The Jupiter Laser Facility at LLNL

William H. Goldstein
Associate Director, Physical and Life Sciences

September 6, 2009
LLNL-PRES-417776

This work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

JLF is an intermediate-scale laser user facility operated by LLNL's Physical and Life Sciences Directorate

Mission

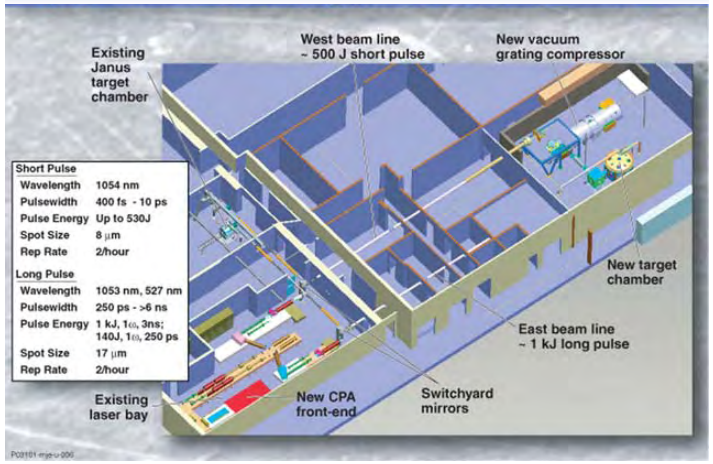
- Expand the frontiers of high energy density laboratory plasma science
- Support high energy-density physics at LLNL in multiple programs: weapons, inertial fusion, underlying science;
- Support, collaborate with, and expand the broader HED physics community;
- Help train and recruit future scientific workforce for NNSA

Since 2008 Jupiter has operated as a user facility:

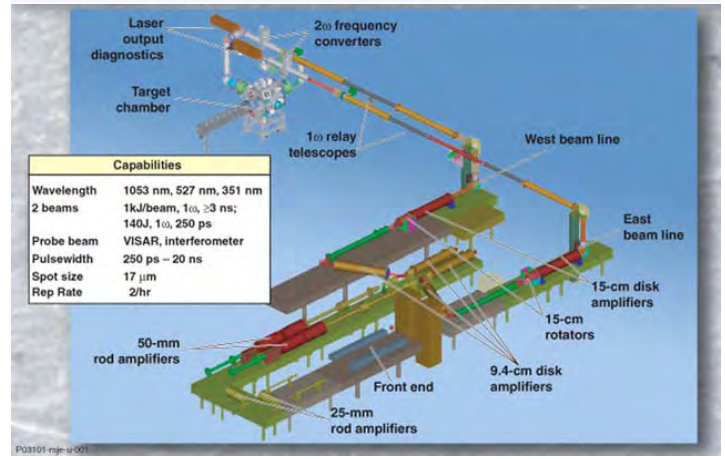
- **All shots are awarded on a competitive basis in an open call**
- **the facility is provided free of charge to users**

Jupiter is a unique multi-platform user facility for high energy-density physics

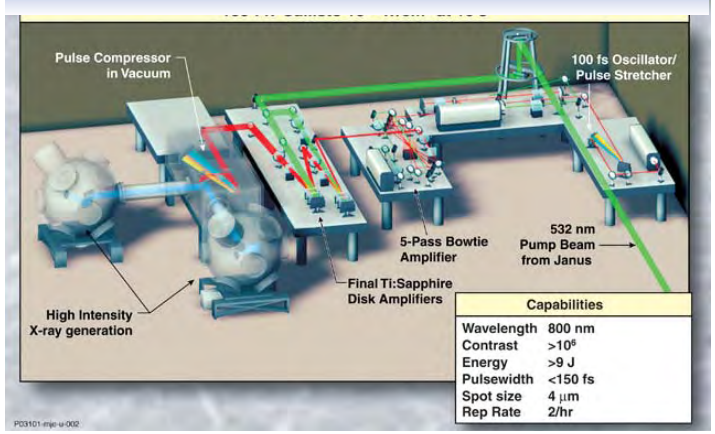
Titan



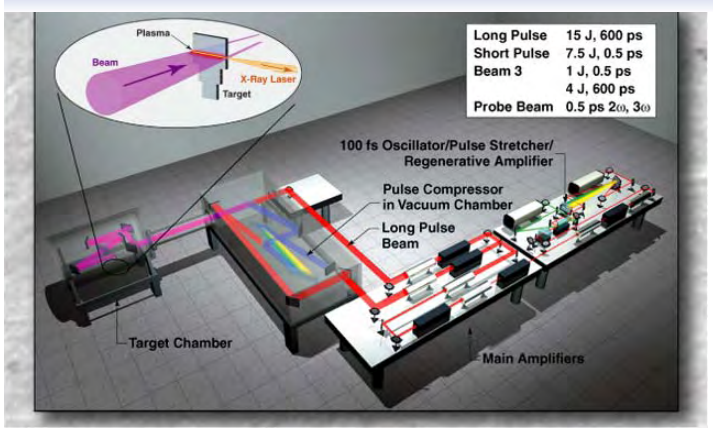
Janus



Callisto



Comet



Fusion Research • Material Science • HED Laser Plasma Physics

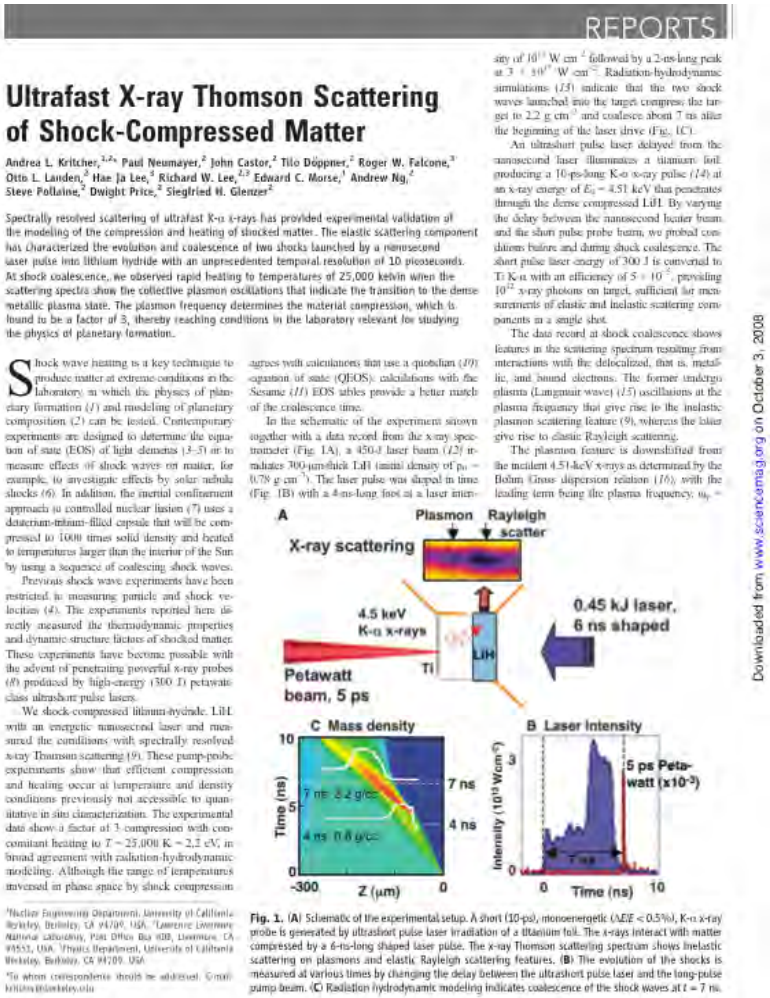
The laser platforms at JLF provide a wide range of experimental capabilities

Laser	Type	Beams	Pulse Length	Pulse Energy @1ω	Rep Rate	Chambers
Titan	Nd-glass	Short-Pulse Beam	700 fs - 200ps	150 J - 320 J	Up to 2/hour	1
		Long-Pulse Beam	250 ps - 20ns Abritrary shape	Up to 1 kJ	Up to 2/hour	1
Janus	Nd-glass	Beam One	250 ps - 20 ns Abritrary shape	Up to 1 kJ	Up to 2/hour	2
		Beam Two	250 ps - 20 ns Abritrary shape	Up to 1 kJ	Up to 2/hour	2
Callisto	Ti:Sapphire	150 TW Beam	60 fs	10J	Up to 2/hour	2
COMET	Nd-glass	Short Pulse Beam	500 fs	6 J	Up to 15/hour	2
		Long Pulse Beam	600 ps	25 J	Up to 15/hour	2

Direct measurements at Titan of thermodynamic variables in shocked LiH reported in *Science*

Andrea Kritcher et al.* Science *(Oct. 3, 2008)

Thomson Scattered X-ray Spectrum



REPORTS

Ultrafast X-ray Thomson Scattering of Shock-Compressed Matter

Andrea L. Kritcher,[1,2*] Paul Neumayer,[2] John Castor,[2] Tilo Döppner,[2] Roger W. Falcone,[3] Otto L. Landen,[2] Hae Ja Lee,[2] Richard W. Lee,[2,3] Edward C. Morse,[1] Andrew Ng,[2] Steve Pollaine,[2] Dwight Price,[2] Siegfried H. Glenzer[2]

Spectrally resolved scattering of ultrafast K-α x-rays has provided experimental validation of the modeling of the compression and heating of shocked matter. The elastic scattering component has characterized the evolution and coalescence of two shocks launched by a nanosecond laser pulse into lithium hydride with an unprecedented temporal resolution of 10 picoseconds. At shock coalescence, we observed rapid heating to temperatures of 25,000 kelvin when the scattering spectra show the collective plasmon oscillations that indicate the transition to the dense metallic plasma state. The plasmon frequency determines the material compression, which is found to be a factor of 3, thereby reaching conditions in the laboratory relevant for studying the physics of planetary formation.

Shock wave heating is a key technique to produce matter at extreme conditions in the laboratory, in which the physics of planetary formation (1) and modeling of planetary composition (2) can be tested. Contemporary experiments are designed to determine the equation of state (EOS) of light elements (3–5) or to measure effects of shock waves on matter, for example, to investigate effects by solar nebula shocks (6). In addition, the inertial confinement approach to controlled nuclear fusion (7) uses a deuterium-tritium-filled capsule that will be compressed to 1000 times solid density and heated to temperatures larger than the interior of the Sun by using a sequence of coalescing shock waves.

Previous shock wave experiments have been restricted to measuring particle and shock velocities (4). The experiments reported here directly measured the thermodynamic properties and dynamic structure factors of shocked matter. These experiments have become possible with the advent of penetrating powerful x-ray probes (8) produced by high-energy (300 J) petawatt-class ultrashort pulse lasers.

We shock-compressed lithium-hydride, LiH, with an energetic nanosecond laser and measured the conditions with spectrally resolved x-ray Thomson scattering (9). These pump-probe experiments show that efficient compression and heating occur at temperature and density conditions previously not accessible to quantitative in situ characterization. The experimental data show a factor of 3 compression with concomitant heating to $T \sim 25{,}000$ K ~ 2.2 eV, in broad agreement with radiation-hydrodynamic modeling. Although the range of temperatures traversed in phase space by shock compression agrees with calculations that use a quotidian (10) equation of state (QEOS), calculations with the Sesame (11) EOS tables provide a better match of the coalescence time.

In the schematic of the experiment shown together with a data record from the x-ray spectrometer (Fig. 1A), a 450-J laser beam (12) irradiates 300-μm-thick LiH (initial density of $\rho_0 = 0.78$ g cm^{-3}). The laser pulse was shaped in time (Fig. 1B) with a 4-ns-long foot at a laser intensity of 10^{13} W cm^{-2} followed by a 2-ns-long peak at 3×10^{17} W cm^{-2}. Radiation-hydrodynamic simulations (13) indicate that the two shock waves launched into the target compress the target to 2.2 g cm^{-3} and coalesce about 7 ns after the beginning of the laser drive (Fig. 1C).

An ultrashort pulse laser delayed from the nanosecond laser illuminates a titanium foil, producing a 10-ps-long K-α x-ray pulse (14) at an x-ray energy of $E_0 = 4.51$ keV that penetrates through the dense compressed LiH. By varying the delay between the nanosecond heater beam and the short pulse probe beam, we probed conditions before and during shock coalescence. The short pulse laser energy of 300 J is converted to Ti K-α with an efficiency of 5×10^{-5}, providing 10^{12} x-ray photons on target, sufficient for measurements of elastic and inelastic scattering components in a single shot.

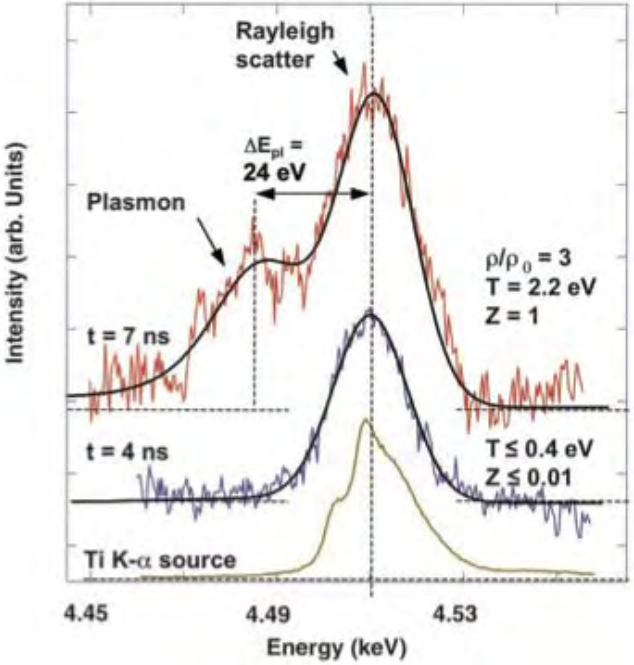
The data record at shock coalescence shows features in the scattering spectrum resulting from interactions with the delocalized, that is, metallic, and bound electrons. The former undergo plasma (Langmuir wave) (15) oscillations at the plasma frequency that give rise to the inelastic plasmon scattering feature (9), whereas the latter give rise to elastic Rayleigh scattering.

The plasmon feature is downshifted from the incident 4.51-keV x-rays as determined by the Bohm-Gross dispersion relation (16), with the leading term being the plasma frequency, $\omega_p =$

[1]Nuclear Engineering Department, University of California, Berkeley, Berkeley, CA 94709, USA. [2]Lawrence Livermore National Laboratory, Post Office Box 808, Livermore, CA 94551, USA. [3]Physics Department, University of California, Berkeley, Berkeley, CA 94709, USA.

*To whom correspondence should be addressed. E-mail: kritcher@berkeley.edu

Fig. 1. (**A**) Schematic of the experimental setup. A short (10-ps), monoenergetic ($\Delta E/E < 0.5\%$), K-α x-ray probe is generated by ultrashort pulse laser irradiation of a titanium foil. The x-rays interact with matter compressed by a 6-ns-long shaped laser pulse. The x-ray Thomson scattering spectrum shows inelastic scattering on plasmons and elastic Rayleigh scattering features. (**B**) The evolution of the shocks is measured at various times by changing the delay between the ultrashort pulse laser and the long-pulse pump beam. (**C**) Radiation hydrodynamic modeling indicates coalescence of the shock waves at $t = 7$ ns.



- Elastic scattering peak measures temperature; plasmon shift indicates density
- Observation of plasmons at 7 ns indicates transition from insulating to dense metallic state

Titan has been used to create a new intense laboratory positron source

Chen et al. Phys Rev. Lett. (March 11, 2009)

PRL **102,** 105001 (2009) PHYSICAL REVIEW LETTERS week ending 13 MARCH 2009

Relativistic Positron Creation Using Ultraintense Short Pulse Lasers

Hui Chen,[1] Scott C. Wilks,[1] James D. Bonlie,[1] Edison P. Liang,[2] Jason Myatt,[3] Dwight F. Price,[1] David D. Meyerhofer,[3] and Peter Beiersdorfer[1]
[1]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[2]*Rice University, Houston, Texas 77005, USA*
[3]*University of Rochester, Rochester, New York 14623, USA*
(Received 5 September 2008; published 11 March 2009)

We measure up to 2×10^{10} positrons per steradian ejected out the back of ~mm thick gold targets when illuminated with short (~1 ps) ultraintense ($\sim 1 \times 10^{20}$ W/cm^2) laser pulses. Positrons are produced predominately by the Bethe-Heitler process and have an effective temperature of 2–4 MeV, with the distribution peaking at 4–7 MeV. The angular distribution of the positrons is anisotropic. Modeling based on the measurements indicate the positron density to be $\sim 10^{16}$ positrons/cm^3, the highest ever created in the laboratory.

DOI: 10.1103/PhysRevLett.102.105001 PACS numbers: 52.38.Ph, 52.59.−f

The ability to rapidly create large numbers of MeV positrons in the laboratory opens the door to new avenues of antimatter research, including an understanding of the physics underlying various astrophysical phenomena such as black holes and gamma ray bursts [1,2], pair plasma physics [3,4], positronium production, and positronium Bose-Einstein condensates [5–7]. The use of short, ultra-intense, lasers represents a promising new approach to achieve this. Since first theorized in 1973 [8], the use of ultraintense lasers to generate positrons has been studied in great detail through theory and modeling [9–15]. It has been predicted that for thick high-Z targets, positron generation through the Bethe-Heitler (BH) process [16] dominates over the Trident process [16,12,13]. For thin targets (less than 30 microns for solid gold), the reverse is expected [9]. In the BH process, laser-produced hot electrons make high-energy bremsstrahlung photons that produce electron-positron pairs by interacting with the nuclei, while in the Trident process, the hot electrons produce pairs directly interacting with the nuclei. Although estimates vary, approximately 10^{10} to 10^{11} positrons/kJ of laser energy are predicted to be created, assuming various laser target conditions [13–15]. Experimentally, the ability of intense short laser pulses to create positrons in laser-solid interaction was first demonstrated on the Nova peta-watt laser by Cowan *et al.* [17] and later on a tabletop laser by Gahn *et al.* [18], where small numbers of positrons were measured.

In this Letter, up to 2×10^{10} positrons/sr with positron kinetic energy up to 20 MeV were observed by irradiating ~millimeter thick gold targets with short-pulse lasers. Positron temperatures were measured for the first time, and were found to be about half that of hot electron temperature. A strong anisotropy in the angular positron emission was observed, with the number ejected near the normal to the rear of the target being more than 10 times the number more obliquely observed from the front of the target on a given shot. The positron density inside the target is estimated to be about 10^{16} positrons/cm^3, making this the densest collection of positrons produced in the laboratory [19]. These conclusions result from the best statistics and energy resolution positron spectra ever obtained using short-pulse lasers. The data are consistent with the BH process in which positrons were produced by MeV photons interacting with gold nuclei.

The experiment was carried out at the Titan laser at the Jupiter laser facility [20] at Lawrence Livermore National Laboratory. For the experiments described here, the pulse-length of the laser (1054 nm, *s*-polarized) was varied between 0.7 to 10 ps, and the laser energy was between 120 to 250 J. The pre-pulse to main-pulse intensity contrast is less than 10^{-5}. Focused with an $f/3$ off-axis parabola, the full-width at half-maximum of the focal spot was about 8 microns and contains about 60% of laser energy. The experimental setup is shown in Fig. 1. The short pulse was incident to the targets at an 18-degree angle. Two absolutely calibrated electron-positron spectrometers [21] observed the hot electrons and the positrons from the targets with energy coverage from 0.1–100 MeV and a resolution $E/\delta E$ of 10–100, much improved from the previous positron spectrometer from which a hint of positron signal was observed [22]. The energy coverage and resolution are higher than previously achieved in positron energy mea-

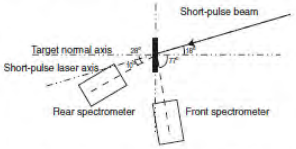
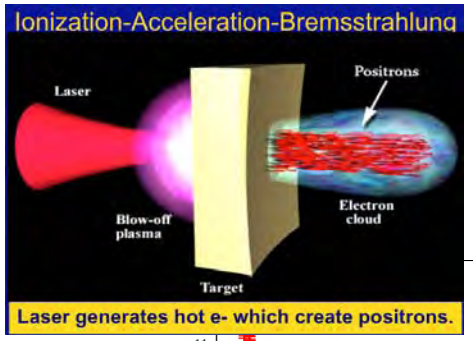
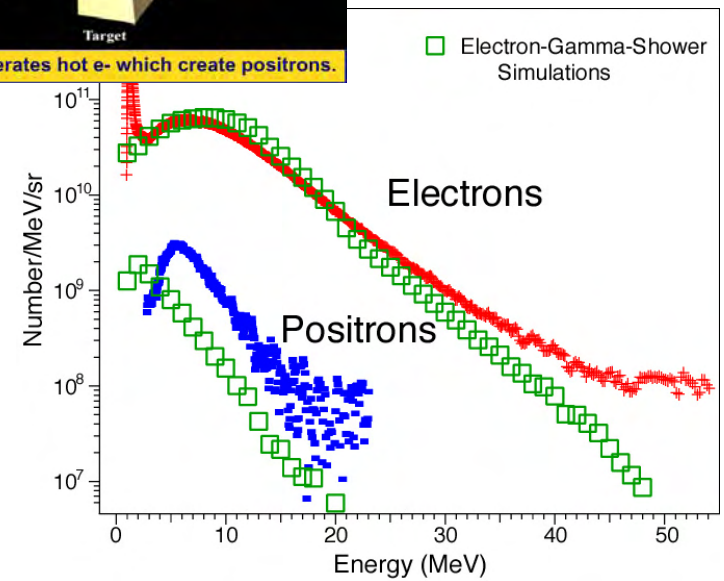


FIG. 1. Illustration of the experimental set up. The location of two spectrometers relative to the lasers and target is marked.

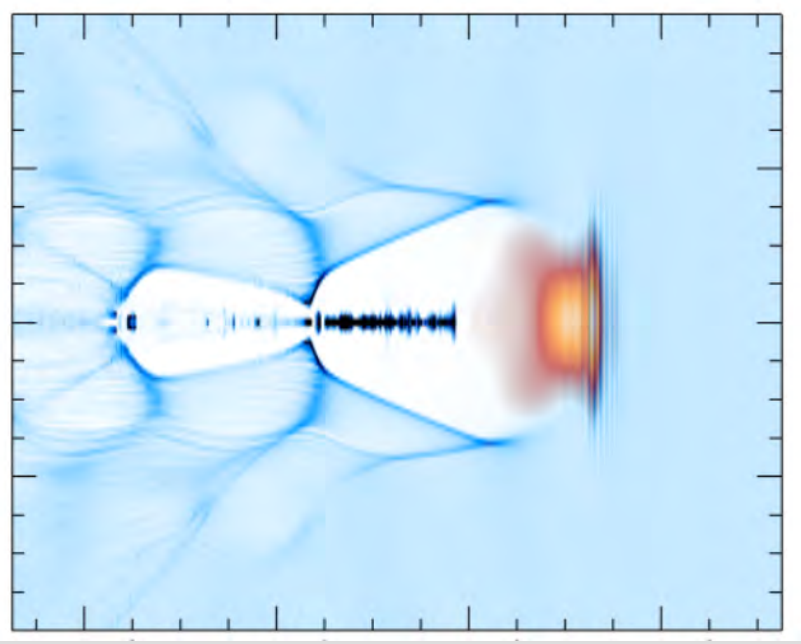




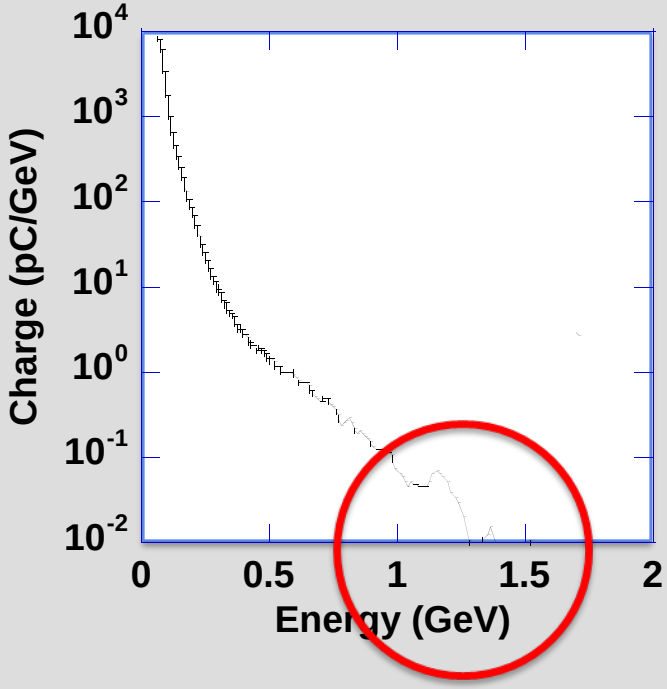
Positron density of 10^{16} e^+/cm^3 is the highest ever created in the laboratory

Electron acceleration experiments on Callisto have broken the GeV energy "barrier"

Full 3D, centimeter-long PIC simulations of this experiment predict electrons accelerated to GeV energies

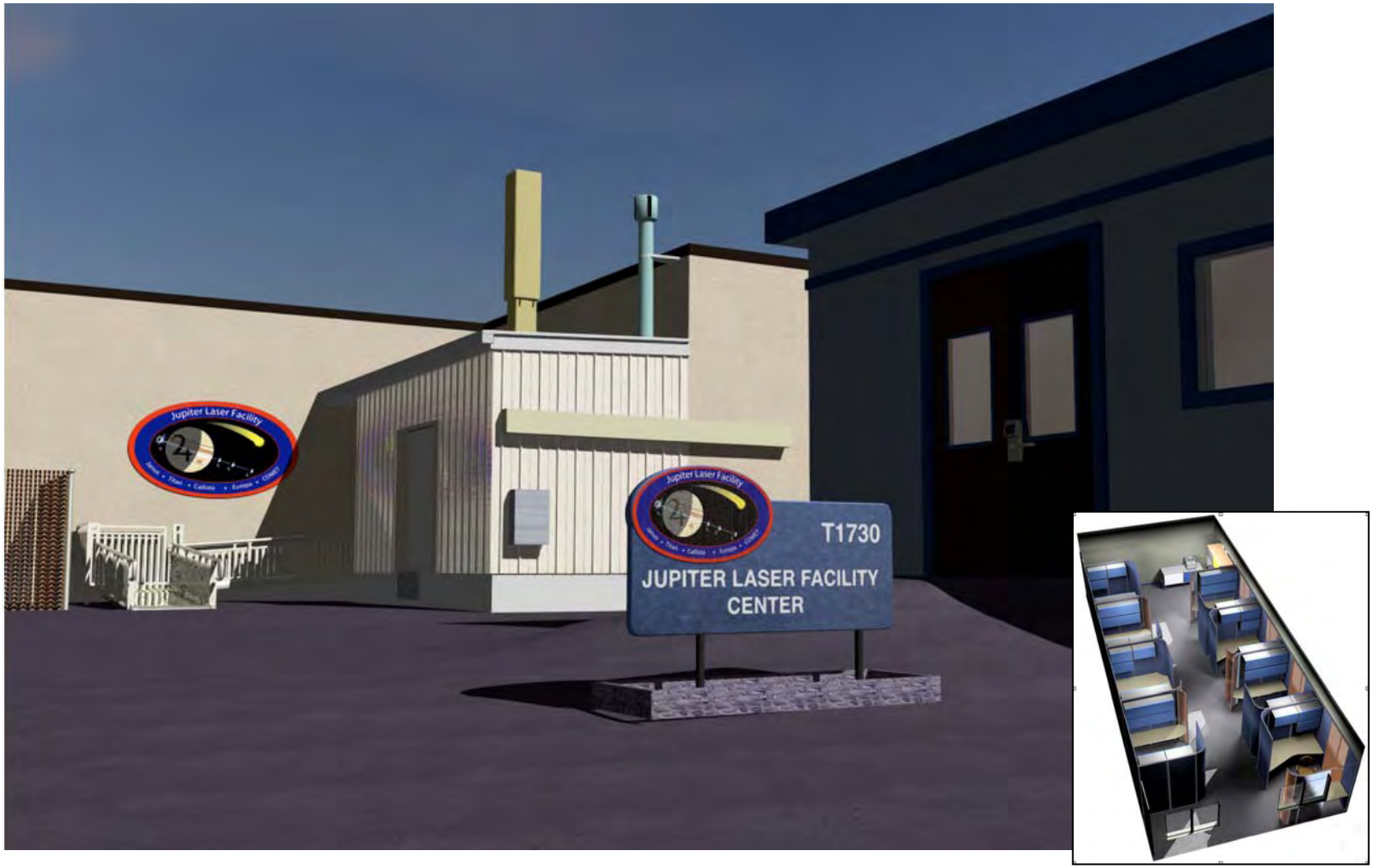


Measurements show electrons accelerated beyond one GeV



- UCLA collaboration
- Experiments will continue to investigate unexplained pre-pulse behavior
- To be submitted to *Nature Physics*

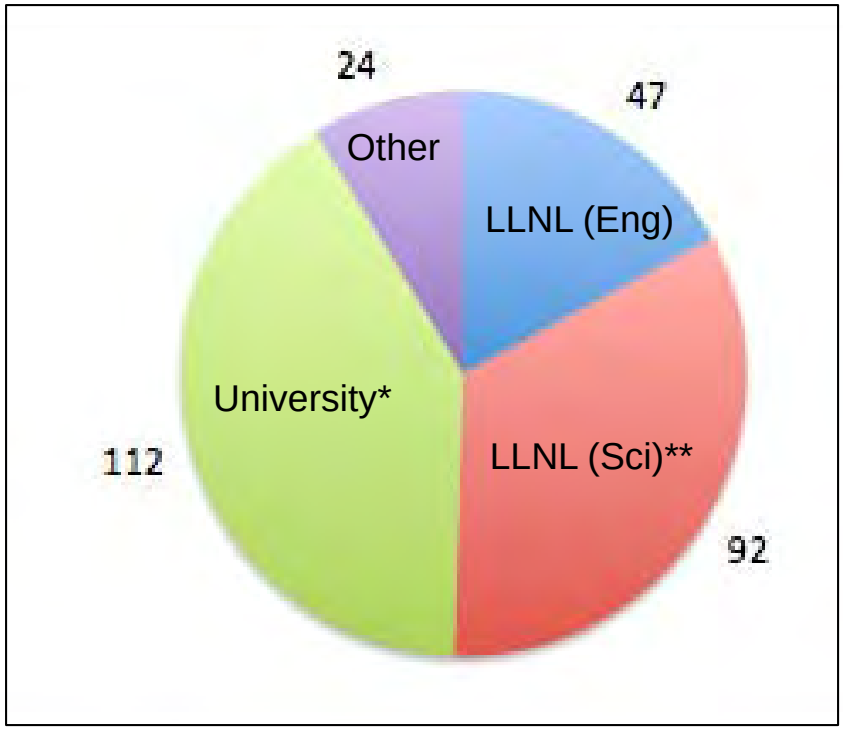
New user center houses academic visitors



JLF has 275 users, a community that reaches well beyond LLNL

GA
LANL
NIST
NRL
NSTEC
SLAC

AWE
CEA
GSI
Japan AEC



- **228 user scientists, incl.**
- **57 students**
- **82 non-US citizens**

BYU
Cal Poly
CSU
Colo State
Florida A&M
MIT
OSU
Princeton
St Mary's
Stanford

U Maryland
U Rochester
U Texas
UC - Berkeley
UC - Davis
UCLA
UC - Santa Barbara
UC - San Diego
U Michigan
Villanova

Ecole Polytechnique
Osaka University
Queen's University
U Alberta
U Madrid
U Milan
U Oxford
U Pisa
U Toronto
U York
U British Columbia

* Twice the number of 3 years ago

** 50% more than 3 years ago

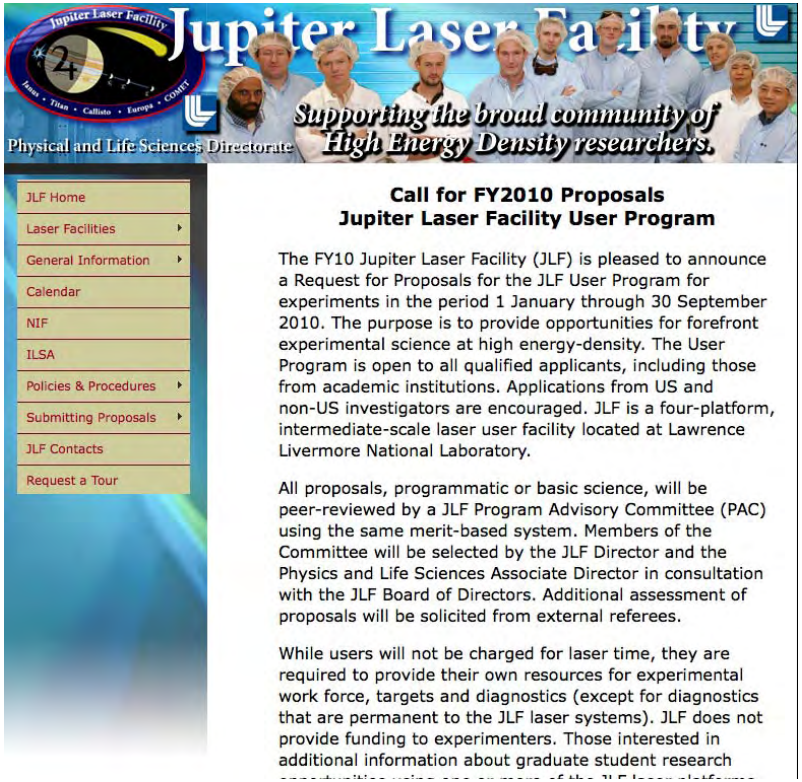
JLF FY10 user program solicitation just closed

- **Solicitation for Jan – Sept 2010**
  - **Short year due to closure in FY09**
  - **FY11 call will be in April**

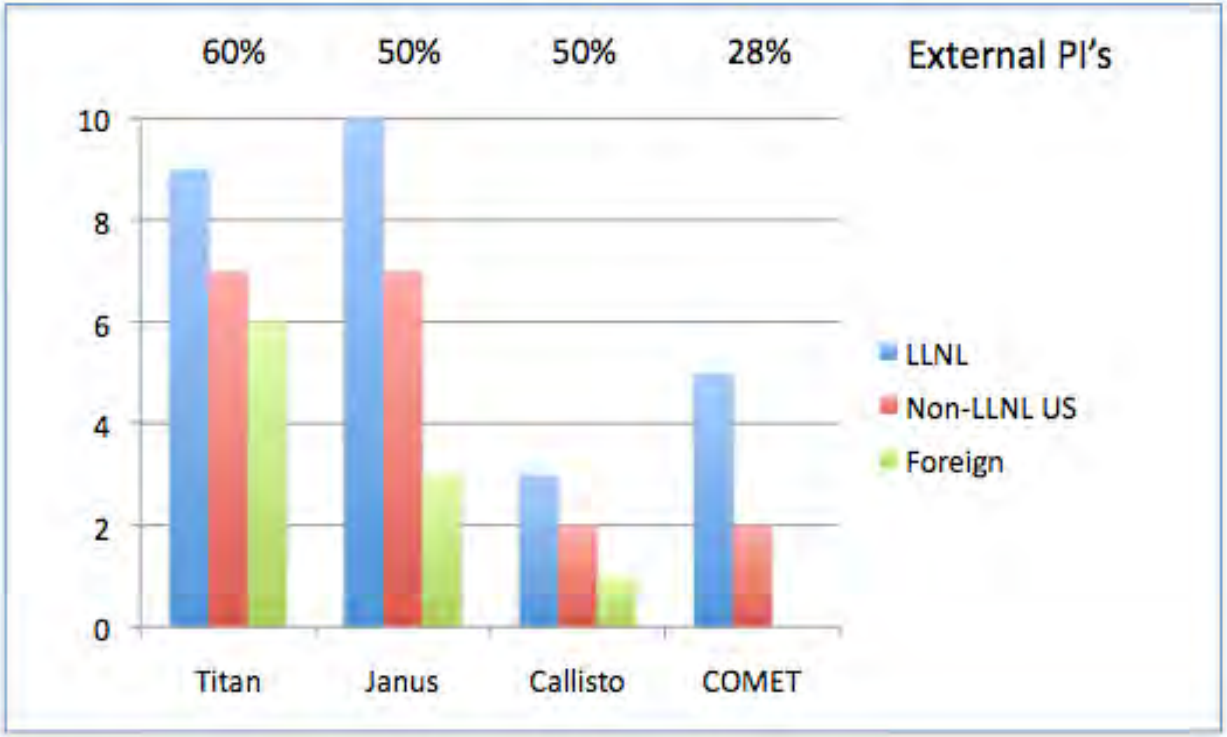
- **100% of the 4 platforms competed**

- **Proposals will be reviewed using a merit-based system by a panel consisting of internal and external scientists, including members of the NIF/JLF Program Advisory Committee, and mail-in reviews from a larger set of peers**

- **The call was very broad: work was solicited in all areas of high energy density science**

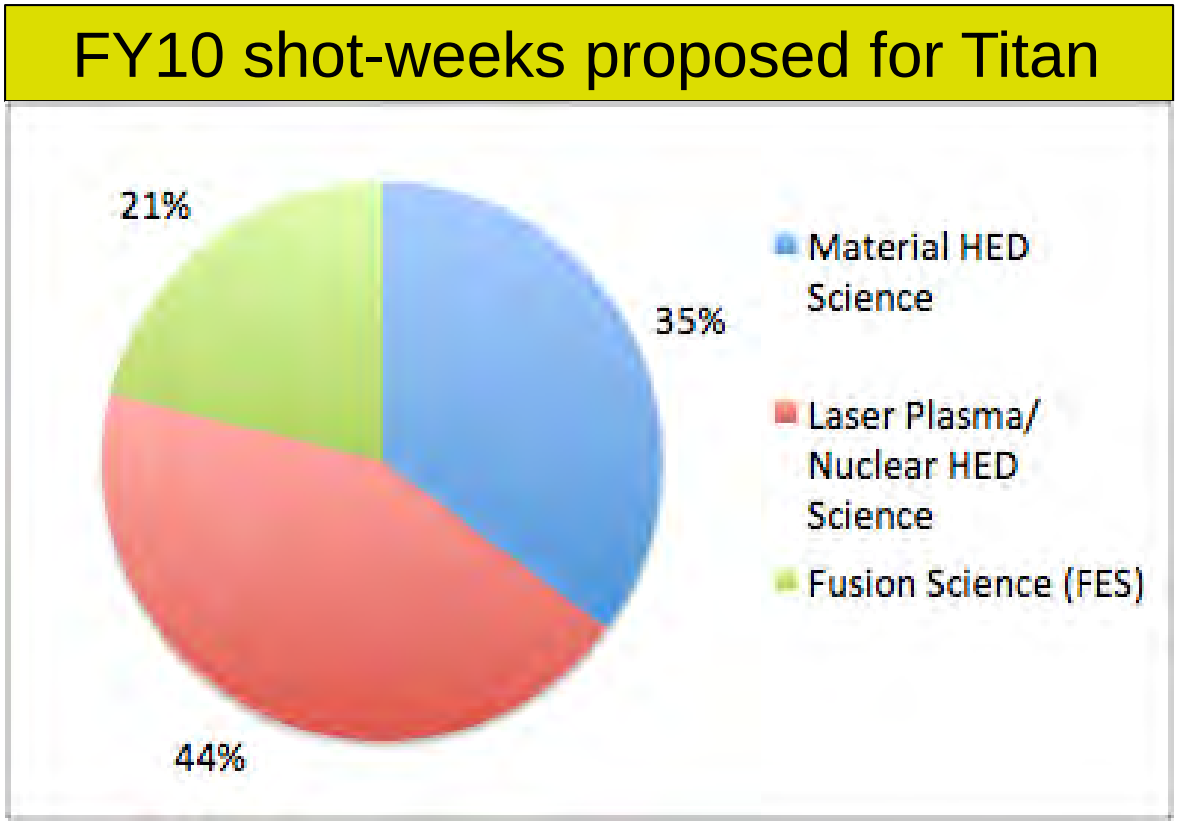


About half of FY10 proposals are by non-LLNL PI's



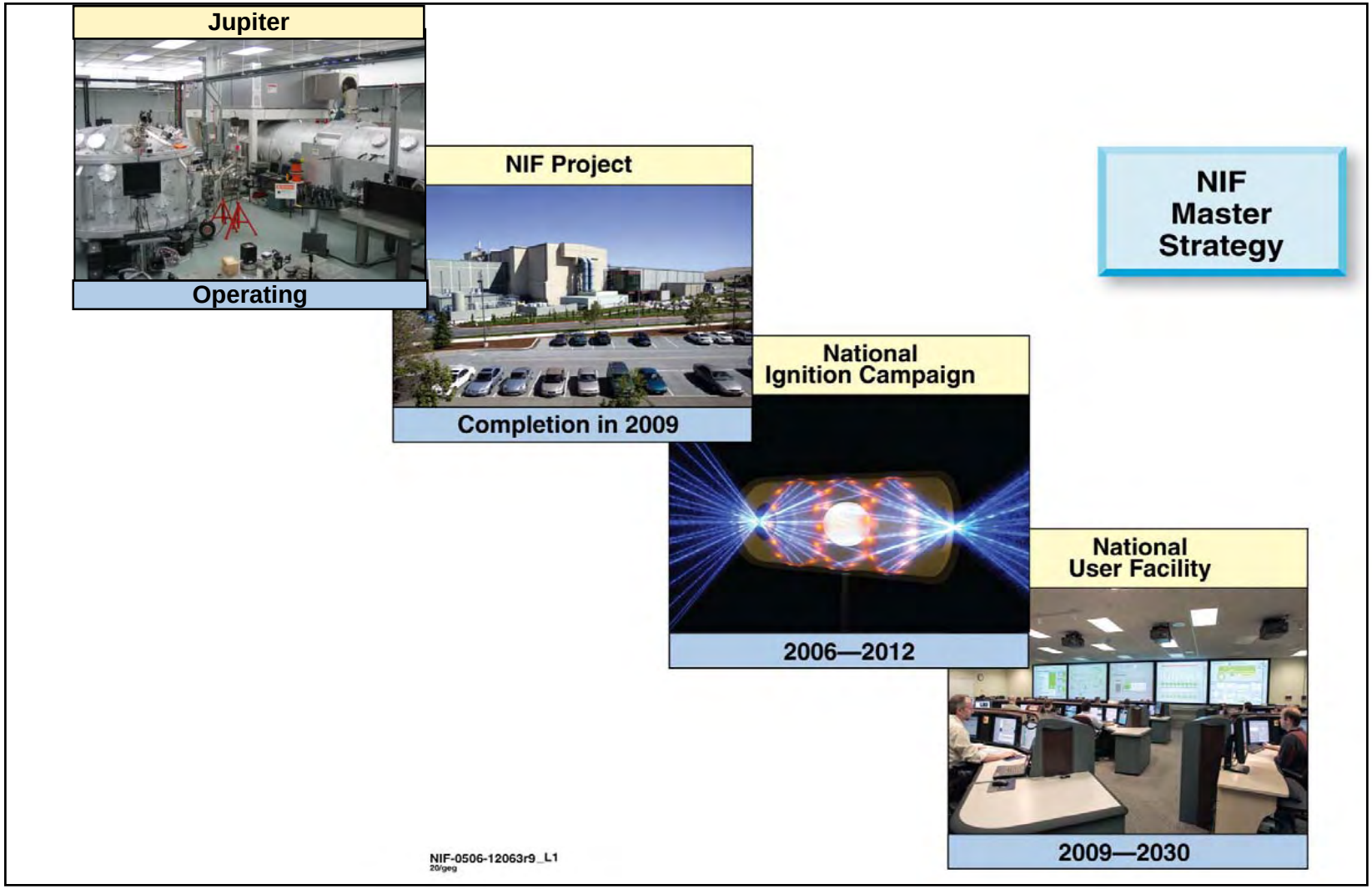
- **Number of FY10 proposals up 10% over FY09**
- **Fraction of non-LLNL PI's is more than twice FY09**

Proposals reflect diverse science interest and 2x oversubscription of the facility



- **FY10 proposals for Titan request 71 shot-weeks.**
  - **32 shot-weeks are available**
- **Similar story for Janus and COMET**

Jupiter connects directly to NIF as a user facility



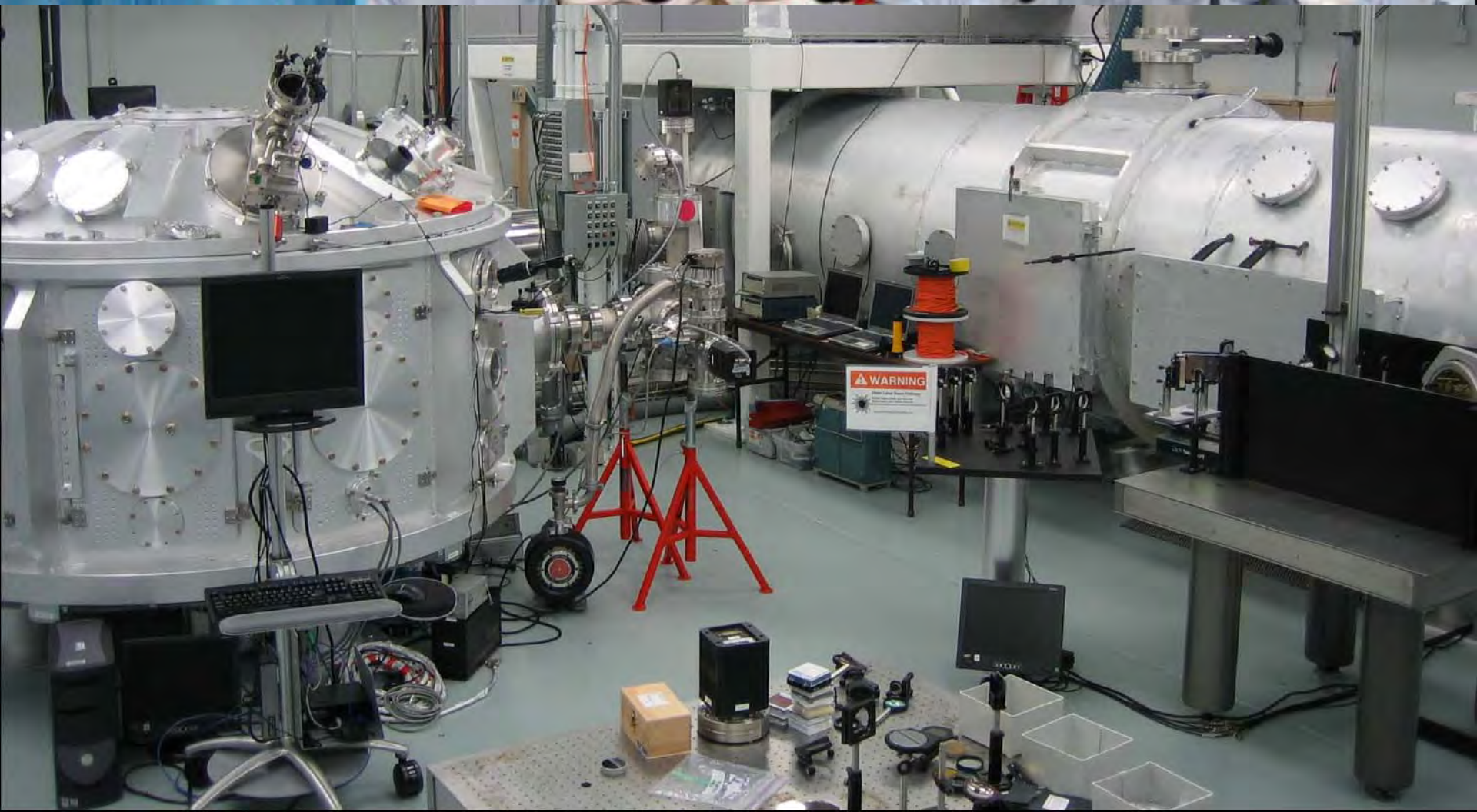
Jupiter Laser Facility

Jupiter Laser Facility

Janus • Titan • Callisto • Europa • COMET

Physical and Life Sciences Directorate

Supporting the broad community of High Energy Density researchers.




Jupiter Laser Facility
Janus • Titan • Callisto • Europa • COMET
Jupiter Laser Facility
Physical and Life Sciences Directorate
Supporting the broad community of
High Energy Density researchers.

jlf.llnl.gov