Science at the
Jupiter Laser Facility

Pravesh Patel
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This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
JLF is a premier research facility for HED Science

- Relativistic Laser Absorption
- Warm Dense Matter
- Material Strength
- Fast Ignition
- EOS
- Opacity
- X-ray Lasers
- Proton Acceleration
- Relativistic Pair Plasmas
- Laser Wakefield Acceleration
- Thermal Broadband Backlighting
- Compton Radiography
- K-alpha Radiography
- Proton Radiography
- X-ray Diffraction
- X-ray Interferometry
- X-ray Thomson Thomson Scattering
- NIF Diagnostic Development
Janus has enabled three decades of research in ICF, plasma physics, EOS, material properties, LPI, more…
The first measurements of relativistic effects in collective Thomson scattering were demonstrated on Janus

Thomson scattering from electron-plasma waves in a $T_e \sim 200$ eV, $N_e \sim 10^{19}$ cm$^{-3}$, gas-jet plasma

Thomson-scattering form factor including relativistic effects shows excellent agreement with measurement


J. S Ross, G. Tynan (UCSD)
D. H. Froula, J. Palastro (LLNL)
Dynamic Whitelight Laue is a new diagnostic technique spearheaded by the University of Oxford

J. Wark (University of Oxford)
N. Park (AWE)
J. Hawreliak, B. Remington (LLNL)

- Mixed element foil is used to generate a broadband source
- X-rays diffracted from single crystal samples provide nsec resolution to investigate dynamic material processes

Dynamic Broadband experiments

Experimental Data
Janus May 2009
Europa was built as a high rep-rate, ultrashort-pulse laser with multiple chambers for simultaneous experiments.
Pump-probe experiments on USP measured the dielectric function of warm dense gold

Y. Ping (LLNL)
University of British Columbia

- Warm dense matter is created by isochoric laser heating of free-standing nano-foils. The ultrafast excitation leads to a non-equilibrium state with $T_e \gg T_i$.

- A super-continuum probe is employed to measure the evolution of both intraband and interband transitions.
COMET was the first LLNL laser combining long-pulse and short-pulse beams.
X-ray lasers provide unique, ultrabright sources for dynamic probing of materials and dense plasmas

Photoemission spectroscopy of laser-heated Cu foils tracks the depopulation of 3d electronic states during heating

X-ray laser interferometry at 14.7 nm of laser-produced Al plasma revealed new high density plasma phenomena

A new concept for high rep-rate (10 Hz), high efficiency X-ray laser was demonstrated on the JLF “tabletop” lasers at 18.9 nm

J. Dunn et al. (LLNL)

J. Rocca (Colorado State University)

S. Shlyaptsev (UC Davis)
Recently, an experimental platform for line emission opacity measurements has been developed on COMET

**High \( n \) lineshape measurements to test LLNL OPAL code**

Laser and Target Parameters:
- \( \lambda: 527 \) nm
- \( t: 150 \) ps (FWHM) Gauss.
- \( E: 4.0 \) J
- Focus \( \sim 20 \) µm (FWHM) Gauss.
- \( I = 5 \times 10^{15} \) W cm\(^{-2}\).
- Target material: 3 µm foil Mylar (\( \text{C}_{10}\text{H}_{8}\text{O}_{4} \)) \( \rho 1.4 \) gm cm\(^{-3}\)

*OPAL Voigt with a cut-off from second-order line shape theory

*C.A. Iglesias, B. Wilson, LLNL OPAL calculations (2008)

**Satellite structure measurements to test LANL ATOMIC code**

‘Mixed’ Two temperature spectra:
- 99% hot, less dense \((T_e = 150 \text{ eV}, N_e = 3.6 \times 10^{20} \text{ cm}^{-3})\)
- 1% colder, denser \((T_e = 60 \text{ eV}, N_e = 5 \times 10^{22} \text{ cm}^{-3})\)


Callisto is an ultrahigh intensity laser used to study relativistic laser-plasma interaction physics.
Callisto has been used to study laser absorption at ultra-relativistic laser intensities

- Absorption reaches 80-90% for 45p at intensities above $10^{20}$ W/cm$^2$.
- Both preplasma and hole boring effects contribute to the enhanced absorption in the ultra-relativistic regime.
- 2D PIC simulations show that of ~90% absorbed energy, ~60% goes to hot electrons, and the rest to ion acceleration, field generation and hydro motion.

Generation of intense proton beams was studied, and applications developed in isochoric heating/radiography.

**Ultraintense proton beam generation on the Callisto laser**

- 10J, 100fs laser pulse
- aluminum foil
- relativistic electron cloud
- proton beam
- 5MeV
- 15MeV
- 25MeV

**Effects of heavy ions on proton acceleration**

- f=0.30  H
- C+4
- O+4
- f=0.40  H
- Er+10

**Enhanced proton production from hydride-coated foils**


**Observations of Proton Beam Enhancement Due to Erbium Hydride on Gold Foil Targets**

Ultrafast optical probing and x-ray imaging is being used to study high intensity laser channeling.

Innovative Geometry for Simultaneous X-ray Imaging and Interferometry

These experiments are studying high intensity laser-plasma-electron coupling physics and energy balance.
An LLNL/UCSD/UCLA collaboration is combining Callisto and Janus lasers to study Laser Wakefield Acceleration

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<th>Lawrence Livermore National Laboratory</th>
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<tr>
<th>University of California at San Diego</th>
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<td>B. B. Pollock, J. S. Ross, G. Tynan</td>
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<th>University of California at Los Angeles</th>
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<td>C. E. Clayton, S. Martins, A. Pak, K. A. Marsh, W. B. Mori, C. Joshi</td>
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These experiments are part of a strong university/LLNL collaboration.

A gas cell was used with laser powers up to 300 TW; highest power LWFA experiments to date.

A 170 TW, 60 fs laser pulse was self-guided through a gas tube and measured to have <20 μm radius after propagating 1.5 cm.

J. Ralph, Invited Talk at the upcoming DPP, Atlanta (2009)
Self-guiding a 200 TW short pulse laser beam has accelerated electrons beyond 1 GeV.

The self-injection threshold for LWFA was measured using 200TW/60fs.


The acceleration length was scaled by increasing the plasma length.

A novel injection method* was instrumental in accelerating >1.5 pC of charge over 1 GeV.

Using Janus a magnetically-controlled plasma channel is being developed to guide the 200TW Callisto beam 5 cm.

The depth of the channel can be matched for ideal guiding using the magnetic field.

Introducing a magnetic field localizes the heat flux allowing channels to be produced at densities less than $10^{18}$ cm$^{-3}$.

Froula et al. PRL 98, 135001 (2007)
Titan combines a 350 J Petawatt-class short-pulse beam with a 1 kJ long-pulse beam.
TITAN has enabled accurate measurements of high intensity laser to fast electron coupling for Fast Ignition

<table>
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<tr>
<th>TITAN experiment</th>
<th>Vacuum electron spectrum</th>
<th>1-Temp fit to brems data</th>
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<tr>
<td>150 J, 0.5 ps, $10^{20}$ Wcm$^{-2}$</td>
<td><img src="image" alt="Vacuum electron spectrum" /></td>
<td><img src="image" alt="1-Temp fit to brems data" /></td>
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<tr>
<td>Al–Cu–Al</td>
<td>1.1 MeV, 13 MeV</td>
<td>Data</td>
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<td>$K_{\alpha}$ yield</td>
<td><img src="image" alt="Graph" /></td>
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2-Temp allowable distributions

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<th>Conversion efficiency</th>
<th>Full-scale PIC modeling</th>
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<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Field energy density" /></td>
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<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Electron density" /></td>
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Experiments were recently performed by a UCSD group to study fast electron transport in WDM

M.S. Wei, F. Beg et al. (UCSD)
K. Akli, R. Stephens (GA)
A. MacPhee, S. LePape, D. Hey et al. (LLNL)
TITAN is used for development of short-duration broadband x-ray sources for opacity measurements.

Measured soft x-ray spectra from back of ~3µm thick Cu

- Broad-band spectra:
  - optically thick
  - high radiation field in target
  - back side is cold if pulse length < 5 ps

Measure spot size on back of target with soft x-ray imager

- Images at 3 energy bands
  - < 800 eV
  - 400 – 800 eV
  - > 6000 eV
- Heated spot size varies, ~ 50µm

M. Schneider et al.
The highest density of positrons in the laboratory were generated on TITAN experiments.

Super hot electrons (~9 MeV temperature) 
1x10^6 e+ observed, implies 10^{16} e+/cm^3 inside target 
Positron/Electron ratio >10^{-2} (about 10^{-4} from NOVA)

TITAN short-pulse was used for the first ultrafast x-ray Thomson scattering measurements of shocked matter.

Scattering at 4 ns shows small inelastic signal indicating low Temp & Z*

Observation of plasmon at 7 ns indicates transition from an insulator to a dense metallic state.
Further experiments have characterized the plasma collisionality in shocked Boron

Radiography on shocked B has established the target platform

Radiography at t = 3.8 ns delay with a smoothed green laser, 13 TW/cm²

K-α ray scattering spectra provides accurate measurements of $n_e$, $v_{ei}$

- 1st order Born approximation
- Electron density from X-ray Thomson scattering agrees with radiography
- S. LePape et al., Invited Talk at the upcoming APS DPP meeting (2009)
40kev K-alpha radiography with 10um resolution has been used to measure RM/RT instability growth rates.

Laser E=128 J, 1.5 ns, 1mm x 1mm phase plate; Backlighter, Sm 40 keV, 100x100x10 μm, delay 200 ns.

We find that the measured growth factors are smaller than simulations using the nominal Steinberg-Guinan strength model.

(H. Park, Plasticity, 2007)
JLF is playing an important role in the development of NIF diagnostics for NIC and HED Science Campaigns.

Multi-pulse Compton radiography, using NIF ARC, is being developed to measure $\rho R$ and asymmetry of the compressed core in NIF implosions.

R. Tommasini

Compton scattered x-rays

NIF ARC Quad beamlines

$t_8 + 75 ps$

$t_8 + 25 ps$

$t_8 - 75 ps$

Multiple x-ray radiographs capture time evolution of compression
TITAN experiments were used to optimise source size and conversion efficiency into 100-200keV x-rays

Titan parameters:
- Spot size ~ 50 m FWHM (15 m)
- Energy ~ 150J; Intensity: variable by changing pulse duration
- Incidence angle matching ARC: 35 deg

10 µm-diameter Au wire

Al substrate

TITAN laser

TITAN results are scaled to NIF ARC laser parameters
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