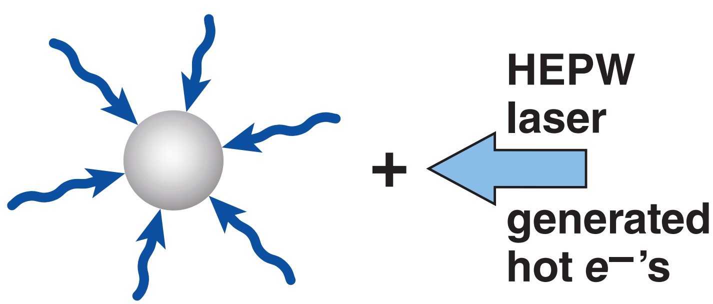
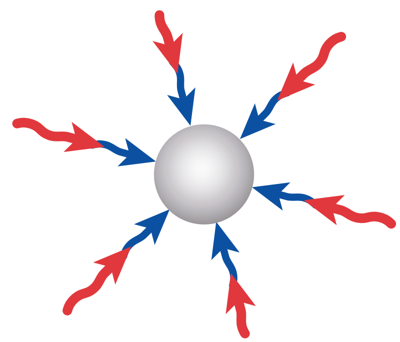
- In the current hot-spot ignition, the driver provides both compression (ρR) and heating (T_i).
- Both fast ignition and shock ignition use a second drive to provide heating (T_i).
- Not as developed as conventional ICF.

Fast Ignition



Compression

Shock Ignition



Compression + shock pulse

- Measured cryogenic target areal densities are relevant to these schemes.

Two-step ignition offers lower driver energies with the possibility of higher gain.

R. L. McCrory, Phys. Plasmas 15, 055503 (2008).

Advanced Ignition

The difference between conventional and two-step ignition is similar to that between a diesel and gasoline engine

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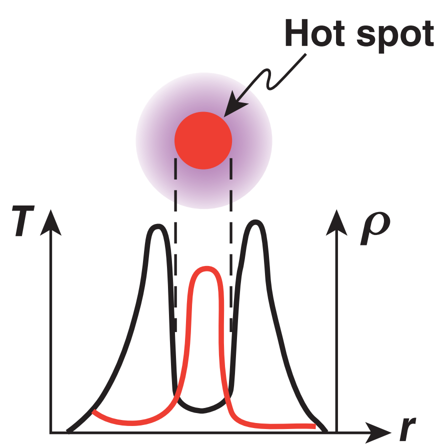
Self-Ignition

Conventional ICF

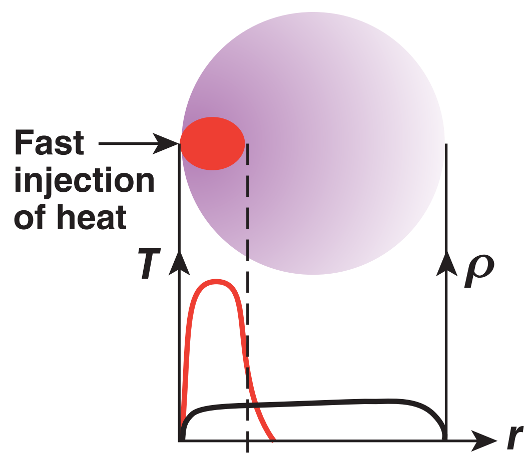


Low-density central spot ignites a high-density cold shell

$\rho T_{hot} \approx \rho T_{cold}$ (isobaric)

External "Spark"

Fast Ignitor

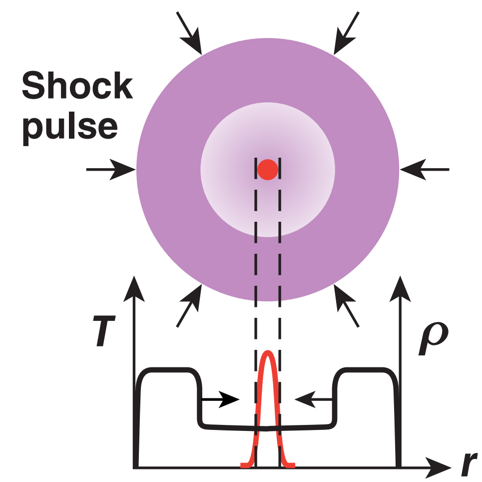


Fast-heated side spot ignites a high-density fuel ball

$\rho_{hot} \approx \rho_{cold}$ (isochoric)

External "Spark"

Shock Ignition



Spherical shock wave ignites a high-density fuel ball

$\rho T_{hot} \gg \rho T_{cold}$

In conventional ignition the "hot spot" contains 1%~2% of the mass but 50% of the compressed energy.

Advanced Ignition

Integrated fast-ignition experiments with re-entrant cone targets have begun at the OMEGA/OMEGA EP Laser Facility*

FSC

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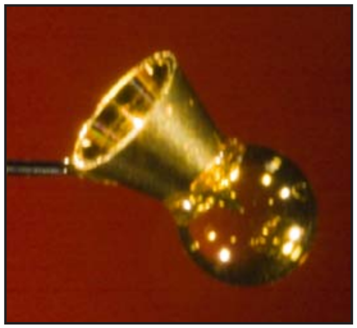
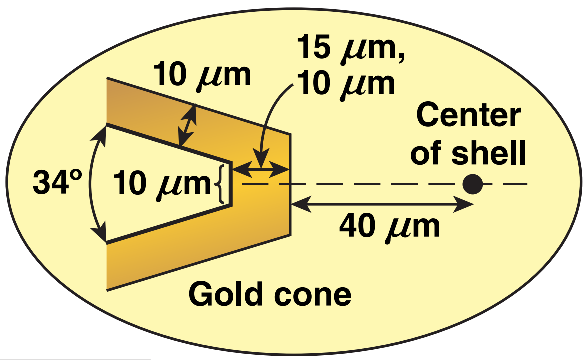


Shell material	CD
Shell diameter	~870 μm
Shell thickness	~40 μm

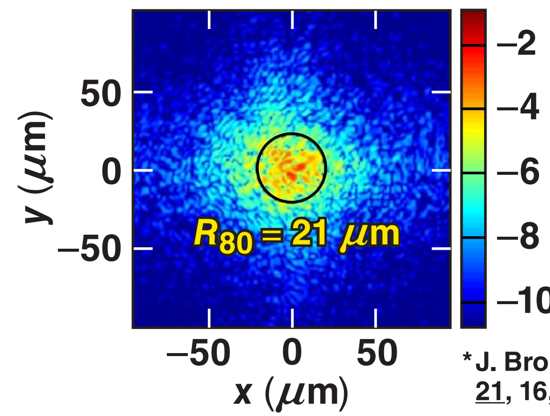


*Funded by OFES through the Fusion Science Center for Fast Ignition, shot time through LBS

Implosion

Energy	~18 kJ (54 beams)
Wavelength	351 nm
Pulse shape	Low-adiabat, $\alpha \approx 1.5$
Pulse duration	~3 ns
Implosion velocity	~2×10^7 cm/s

Target focal spot, log scale*



*J. Bromage *et al*., Opt. Express 21, 16,561 (2008).

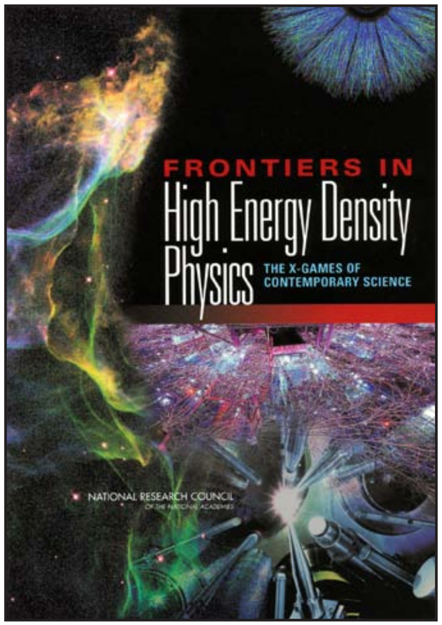
Heating beam

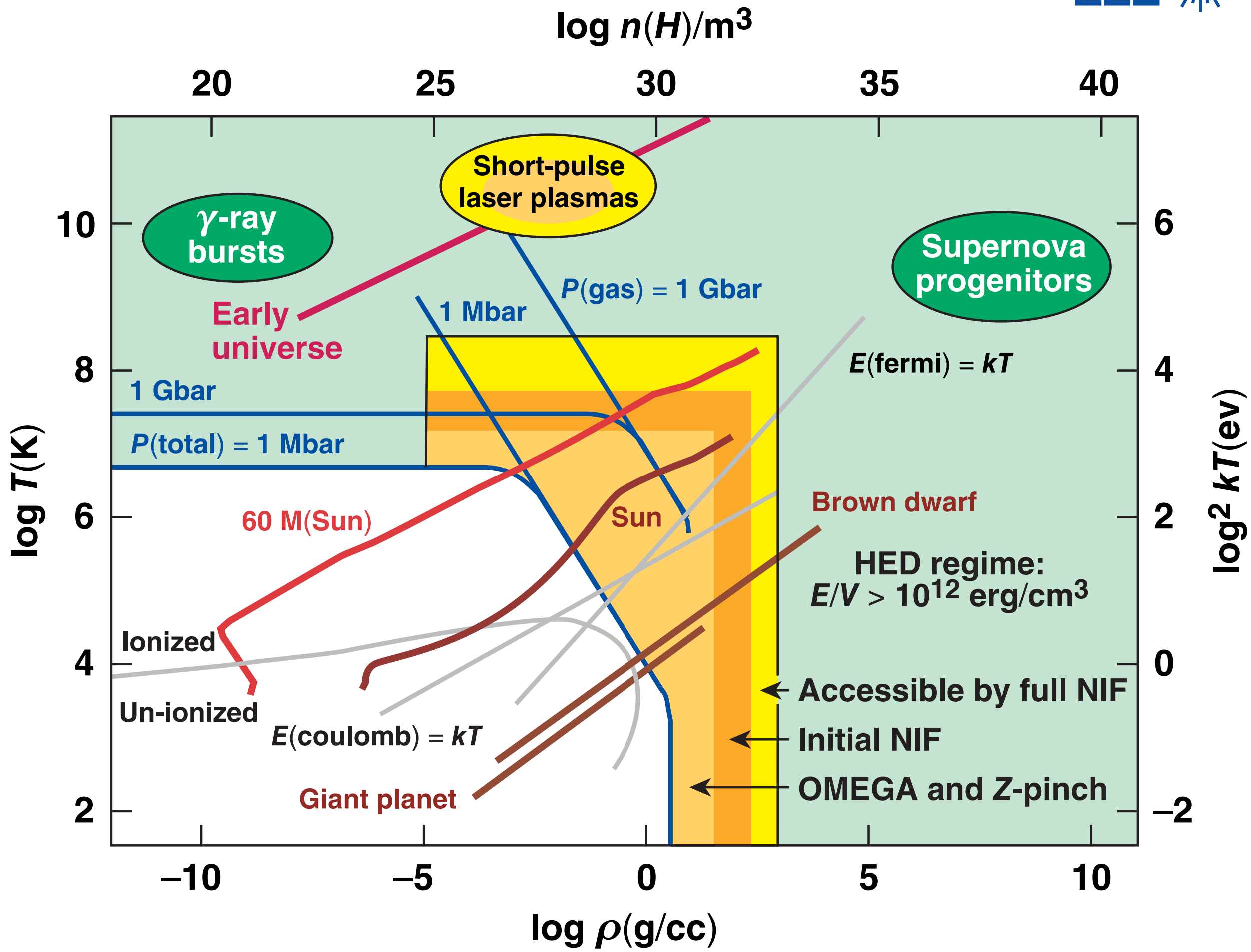
Energy	~1.0 kJ
Wavelength	1053 nm
Pulse duration	~10 ps
Intensity	~1×10^{19} W/cm^2

Relative timing varied

Basic Science

High-energy-density conditions (pressures greater than one million atmospheres) are found throughout the universe





The combined OMEGA/OMEGA EP system significantly expands the accessible HED phase space.

UNIVERSITY of ROCHESTER

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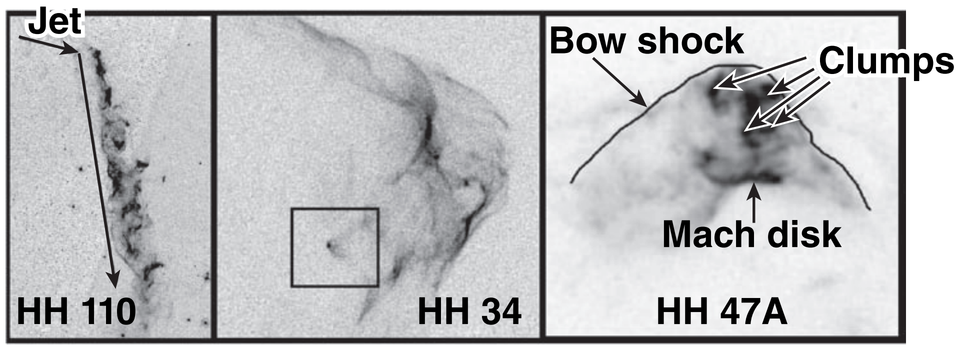
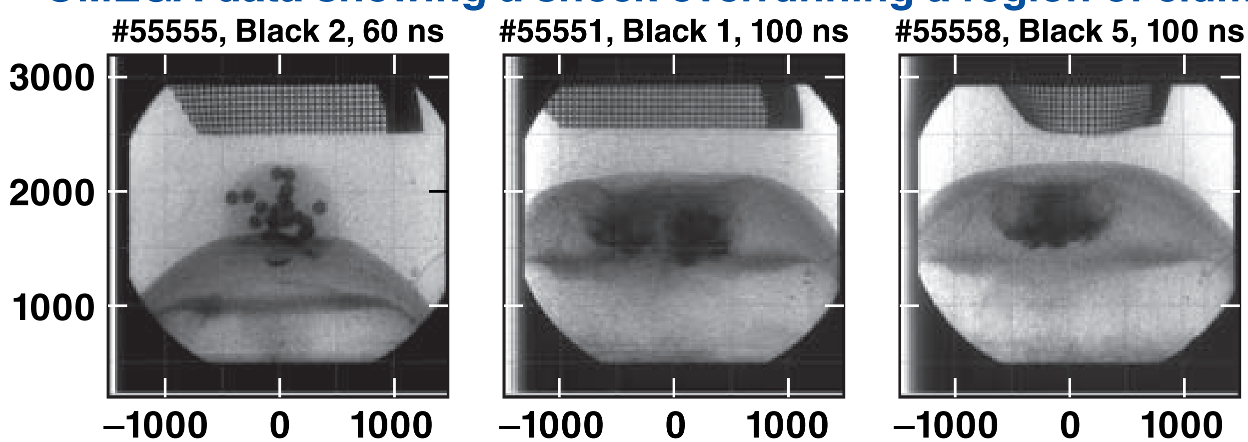
Data from an NLUF experiment on OMEGA was used to obtain an award of observational time on the Hubble Space Telescope (HST)

- Using the HST, P. Hartigan (Rice) and collaborators study the interaction of astrophysical jets with clumps in the interstellar medium and the same physics on OMEGA

Examples of shocked clumps from jets in young stars (HST images)



OMEGA data showing a shock overrunning a region of clumps



It may be possible to create an electron positron plasma with OMEGA EP

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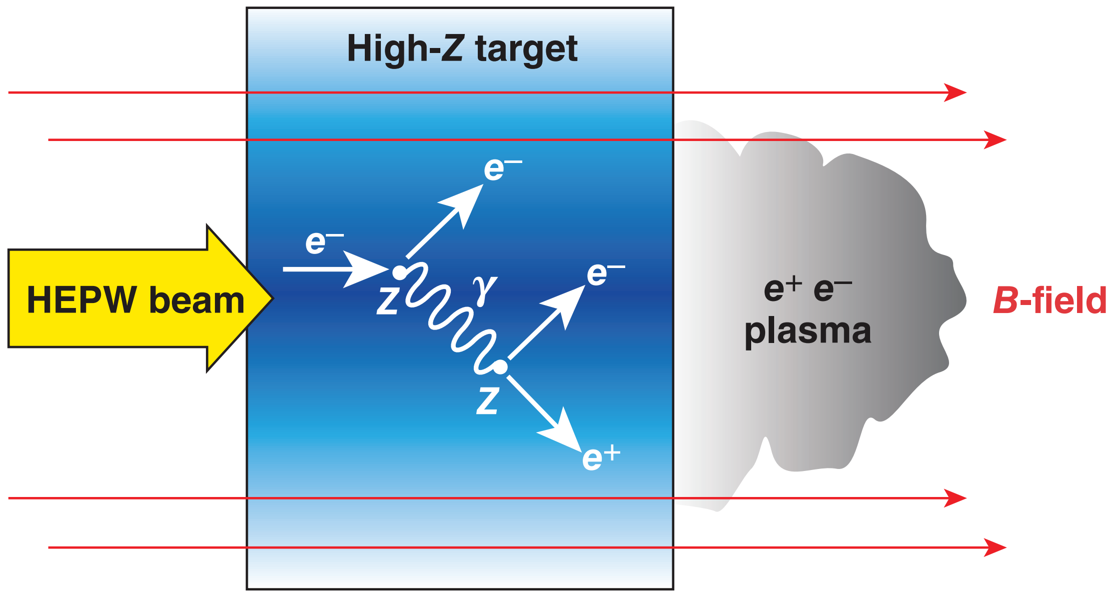
- With sufficient HEPW energy an electron-positron plasma may be created
  - conversion of HEPW energy to hot electrons in a high-Z target
  - bremmsstrahlung produces high-energy gammas
  - gammas decay into electron–positron pairs
  - charge-neutral plasma escapes the target — magnetic-field confinement



Electron–positron plasmas are thought to be part of gamma ray bursters and other astrophysical objects.