4th International Conference on High Energy Density Physics
25-28 June 2013
Saint Malo - FRANCE

ICHED 2013

- Material Science and Planetary Physics
- Nuclear and Particle Acceleration Physics
- Laboratory Astrophysics
- Laser Plasma Physics
- Diagnostics for HED
- ICF Physics
# Program

**Tuesday, June 25**

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<td>12:00-13:50</td>
<td>Lunch</td>
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<tr>
<td>13:50-14:00</td>
<td>Welcome</td>
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<td>14:00-14:30</td>
<td><strong>UHI 1</strong> <em>Chair: L. Yin</em></td>
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<td>14:00-14:30</td>
<td>A. Kemp</td>
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<td>Kinetic particle-in-cell modeling of Petawatt laser plasma interaction relevant to HEDLP experiments</td>
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<tr>
<td>14:30-14:50</td>
<td>R. Shah</td>
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<td>Dynamics and Application of Relativistic Transparency</td>
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<td>14:50-15:10</td>
<td>C. Ridgers</td>
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<td>QED effects at UI laser intensities</td>
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<td>15:10-15:30</td>
<td>L. Cao</td>
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<td></td>
<td>Efficient Laser Absorption, Enhanced Electron Yields and Collimated Fast Electrons by the Nanolayered Structured Targets</td>
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<td>15:30-16:00</td>
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<td>16:00-16:30</td>
<td><strong>Laboratory Astrophysics 1</strong> <em>Chair: P. Drake</em></td>
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<td>16:00-16:30</td>
<td>J. Bailey</td>
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<td></td>
<td>Laboratory opacity measurements at conditions approaching stellar interiors</td>
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<tr>
<td>16:30-16:50</td>
<td>A. Pak</td>
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<td>Radiative shock waves produced from implosion experiments at the National Ignition Facility</td>
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<td>16:50-17:10</td>
<td>B. Albertazzi</td>
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<td>Modeling in the Laboratory Magnetized Astrophysical Jets: Simulations and Experiments</td>
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<td>17:10-17:30</td>
<td>C. Kuranz</td>
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<td></td>
<td>Magnetized Plasma Flow Experiments at High-Energy-Density Facilities</td>
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<td>09:00-09:40</td>
<td>N. Landen</td>
<td>Status of the ignition campaign at the NIF</td>
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<td>09:40-10:00</td>
<td>G. Huser</td>
<td>Equation of state and mean ionization of Ge-doped CH ablator materials</td>
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<td>10:00-10:20</td>
<td>B. Remington</td>
<td>Hydrodynamic instabilities and mix in the ignition campaign on NIF: predictions, observations, and a path forward</td>
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<td>M. Olazabal</td>
<td>Laser imprint reduction using underdense foams and its consequences on the hydrodynamic instability growth</td>
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<td>11:10-11:30</td>
<td>R.W. Lee</td>
<td>A Review of Progress in the Area of Warm Dense Matter Research</td>
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<td>11:50-12:10</td>
<td>O. Ciricosta</td>
<td>Measurements of Continuum Lowering in Isochorically Heated Hot-Dense Aluminum</td>
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<td>12:10-12:30</td>
<td>P. Neumayer</td>
<td>Structure factor measurements in strongly coupled plasmas in the long wavelength limit</td>
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<td>12:30-14:00</td>
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<td>Lunch</td>
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<tr>
<td>14:00-14:40</td>
<td>G. Chabrier</td>
<td>Warm dense matter in astrophysics</td>
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<td>14:40-15:00</td>
<td>B. Militzer</td>
<td>Path integral Monte Carlo calculations of dense plasmas and density functional molecular dynamics simulations for giant planet interiors</td>
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<td>15:00-15:20</td>
<td>R. Smith</td>
<td>Ramp Compression of materials to high-pressure low-temperature states</td>
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<tr>
<td>15:20-15:40</td>
<td>M. Knudson</td>
<td>Probing planetary interiors: Shock compression of water to 700 GPa and 3.8 g/cc, and recent high precision Hugoniot measurements of deuterium</td>
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<td>15:40-16:10</td>
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**Thursday, June 27**

**ICF 2**  
Chair: N. Landen

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<tr>
<td>09:00-09:30</td>
<td>L. Masse</td>
<td>Sensitivity of ignition designs to hydrodynamic instability</td>
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<tr>
<td>09:30-10:00</td>
<td>R. Betti presented by B. Nora</td>
<td>Progress toward conventional and shock ignition for direct drive ICF</td>
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<tr>
<td>10:00-10:20</td>
<td>M. Chen</td>
<td>Simulation and Experiment Study on Implosion of Cone-Wire Target in Fast Ignition</td>
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<tr>
<td>10:20-10:40</td>
<td>L. Gao</td>
<td>Observation of Self-Similarity in the Magnetic Fields Generated by the Ablative Nonlinear Rayleigh–Taylor Instability</td>
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<tr>
<td>10:40-11:00</td>
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<td>Coffee break</td>
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**Diagnostics and Sources**  
Chair: P. Renaudin

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<tr>
<td>11:00-11:30</td>
<td>C. Li</td>
<td>Advanced Nuclear Diagnostics for the National Ignition Facility, OMEGA, and High-Energy-Density Physics</td>
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<td>11:30-11:50</td>
<td>K. Ta Phuoc</td>
<td>Femtosecond X-rays from laser plasma accelerators</td>
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<td>11:50-12:10</td>
<td>T. Nagayama</td>
<td>Polychromatic tomography of high energy density plasmas</td>
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<td>12:10-12:30</td>
<td>E. Gamboa</td>
<td>Simultaneous measurement of several state variables by imaging x-ray scattering</td>
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<td>12:30-14:00</td>
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**Plasma Physics**  
Chair: L. Gremillet

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<td>L. Yin</td>
<td>Self-organized, coherent bursts of stimulated Raman scattering and speckle interaction in multi-speckled laser beams</td>
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<td>P. Michel</td>
<td>Cross-beam energy transfer in ICF/HEDP experiments: theory and measurements</td>
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<td>14:50-15:10</td>
<td>A. Stockem</td>
<td>Exploring the transition from electromagnetic shocks to electrostatic shocks</td>
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**Nuclear & Particle Physics**  
Chair: P. Neumayer

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<tr>
<td>15:10-15:40</td>
<td>V. Smalyuk presented by B. Remington</td>
<td>NIF capsule implosions: a unique venue for studying nuclear reactions in astrophysically relevant, dense thermal plasmas</td>
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<tr>
<td>15:40-16:00</td>
<td>P. Grabowski</td>
<td>Direct Numerical Tests of Kinetic Theory Collision Integrals with Molecular Dynamics Simulations of Stopping Power in Plasmas</td>
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<td>16:20-19:30</td>
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<td>Coffee break &amp; poster session</td>
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<td>19:30-22:30</td>
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<td>Conference dinner</td>
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### Friday, June 28

#### ICF 3  
*Chair: Y. Ping*

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<th>Topic</th>
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<tr>
<td>09:00-09:30</td>
<td>S. Fujioka</td>
<td>Fast-ignition laser inertial fusion research on GEKKO-LFEX laser facility</td>
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<tr>
<td>09:30-09:50</td>
<td>S. Bastiani</td>
<td>X-ray emission spectroscopy of well-characterized, NLTE Nb and W plasmas</td>
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<tr>
<td>09:50-10:10</td>
<td>F. Doss</td>
<td>Instability and turbulence in laser-driven shock-induced counterflowing shear experiments</td>
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<tr>
<td>10:10-10:30</td>
<td>B. Albright</td>
<td>Effects of ion kinetic physics on thermonuclear burn in inertial fusion hot spots</td>
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<td>10:30-11:00</td>
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<td>Coffee break</td>
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#### Laboratory Astrophysics 2  
*Chair: S. Bouquet*

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<td>A. Spitkovsky</td>
<td>Collisionless shocks</td>
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<td>11:30-11:50</td>
<td>J. Zhong</td>
<td>Reconnections of ultra-strong magnetic fields in laser produced plasmas</td>
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<td>11:50-12:10</td>
<td>Y. Kuramitsu</td>
<td>Laboratory experiments of magnetic field in the universe</td>
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<tr>
<td>12:10-12:30</td>
<td>J. Meinecke</td>
<td>A platform to study magnetic field amplification of laser driven shocks due to induced turbulence</td>
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<tr>
<td>12:30-14:00</td>
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<td>Lunch</td>
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#### UHI 2  
*Chair: M. Nakatsutumi*

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<td>Radiation pressure acceleration of ions from ultrathin high Z targets</td>
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<td>14:30-14:50</td>
<td>X.Q. Yan</td>
<td>Laser driven plasma lens for pulse shaping/cleaning and ion acceleration</td>
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<tr>
<td>14:50-15:10</td>
<td>L. Jarrott</td>
<td>Fast Electron Transport and Spatial Energy Deposition into Imploded High Density Plasmas using Cu-Doped CD Shell Targets</td>
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<td>15:10-15:30</td>
<td>M. Levy</td>
<td>General Model of Conversion Efficiency in Ultraintense Laser-Overdense Plasma Interactions</td>
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<td>15:30-16:00</td>
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<td>Closing remarks</td>
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Committees

INTERNATIONAL STEERING COMMITTEE

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Luis SILVA — Instituto Superior Tecnico, PORTUGAL

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Claire MICHAUT — Laboratoire Univers et Théories (LUTH), Observatoire de Paris
Alessandra RAVASIO — Laboratoire pour l'Utilisation des Lasers Intenses (LULI), Ecole Polytechnique
Tuesday
Kinetic particle-in-cell modeling of Petawatt laser plasma interaction relevant to HEDLP experiment.

Andreas Kemp, Frederic Perez, Laurent Divol

*Lawrence Livermore National Laboratory, Livermore, CA 94550*

**ABSTRACT.**

We present new results on kinetic particle-in-cell modeling of Petawatt laser plasma interaction relevant to HEDLP experiments. Fully resolved simulations of relativistic electron beams at reduced scale provide guidance on numerical requirements and mitigation strategies with respect to instabilities that occur near the laser-plasma interaction region. 2D and 3D simulations are used to characterize the temporal evolution of the laser energy conversion into hot electrons, i.e., conversion efficiency as well as angular- and energy distribution; the impact of return currents on the laser-plasma interaction; and the effect of self-generated electric and magnetic fields on the onset of electron transport near the laser interaction region. We report applications to current experiments and to a Fast-Ignition point design.
Dynamics and Application of Relativistic Transparency

Rahul C. Shah¹, S. Palaniyappan¹, B. J. Albright¹, J. C. Fernandez¹, D. C. Gautier¹, B. Manuel Hegelich¹,², D. Jung¹,³, J. Schreiber⁴, H.-C. Wu¹,⁵, and L. Yin¹

¹Plasma Physics (P-24), Los Alamos National Laboratory, USA
²now at Dept. of Physics, University of Texas, Austin, USA
³now at Dept. of Physics and Astronomy, Queens University, Belfast, IRELAND
⁴Max Planck Inst. of Quantum Optics, Garching, GERMANY
⁵now at Inst. of Fusion Theory and Simulation, Zhejiang University, Hangzhou, CHINA

ABSTRACT

Overdense plasmas are usually opaque to laser light, however when the light is of sufficient intensity to drive electrons to near light speeds, the relativistically heavy electrons render the plasma transparent. The process, known as relativistic transparency, is not only of fundamental importance, but also foundational to novel regimes of enhanced laser-particle acceleration, x-ray sources and techniques for controlling the shape and contrast of intense laser pulses. In the interaction of an intense laser with a nano-foil target, the plasma density and electron mass evolve on the femtosecond timescale, creating a dynamic process, which includes a stage of relativistic transparency. Previous measurements had looked at time integrated light transmission as well as ion and electron spectra. In those cases, the dynamics of relativistic transparency could only be inferred from simulations. Our experiments have directly examined the reflected and transmitted optical electric fields from such an interaction, including both intensity and phase. A rich body of time resolved experimental signatures have been compared in detail with two-dimensional particle-in-cell-simulation [1]. For the first time, the data captures the evolution from a reflective over-dense surface to a volumetric interaction within relativistically modified plasma.

Our studies, conducted at Los Alamos’s Trident laser, began with auto-correlation measurements demonstrating pulse shortening of the light transmitted thru 10s of nm diamond-like-carbon foils. Simultaneous measurements showed spectral broadening consistent with relativistic modulation of the optical index. Spectrally resolving the auto-correlation provided frequency-resolved-optical gate (FROG) data from which the electric field was measured. In the transmitted light the optical phase showed a sharp variation associated with a transition from overdense to transparent plasma. At later times, the phase derivative reversed sign more gradually, consistent with a reduction in the relativistic modification of the plasma index. A numerical calculation of the optical phase from the simulation profiles of density and electron Lorentz factor showed these signatures as consistent with relativistic modification and transparency of the plasma index of refraction. The reflected light measurements showed time resolved initial signatures of surface bending and hole-boring (ν~0.01c) followed by transparency.

We are now investigating the utility of these dynamics for spatial and temporal shaping of the laser pulse incident upon a secondary target. These studies involve direct characterization of the transmitted light with a spectral interferometer for high-dynamic contrast measurement as well as measurement of the reflected electric field from the combination of the pulse-shaping and secondary target foils.

REFERENCES


INVITED
QED effects at ultra-high laser intensities

C.P. Ridgers
University of York

ABSTRACT.

With construction beginning soon on several next-generation 10PW lasers as part of the European Union's Extreme Light Infrastructure (ELI) project, an exciting new frontier will soon be reached in high-power laser-plasma physics. 10PW lasers will create strong enough electromagnetic fields to access non-linear quantum electrodynamics (QED) processes usually only seen in particle physics experiments. Particle physics experiments are arranged such that these QED scattering processes can be studied in isolation (and their cross-sections compared to QED calculations). By contrast, the fields in a 10PW laser's focus will directly access non-linear QED processes and create a completely novel plasma state: a 'QED-plasma', similar to that predicted to exist in the atmospheres of pulsars. Here the microscopic QED processes are inherently entwined with the full complexity of a macroscopic laser-plasma interaction and neither may be considered in isolation [5]. As a result the fundamental plasma physics must be re-examined in the QED-plasma regime. In particular we will present calculations showing strong (~50%) laser-absorption into gamma-rays and electron-positron pairs can occur by new absorption mechanisms, and that for high enough intensities an avalanche of electron-positron pairs can be initiated. However, experimental investigation of the QED-Plasma regime and the resulting constraint of these theoretical calculations is highly desirable. We will present several possible experiments which could begin such an investigation using today's PW-class high-power laser facilities.
Efficient Laser Absorption, Enhanced Electron Yields and Collimated Fast Electrons by the Nanolayered Structured Targets

Lihua Cao\textsuperscript{1,2,*}
\textsuperscript{1}Institute of Applied Physics and Computational Mathematics, Beijing 100094, China
\textsuperscript{2}HEDPS, Center for Applied Physics and Technology, Peking University, Beijing, 100871, China

ABSTRACT.
Laser-solid interaction is the base of laser fusion, the production of energetic particles, such as high energy electron beam, energetic ions or protons, pulsed neutron source, X ray or K\textalpha{} source. The key problems are to improve the absorption by the targets and to enhance the conversion efficiency. To generate high quality energetic particle beams, they are required to be highly collimated with small energy spread. However, the solid target is dense with high density, a laser interacts with the solid target only within a thin skin depth. The inefficient laser-to-solid coupling results in the limited absorption and low conversion efficiency. An attractive way to increase the absorption is structuring the target surface. different types of targets have been proposed, including targets with subwavelength gratings, velvet surfaces, holes and nanoholes and nanotubes, as well as targets made of porous silicon, clusters, low-density foam, etc.

We propose a novel nanobrush (nanolayered) target having a front surface consisting of a stack of closely (subwavelength) spaced fibers. The 2D3V PIC simulations show that fast electrons are generated ponderomotively by $j \times B$ acceleration and then propagate forward with most of the absorbed laser energy around the surfaces of the plasma layers. Compared to a regular planar target, the depth of laser energy penetration is larger than the skin length and more laser energy goes into kinetic energy of fast electrons, so the laser coupling efficiency is greatly increased. The dependence of absorption or reflection on target parameter is demonstrated. Furthermore, some improved nanolayered targets, such as conical nanolayered, cone-nanolayered and tailored cone-nanolayered targets, are proposed. The laser absorption and generated fast electrons are investigated.

They present a very attractive controlling in designing high brightness X-ray or K\textalpha{} sources by matching the target parameters and laser conditions. The manipulation of the properties of the hot electrons is discussed by matching the parameters of nanolayered target and laser pulse.

REFERENCES

* Electronic mail: cao_lihua@iapcm.ac.cn.
LABORATORY OPACITY MEASUREMENTS AT CONDITIONS APPROACHING STELLAR INTERIORS

J.E. Bailey\textsuperscript{1}, C. Blancard\textsuperscript{2}, J. Colgan\textsuperscript{3}, Ph. Cosse\textsuperscript{2}, G. Faussurier\textsuperscript{2}, C.J. Fontes\textsuperscript{3}, F. Gilleron\textsuperscript{2}, I. Golovkin\textsuperscript{4}, S.B. Hansen\textsuperscript{1}, C.A. Iglesias\textsuperscript{5}, D.P. Kilcrease\textsuperscript{3}, G. Loisel\textsuperscript{1}, J.J. MacFarlane\textsuperscript{4}, R.C. Mancini\textsuperscript{6}, T. Nagayama\textsuperscript{1}, S.N. Nahar\textsuperscript{7}, T.J. Nash\textsuperscript{1}, J.C. Pain\textsuperscript{2}, M. Pinsonneault\textsuperscript{7}, A.K. Pradhan\textsuperscript{7}, G.A. Rochau\textsuperscript{1}, M. Sherrill\textsuperscript{3}, and B.G. Wilson\textsuperscript{5}

\textsuperscript{1} Sandia National Laboratories, Albuquerque, New Mexico
\textsuperscript{2} CEA, DAM, DIF, F-91297 Arpajon, France
\textsuperscript{3} Los Alamos National Laboratory, Los Alamos, New Mexico
\textsuperscript{4} Prism Computational Sciences, Madison, Wisconsin
\textsuperscript{5} Lawrence Livermore National Laboratory, Livermore, California
\textsuperscript{6} University of Nevada, Reno, Nevada
\textsuperscript{7} Ohio State University, Columbus, Ohio

ABSTRACT.

Opacities are an essential ingredient of stellar models and opacity models have become highly sophisticated, but laboratory tests have not been done at the conditions existing inside stars. This hinders present understanding of stars. For example, solar models presently disagree with helioseismic observations and one possible explanation is that opacity models under-predict the true opacity of the solar interior matter. Furthermore, the rapid growth of asteroseismology has raised the importance and scrutiny of stellar opacity knowledge for stars outside our solar system. Our research is presently focused on measuring Fe opacity at conditions relevant to the base of the solar convection zone, where the electron temperature and density are believed to be $T_e=190$ eV and $n_e=9 \times 10^{22}$ e/cc, respectively. The opacity science platform at the Z facility was used to volumetrically heat tamped iron samples to $T_e=195 \pm 6$ eV at a density $n_e = 4.44 \pm 1.56 \times 10^{22}$ cm\textsuperscript{-3}. We measured the frequency-resolved opacity with typical uncertainty of approximately $\pm$ 10\% over the 935 – 1550 eV range using the approximately $\sim 370$ eV Planckian backlight produced by the dynamic hohlraum source. The sample spatial uniformity was directly measured using tracer layer spectroscopy. The measured opacities are reproducible and satisfy the expected scaling with areal density. The comparison of the measurements with opacity model calculations, the implications for our understanding of atoms in plasmas, and the possible impact on stellar physics will be discussed.

++Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Email: jebaile@sandia.gov

INVITED
Radiative shock waves produced from implosion experiments at the National Ignition Facility

A. Pak

Lawrence Livermore National Laboratory, Livermore, CA. 94550

ABSTRACT.

Spherically expanding radiative shock waves have been observed from inertially confined implosion experiments at the National Ignition Facility. In these experiments, a spherical fusion target, initially 2 mm in diameter is compressed via the pressure induced from the ablation of the outer target surface. At the peak compression of the capsule, x-ray and nuclear diagnostics indicate the formation of a central core, with a radius and ion temperature of \( \sim 20 \) microns and \( \sim 2 \) keV, respectively. This central core is surrounded by a cooler compressed shell of deuterium-tritium fuel that has an outer radius of \( \sim 40 \) microns and a density of \( > 500 \) g/cc. Using inputs from multiple diagnostics, the peak pressure of the compressed core has been inferred to be of order 100 Gbar for the implosions discussed here. The shock front, initially located at the interface between the high pressure compressed fuel shell and surrounding in-falling low pressure ablator plasma, begins to propagate outwards after peak compression has been reached. Approximately 200 ps after peak compression, a ring of x-ray emission created by the limb-brightening of a spherical shell of shock-heated matter is observed to appear at a radius of \( \sim 100 \) microns. Hydrodynamic simulations, which model the experiment and include radiation transport, indicate that the sudden appearance of this emission occurs as the post-shock material temperature increases and upstream density decreases, over a scale length of \( \sim 10 \) microns, as the shock propagates into the lower density (\( \sim 1 \) g/cc), hot (250 eV) ablation front plasma. The expansion of the shock-heated matter is temporally and spatially resolved and indicates a shock expansion velocity of \( \sim 300 \) km/s in the laboratory frame. The magnitude and temporal evolution of the luminosity produced from the shock-heated matter was measured at photon energies between 5.9 and 12.4 keV. The observed radial shock expansion, as well as the magnitude and temporal evolution of the luminosity from the shock-heated matter, are consistent with 1-D radiation hydrodynamic simulations. Analytic estimates indicate that the radiation energy flux from the shock-heated matter is of the same order as the in-flowing material energy flux, and suggests that this radiation energy flux modifies the shock front structure. Simulations support these estimates and show the formation of a radiative shock, with a precursor that raises the temperature ahead of the shock front, a sharp, approximately micron thick spike in temperature at the shock front, followed by a post-shock cooling layer.
Modeling in the Laboratory Magnetized Astrophysical Jets: Simulations and Experiments

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\textbf{ABSTRACT}

Astrophysical jets are fascinating and ubiquitous phenomena in the Universe. These high speed, well-collimated, outflows are associated with a wide range of objects such as young stellar objects (YSO) \cite{ref1}, accreting stellar mass black holes, microquasars \cite{ref2}, massive black holes in active galactic nuclei (AGN) \cite{ref3}, planetary nebulae \cite{ref4}. The common model used to describe the launching and self-collimation of non-relativistic jets is the Blandford and Payne model \cite{ref5} which shows that a rotating magnetic field anchored in an accretion disc accelerates the flow by magneto-centrifugal means. Although the toroidal field generated by differential rotation collimates the flow radially, without external influence, matter can leave at very wide angle. Here we explore the suggestion of Kwan and Tademaru \cite{ref6} in which jets can be collimated by a poloidal magnetic field anchored in the disc \cite{ref7} and which we have recently shown to be very effective \cite{ref8}. In order to study experimentally such magnetized astrophysical jets, we have developed a platform able to produce a strong magnetic field (up to 40 T) external to the laser plasma interaction \cite{ref9}. The experimental results coupled to 3D MHD simulations, show the magnetic field confining the laser-generated plasma plume into a shock-enveloped cavity which redirects the flow towards the axis. This radially-converging plasma can then produce well collimated jets via a standing conical shock.

\textbf{REFERENCES}

Magnetized Plasma Flow Experiments at High-Energy-Density Facilities

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ABSTRACT

Despite their ubiquity in astrophysics, magnetized, rotating, turbulent flows are not well understood. The study of such flows has relied heavily on numerical simulations in limited parameter regimes and has had little guidance from controlled laboratory experiments to test underlying principles. Our initial experimental work has aimed to characterize plasma flows and their collisions created with high-energy lasers.

Experiments at the Omega Laser Facility created single and colliding plasma jets. These experiments were diagnosed with Thomson scattering, optical pyrometry, and optical imaging. Future experiments on Omega will examine jet and jet collisions with and without a seeded magnetic field. These experiments will use spatially resolved Thomson scattering and proton deflectometry to characterize the plasma parameters along the jet as well as the magnetic field. We will also present initial experimental results from the Titan Laser Facility that will explore a single plasma flow in a magnetic field. The magnetic field will be varied using a Bitter magnet and the experiment will be diagnosed using proton deflectometry and optical diagnostics, such as, schlieren imaging, interferometry and optical pyrometry.

The overall goal of this suite of experiments is to create a plasma flow suitable for long-term driving of rotating flow with an embedded magnetic field. The differential rotation and resulting turbulence of this disk are important elements of the physics of astrophysical accretion disks. We will to use experiments to explore the created or enhanced magnetic field which is largest near the central object and which pushes the disk material up and down in the vicinity of the axis. We also hope to explore the viscosity of the disk and how it affects the rate of accretion.

This work is funded by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-FG52-09NA29548, by the National Laser User Facility Program, grant number DE-NA0000850, by the Predictive Sciences Academic Alliances Program in NNSA-ASC via grant DEFC52-08NA28616, by the Defense Threat Reduction Agency, grant number DTRA-1-10-0077, by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC52-08NA28302 through the Laboratory for Laser Energetics, University of Rochester, and by the Los Alamos National Laboratory, subcontract 129021.
Wednesday joint with WDM
Status of the ignition campaign at the NIF

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ABSTRACT.

The progress and challenges in compressing mm-scale cryogenic DT-filled doped CH capsules with sufficient efficiency, velocity and uniformity to achieve ignition using cm-scale hohlraums driven by the MJ-class NIF laser facility is described in the context of ongoing hohlraum and capsule performance optimization¹ and cryogenic implosion² experiments. Imaging and spectroscopy of the X-rays and neutrons emitted from the compressed core show that we have reached fuel areal densities of (1.2±0.1) g cm⁻² and fuel densities approaching 600 g cm⁻³, within 20% of that required by the point design. The hot-spot plasma has reached ion temperatures of 4±0.2 keV producing neutron yields up to 9e14 (2.5 kJ) emitted over < 200 ps. These indirect-drive implosions represent the highest areal densities and neutron yields achieved on laser facilities to date representing stagnation pressures up to ≈120 Gbar, within a factor of two-to-three required for reaching self alpha heating and a burning plasma. We have also uncovered residual shape and areal density distortions from in-flight x-ray backlight shell radiography, and greater than expected hydrodynamic mixing of ablator material into the DT hot spot at ignition-relevant implosion velocities³, both of which will impede ignition. Current research is therefore focused on improving the time-dependent low mode x-ray drive symmetry, mitigating the potential seeds for hydrodynamic instability from such sources as the capsule support tent and assessing the ablation front hydrodynamic growth rates. In addition, parallel efforts are ongoing at further improving laser-hohlraum coupling efficiency by testing elliptically-shaped hohlraums⁴.

REFERENCES

Equation of state and mean ionization of Ge-doped CH ablator materials

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ABSTRACT.

We are currently investigating ways to reduce hydrodynamic instabilities in inertial confinement fusion capsules. Current ICF capsules are made of several layers of plastic doped with a mid-Z element. These complex structures are expected to protect the fuel from preheating while ensuring hydrodynamic stability of the pusher/fuel interface. Validation of such designs is currently underway using surrogate targets on 10kJ-scale facilities. These surrogates use Ge-doped plastic materials which properties such as equation of state and mean ionization need to be determined. Such experimental data have recently been gathered during recent joint research experiments on the Gekko XII facility at the University of Osaka. We present multimegabar Hugoniot measurements of mean ionization and discuss implications for ICF capsule design.
Hydrodynamic instabilities and mix in the ignition campaign on NIF: predictions, observations, and a path forward*

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ABSTRACT.

An extensive campaign of inertial confinement fusion implosion experiments have been done on the National Ignition Facility. These implosions use hohlraums irradiated with shaped laser pulses at laser energies ranging from 1.3-1.9 MJ energy. The laser peak power and duration at peak power were varied, as were the capsule ablator dopant concentrations and shell thicknesses. Hydrodynamic instabilities lead to mixing of ablator material into the hot spot, causing radiative loses, cooling the hot spot, and degrading performance. The amount of ablator mixed into the hot spot is inferred from the measured elevated absolute x-ray emission from the hot spot. [1] We observe that DT neutron yield and ion temperature decrease abruptly as hot spot mix mass increases above a “mix cliff” at ~200 ng. Comparisons with radiation-hydrodynamics simulations indicate that low mode asymmetries and increased ablator surface perturbation growth may be partly responsible for the current performance levels. Several new platforms and diagnostic techniques are under development to test the leading hypotheses for the observed level of hot spot mix. Progress to date and plans going forward will be described.

REFERENCES


*Prepared by LLNL under Contract DE-AC52-07NA27344.
Laser imprint reduction using underdense foams and its consequences on the hydrodynamic instability growth

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ABSTRACT

Mitigation of hydrodynamic instabilities development is an important issue in the direct-drive inertial confinement fusion [1]. These instabilities are seeded by the initial perturbations of the target surface and/or by the laser intensity non uniformities that are imprinting density modulations at the beginning of the laser pulse. The Rayleigh-Taylor (RT) instability starts to grow at a later time when the target is accelerated under the ablation pressure. To control the instability growth one can reduce either the initial perturbation amplitude or the instability growth rate by using dedicated target designs. Laser imprint reduction by thermal smoothing takes place naturally during the late time plasma expansion due to the increase of the conduction zone length. At the early time, the plasma corona is very short and thermal smoothing cannot mitigate the laser imprint. Other methods of imprint reduction have to be used. We present a study on the use of a low, sub-critical density foam on the target front-side to enhance the laser beam smoothing [2]. In a first part, based on a chain of dedicated multi-dimensional numerical tools, the effects of the foam on the spatial and temporal coherence of the laser beam are analyzed and the consequences on the hydrodynamic instability growth are highlighted. The plasma induced laser beam smoothing, driven by the filamentation instability and the stimulated Brillouin scattering in near forward direction leads to a broadening of the laser frequency spectrum, a reduction of the low mode fluctuation level and a reduced life-time of the speckles. 2D multimode simulations show how the spectrum modification acts on the ablative Richtmyer-Meshkov and RT instability development. In a second part, an experimental approach for principle validation is presented. It is pointed out that an improvement of the foam modelling is needed in hydrodynamic codes to reproduce laser propagation through the foam in future target designs [3] and in particular to estimate the fraction of laser energy absorbed in the foam. A recent dedicated experiment has been carried out on the Omega laser facility. The initial perturbation was imprinted using specific phase plates leading to 30 and 60 µm wavelength modulations onto the target. The RT instability growth has been measured using different foam characteristics and a preliminary analysis of the experimental results will be presented.

REFERENCES


INVITED
A Review of Progress in the Area of Warm Dense Matter Research.

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ABSTRACT.

The research into the area of warm dense matter started in the 1990’s. We will provide a brief overview of the field to understand the progress that has been made in the ensuing years. We will discuss those experiments where short pulse lasers, large-scale nanosecond lasers or x-ray free-electron lasers have been employed. We will also discuss the progress made in the developing theoretical tools to assist in designing, i.e., predicting, experiments, as well as analyzing experimental data.
Measurements of Continuum Lowering in Isochorically Heated Hot-Dense Aluminum


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ABSTRACT.

By using the Linac Coherent Light Source (LCLS), we generated samples of hot dense aluminum, by isochoric heating of thin foils up to 180 eV [1]. As the system is ionized by K-shell photoabsorption, the K-alpha satellites fluorescence allows us to monitor the absorption process as it occurs (due to the short lifetimes of K-shell holes) and resolve the absorbing charge state. Thus by observing the number of K-α satellites that can be excited as a function of the X-ray pump’s photon energy, we can directly measure the position of the K-edges for the different ions within the system [2]. The measured edges are found to be substantially lower than the ones predicted by using the standard Stewart-Pyatt model for continuum lowering, with the disagreement becoming more marked for higher charge states; the values are instead consistent with the earlier model of Ecker and Kröll, which predicts a different scaling of the ionization potential depression with the charge of the ion.

REFERENCES


INVITED
Structure factor measurements in strongly coupled plasmas in the long wavelength limit

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ABSTRACT

We present measurements of the static structure factor in high energy density matter. Angle-resolved x-ray scattering was performed at the Matter at Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS). Strongly coupled warm-dense aluminium was produced by laser shock compression using the MEC high-energy long pulse laser system. Scattering of 8 keV probe radiation from the FEL was spectrally resolved by highly efficient scattering spectrometers to distinguish quasi-elastic and inelastic scattering components. Covering a wide range of scattering angles with unprecedented angular resolution the correlation peak of the ion-ion structure factor could be well resolved, providing direct determination of the ion-ion distance and thus the ion density.

The exceptional collimation of the LCLS beam enabled measurements at small scattering angles, thus accessing small scattering k-vectors while using x-rays sufficiently hard to penetrate the dense plasma.

Our measurements provide stringent benchmark to structure factor calculations which are strongly model dependent at these large scale lengths.

For the first time we have realized k-vectors down to 0.3Å\textsuperscript{-1}, approaching the long wavelength limit, where the material compressibility is fundamentally linked to the ion-ion structure factor via the compressibility sum rule. This holds the potential for a novel approach to measure compressibility of HED matter.

INVITED
Warm dense matter in astrophysics

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ABSTRACT.

In this talk, I will review our present knowledge of the description of warm dense matter in the context of various astrophysical situations. I will first address the description of the equation of state of various elements of astrophysical interest, hydrogen, helium, water, iron under conditions characteristic of the interior of astrophysical bodies. Then, I will examine the impact of these properties on the structure and the evolution of solar and extrasolar giant planets and of compact objects like white dwarfs and neutron stars.
Path Integral Monte Carlo Calculations of Dense Plasmas and Density Functional Molecular Dynamics Simulations for Giant Planet Interiors

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ABSTRACT
This presentation will review three recent applications of first-principles computer simulation techniques to study warm dense matter. First we report a recent methodological advance in all-electron path integral Monte Carlo (PIMC) that allowed us to extend this method beyond hydrogen and helium to elements with core electrons [1]. We combine results from PIMC and with density functional molecular dynamics (DFT-MD) simulations and derive a coherent equation of state (EOS) for water and carbon plasmas from 1-50 Mbar and 10^4-10^9 K.

Second we apply DFT-MD simulations to characterize superionic water in the interiors of Uranus and Neptune. By adopting a thermodynamic integration technique, we derive the Gibbs free energy in order to demonstrate the existence of a phase transformation from body-centered cubic to face-centered cubic superionic water [2]. Finally we again use DFT-MD to study the interiors of gas giant planets. We determine the EOS for hydrogen-helium mixtures spanning density-temperature conditions in the deep interiors of giant planets, 0.2-9.0 g/cc and 1000-80000 K [3]. We compare the simulation results with the semi-analytical EOS model by Saumon and Chabrier. We present a revision to the mass-radius relationship which makes the hottest exoplanets increase in radius by ~0.2 Jupiter radii at fixed entropy and for masses greater than 0.5 Jupiter masses. This change is large enough to have possible implications for some discrepant inflated giant exoplanets.

We conclude by demonstrating that all material in the cores of giant planets, ices, MgO, SiO2, and iron, will all dissolve into metallic hydrogen [4]. This implies the cores of Jupiter and Saturn have been at least partially eroded.

REFERENCES

INVITED
Ramp Compression of materials to high-pressure low-temperature states

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ABSTRACT.

The thermodynamics of compression are typically examined under isothermal conditions or with shock waves, where compressions are limited by the achievable pressure or dissipative heating, respectively. A relatively new dynamic compression technique, ramp compression, enables the adiabatic compression of matter with reduced dissipative heating as compared to shock compression and potentially allows the exploration of solids to the extreme densities expected to exist in the deepest interiors of giant planets. Ramp compression is however unstable relative to a shock because sound velocities typically increase with pressure. Therefore, to ramp compress matter into the multi-Mbar pressure regime, the pressure-loading history must be gentle enough to avoid shock formation, while sufficiently intense to achieve high pressures, constraints that until now were out of reach for laboratory experiments.

I will describe ramp compression experiments on the NIF laser in which the stress-density of diamond and Fe were determined to peak pressures of 50 Mbar and 8 Mbar, respectively. In recent experiments on the Omega laser facility we have measured x-ray diffraction from solid MgO up to 9 Mbar with the identification of a B1-B2 phase transformation at 6 Mbar. I will also present preliminary data from the new NIF x-ray diffraction platform: TARDIS.
Probing planetary interiors: Shock compression of water to 700 GPa and 3.8 g/cc, and recent high precision Hugoniot measurements of deuterium

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ABSTRACT

The past several years have seen tremendous increase in the number of identified extrasolar planetary systems. Our understanding of the formation of these systems is tied to our understanding of the internal structure of these exoplanets, which in turn rely upon equations of state of light elements and compounds such as water and hydrogen. Here we present shock compression data for water with unprecedented accuracy that shows commonly used models for water in planetary modeling significantly overestimate the compressibility at conditions relevant to planetary interiors. Furthermore, we show that its behavior at these conditions, including reflectivity and isentropic response, is well described by a recent first-principles based equation of state. These findings advocate the use of this model as the standard for modeling Neptune, Uranus, and “hot Neptune” exoplanets, and should contribute to improved understanding of the interior structure of these planets, and perhaps improved understanding of formation mechanisms of planetary systems. We also present very recent experiments on deuterium that have taken advantage of continued improvements in both experimental configuration and the understanding of the quartz shock standard to obtain Hugoniot data with a significant increase in precision. These data will prove to provide a stringent test for the equation of state of hydrogen and its isotopes.
Thursday
Sensitivity of ignition designs to hydrodynamic instabilities.
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ABSTRACT.
After a short overview of current CEA’s ignition designs we discuss the sensitivity of those designs to hydrodynamics instabilities and the different ways to control them. We discuss in particular the influence of the drive temperature and the different tradeoff leading to a robust design. We finally present an experimental platform [1] aimed to assess a part of the main features of hydrodynamic instabilities in the context of ignition capsules.

REFERENCES
PROGRESS TOWARD CONVENTIONAL AND SHOCK IGNITION FOR DIRECT DRIVE ICF

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ABSTRACT

Recent advances in the theory of ignition and burn for inertial confinement fusion indicate that the performance from scaled-down implosion experiments on the OMEGA lasers can be extrapolated to the ignition-relevant energies of the National Ignition Facility (NIF). The data extrapolation analysis from 26kJ to about 1.5MJ of laser energy provides a useful tool to determine if the OMEGA cryogenic implosions will ignite when scaled-up to NIF energies (hydro-equivalent ignition). The scaling only applies to the implosion hydrodynamics characteristics and does not include the effects of laser-plasma interactions. The requirements for hydro-equivalent conventional hot-spot ignition on OMEGA are determined and presented in this talk. It is also shown that ignition through a late shock launched at the end of the laser pulse (shock ignition) may be possible on the NIF at sub-mega Joule energies. Recent experiments on OMEGA have been carried out to demonstrate the generation of strong shocks of hundreds of megabar required for shock ignition. The shock ignition designs for the NIF are developed through two-dimensional hydrodynamic simulations including all sources of nonuniformities and laser-energy deposition from the NIF laser in the polar-drive configuration.

INVITED
Simulation and Experiment Study on Implosion of Cone-Wire Target in Fast Ignition

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ABSTRACT.

In fast ignition scheme of laser fusion [1], the two key issues are the survival of the cone tip during the precompression of the cone target and the divergence of fast electron beams in the transport process [2]. It is shown that a cone target with a wire in the front of the tip can be better to control the hot electron divergence by the self-generation magnetic fields on the surface of the wire and give higher transport efficiency than a common cone target [3]. However, if the cone-wire target is destroyed by the hydrodynamic jet during the precompression process, this kind of advanced target can not be used in fast ignition. We use the two-dimensional radiation hydrodynamic code LARED-S to simulate the implosion of the cone-wire target. The simulation results show that the wire structure can be survival when the implosion compression reaches its maximum and can be influenced by the wire length or the distance between the wire and the pellet core. We also find that by indirect-drive implosion the high Z material of the cone and the wire can be affected seriously by the gold M-band radiation from the laser-hohlraum interactions and the mixing of high Z material and low Z fuel happens [4]. We add the low Z coating on the outside of the cone-wire target and inhibit this mixing effect. In the experiments of indirect-drive implosion on the SG-II laser facility, we verify the above results.

REFERENCES

Observation of Self-Similarity in the Magnetic Fields Generated by the Ablative Nonlinear Rayleigh–Taylor Instability

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ABSTRACT.

Magnetic fields generated by the nonlinear Rayleigh–Taylor growth of laser-seeded, three-dimensional broadband perturbations were measured in laser-accelerated planar targets using ultrafast proton radiography. The experimental data show, for the first time, self-similar behavior in the growing cellular magnetic-field structures. These observations are consistent with a bubble competition and merger model that predicts the time evolution of the number and size of the bubbles, linking the cellular magnetic-field structures with the Rayleigh–Taylor bubble and spike growth. These observations are a first step towards understanding the evolution of large-scale, coherent magnetic field structures that can, under certain circumstances, spontaneously emerge and persist in strongly driven flows at high energy densities. A compelling aspect of this work is the creation of globally coherent magnetic field structures, seeded and forced by hydrodynamic instability growth. This could benefit the understanding of magnetic-seed-field generation in high energy density plasmas and the flow-driven processes that induce global magnetic structure prior to their turbulent amplification. In strongly driven plasmas, such information is difficult to obtain by any other technique.

REFERENCES

Advanced Nuclear Diagnostics for the National Ignition Facility, OMEGA, and High-Energy-Density Physics

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ABSTRACT

Working with our collaborators at LLE, LLNL, and LANL, the MIT High-Energy-Density Physics Division has developed several advanced nuclear diagnostics for experiments at both OMEGA and the National Ignition Facility (NIF). This talk will focus on an overview of a select set of these diagnostics and on some of the more intriguing experimental results.

This work is supported in part by contracts U.S. DOE (DE-FG52-09NA29553), NLUF (NA0000877), FSC (RochesterSubaward PO No. 415023-G, UR Account No. 5-24431),LLE (412160-001G), and by LLNL (B580243).
Femtosecond X-rays from laser plasma accelerators

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ABSTRACT.

For more than a century, several generations of compact and large-scale infrastructure x-ray sources have been developed to deliver always brighter radiation and innovative features to a constantly growing users community. X-ray tubes, Z-pinches, laser-produced plasma x-ray sources, synchrotrons, and free electron lasers have opened novel scientific horizons with countless applications. While free electron lasers produce the most intense radiation ever, only a few facilities exist in the world, and there is a need of complementary sources to satisfy the beam time demand. In addition, applications of ultrashort x-ray sources are becoming increasingly important and there is a race toward the production of a source gathering compactness, high brightness, femtosecond duration or less, tunability over the entire x-ray spectrum, and micrometer or sub-micrometer source sizes.

In this context, novel femtosecond x-ray sources based on laser plasma interaction have been developed. Among them, two sources offer promising perspectives: the Betatron and Compton sources. These sources are based on the use of laser plasma accelerators delivering femtosecond electron bunches at energies in the few hundreds MeV range. Betatron radiation is produced by electrons accelerated and wiggled in a wakefield cavity. The radiation produced can reach a few tens keV. For the Compton source, an intense laser pulse collides with the electron bunch and this can produce radiation in the few hundreds keV range. These sources produce beams of femtosecond radiation and have micrometer source size.

We will present the principle of these sources, their characterization and a few application example.

REFERENCES


INVITED
POLYCHROMATIC TOMOGRAPHY OF HIGH ENERGY DENSITY PLASMAS

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ABSTRACT.

We discuss the observation and analysis of spectrally resolved core image data from argon-doped, deuterium-filled low-adiabat OMEGA direct-drive implosions. The core image data were recorded simultaneously along three quasi-orthogonal lines of sight (LOS) using three identical, gated Multi-Monochromatic x-ray Imager (MMI) instruments. The argon K-shell x-ray line emission is primarily emitted at the collapse of the implosion, thus its spectrum provides a spectroscopic signature of the state of the implosion core. For each LOS, a set of argon emission spectra space-resolved along core chord’s has been extracted from the spectrally-resolved core image data recorded with the MMI instruments. A multi-objective search and forward-reconstruction method, which consists of a Pareto genetic algorithm followed up by a fine-tuning technique, finds the three dimensional electron temperature and density spatial distributions that yield the best simultaneous and self-consistent fits to all the extracted space-resolved spectra recorded along the three LOS\(^1\). The resultant temperature and density spatial structures are shown in a tomographic fashion and discussed. This work demonstrates the feasibility of polychromatic tomography, which relies on limited LOS observations but uses information encoded in multiple wavelengths. The case of illustration is an implosion core plasma but the ideas are general and can be applied to other high-energy density plasmas.

Work supported by DOE/NLUF Grant DE-FG52-09NA29042, and LLNL.

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INVITED
Simultaneous measurement of several state variables by imaging x-ray scattering

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ABSTRACT

We have used the technique of imaging x-ray Thomson scattering to perform simultaneous measurements of the temperature, ionization state, material density, and shock velocity of a hydrodynamic flow. In an experiment on the Omega laser facility, University of Rochester, we irradiated a low-density carbon foam with laser intensities on the order of $10^{15}$ W/cm², launching a planar blast wave. After a delay of several nanoseconds, a laser-heated nickel foil created a source of several keV x-rays that were incident onto the foam. The x-rays scattered at 90° in the foam and were recorded by the imaging x-ray Thomson spectrometer (IXTS). The IXTS uses a toroidally-curved germanium crystal to create high-resolution spectral images of the scattered radiation that are spatially resolved along a one-dimensional profile. We extracted the temperature and ionization profiles of the blast wave from the spatially resolved scattering spectra. Additionally, the spatial intensity of the elastic scattering tracked the ion density, permitting measurement of the material density profile and the shock velocity through varying the time delay of the probe. The measurements indicate high temperatures and ionizations and low shock compressions in the blast wave.

This work is funded by the Los Alamos National Laboratory, by the NNSA-DS and SC-OFES Joint Program in High-Energy-Density Laboratory Plasmas, grant number DE-FG52-09NA29548, and by the National Laser User Facility Program, grant number DE-NA0000850.
Self-organized, coherent bursts of stimulated Raman scattering and speckle interaction in multi-speckled laser beams

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ABSTRACT.

Nonlinear physics governing the kinetic behavior of Stimulated Raman Scattering (SRS) in multi-speckled laser beams has been identified in the trapping regime over a wide range of \( k \lambda_D \) values (here \( k \) is the wave number of the electron plasma waves and \( \lambda_D \) is the Debye length) in homogeneous and inhomogeneous plasmas [1,2]. Hot electrons from intense speckles, both forward and side-loss hot electrons produced during SRS daughter electron plasma wave bowing and filamentation [3,4], seed and enhance the growth of SRS in neighboring speckles by reducing Landau damping. Trapping-enhanced speckle interaction through transport of hot electrons, backscatter, and sidescatter SRS light waves enable the system of speckles to self-organize and exhibit coherent, sub-ps SRS bursts with more than 100% instantaneous reflectivity, resulting in an SRS transverse coherence width much larger than a speckle width and a SRS spectrum that peaks outside the incident laser cone. SRS reflectivity is found to saturate above a threshold laser intensity at a level of reflectivity that depends on \( k \lambda_D \); higher \( k \lambda_D \) leads to lower SRS and the reflectivity scales as \( \sim (k \lambda_D)^{-4} \). As \( k \lambda_D \) and Landau damping increase, speckle interaction via sidescattered light and side-loss hot electrons decreases and the occurrence of self-organized events becomes infrequent, leading to the reduction of time-averaged SRS reflectivity. It is found that the inclusion of a moderately strong magnetic field in the laser direction can effectively control SRS by suppressing transverse speckle interaction via hot electron transport.

REFERENCES

Crossed-beam energy transfer in ICF/HEDP experiments: theory and measurements.

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ABSTRACT.

Cross-beam energy transfer (CBET) is a process where the refractive index modulation imprinted in a plasma by the beat wave between overlapping laser beams can act as a Bragg diffraction grating, and scatter energy from one laser beam into another one [1]. CBET can occur in any ICF or HEDP experiment where intense laser beams ($>10^{13}$ W/cm$^2$) overlap in plasmas, and can have dramatic effects on laser energy coupling to the target [2], irradiation symmetry [3], backscatter levels [4] etc.

In this presentation, we will review recent theoretical and experimental investigations of CBET for typical NIF conditions. We have quantified CBET in new experiments during different phases of a NIF ignition pulse, via its effect on radiation symmetry and backscatter levels. In parallel, theoretical efforts have focused on the saturation mechanisms of CBET and its effects on local hydrodynamics conditions.

Experimental and theoretical results show that CBET can occur at low intensities ($\sim 10^{13}$ W/cm$^2$), like in the “picket” of a NIF laser pulse, where the process is purely linear but can nonetheless increase the intensities of some of the laser beams by more than a factor 2. We have performed the first time-resolved measurements of CBET at low intensity, which show good agreement with simulations using linear CBET models. CBET is also very effective at higher intensities ($\sim 10^{14}$-$10^{15}$ W/cm$^2$), where it can affect local plasma conditions via stochastic ion heating which might in turn lead to its saturation [5]. However, this regime remains difficult to assess quantitatively due to the feedback effect on plasma conditions, which requires a self-consistent treatment of CBET in radiation-hydrodynamics codes. We will present the latest progress in the development of such CBET packages for hydrodynamics codes.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

REFERENCES

Exploring the transition from electromagnetic shocks to electrostatic shocks

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ABSTRACT.

Collisionless shocks can be generated in the laboratory by irradiating a preformed plasma target with a laser [1,2] if the right conditions are fulfilled [3-7]. The heating of the electrons by the laser generates a relatively low bulk flow speed, so that the shock has mainly electrostatic character and ions are accelerated with a quasi-monoenergetic spectrum. For this, it is critical that the TNSA fields appearing at the back of the plasma target can be controlled by using an exponentially decaying target profile with a decay length depending on the laser wavelength. However, the changes in the electron population due to trapping in the downstream give rise to growing electromagnetic modes, which will modify the shock character. A comparison of the time scales allows for a definition of regimes of electrostatic or electromagnetic shock character and a transition region, depending on the input fluid velocity and electron temperature [7]. These predictions are confirmed with particle-in-cell simulations. Furthermore, we observe the appearance of magnetic field structures in the downstream of electrostatic shocks. Simulations with a synthetic proton radiography diagnostic demonstrate that they might explain the electromagnetic field signatures observed in recent laser-driven electrostatic shock experiments [8,9].

REFERENCES

NIF capsule implosions: a unique venue for studying nuclear reactions in astrophysically relevant, dense thermal plasmas

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ABSTRACT

We report on an extensive series of capsule implosion experiments on NIF, spanning a wide range of unique conditions of nuclear reactions in dense thermal plasmas. Three different types of implosion experiments (cryogenic DT layered implosions, gas-filled symmetry capsules, and directly driven exploding pushers) allow temperatures and densities of the reacting hot-spot thermal plasmas to be varied by 2-4 orders of magnitude (0.1 – 10 keV, 10²¹ – 10²⁵ cm⁻³). We will describe the different implosion types and diagnostic techniques, show examples of the data, and draw connections to relevant astrophysical scenarios, like stellar evolution, and supernova explosions. In particular, we will describe how the hot spot plasma conditions, where the nuclear reactions are occurring, can be characterized. We will also examine possibilities for using NIF to address specific issues regarding astrophysical nuclear reaction rates and processes.

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

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Direct Numerical Tests of Kinetic Theory Collision Integrals with Molecular Dynamics Simulations of Stopping Power in Plasmas

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ABSTRACT.

Molecular dynamics can provide very accurate tests of kinetic theories. The plasma stopping power problem, of great interest in its own right, provides a particularly rigorous test of plasma kinetic theories because it probes a velocity-dependent quantity, not a weighted integral over some velocity distribution. We use large-scale simulations of charged-particle stopping to cover the weakly to moderately to strongly coupled plasma regimes and a range of projectile charges to study a wide variation in projectile-target coupling. Our simulations employ a purely classical system that allows for an unambiguous comparison with theoretical models while also maximally challenging the theoretical models. We find that current models are inadequate to describe the simulation results over the entire range of conditions, even with accurate, numerically-generated potentials and cross sections, although adequate agreement is found for weakly coupled plasmas and small projectile charge. We find that the low-velocity stopping is very well described, however, through an inverse relationship with the diffusion coefficient.
Applications of High Power Density Ion Beams Driven by Lasers: Creation of Heterogenous Warm-Dense Matter, Neutron Beam Generation and Fast Ignition

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ABSTRACT

We are leveraging the significant recent progress in laser-driven ion acceleration at the LANL Trident laser facility and applying it as a tool in our research. There are many possible ion-acceleration mechanisms and significant debate in the understanding, modeling and proper identification of these mechanisms in recent experimental work. In this presentation, we summarize the "taxonomy" of these mechanisms [1] to clarify and summarize the physics of the ion beams made at our Trident laser facility. We then highlight the application of these beams to three key areas: isochoric heating to create warm-dense matter, neutron-beam generation, and fast ignition with ion beams. For warm-dense matter, we are interested in the creation of systems with initially sharp boundaries between different ion species in solid/plasma or plasma/plasma states. The nature of the mixing of such heterogeneous species is an open question, predicted to be significantly different according to different credible theories. Ultrafast, ion-beam driven isochoric heating is the only way to create the initial conditions in a unit physics experiment that can answer this question. Such ion beams are only achievable with high-intensity lasers. We present the initial results on this experimental campaign. Proton and deuteron laser-driven beams on Trident with record-breaking performance have also been used to deliver directed neutron beams with the highest yield and energy achieved with lasers to date [2]. We summarize those results and discuss future plans. Finally, we present the results of simulations of an ion beam suitable for ion-driven fast ignition [1], thus specifying the laser parameters needed for fast ignition.

REFERENCES

Friday
Fast-ignition laser inertial fusion research on GEKKO-LFEX laser facility


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ABSTRACT

The world largest PW laser LFEX [1], which delivers energy up to 2 kJ in a 1.5 ps pulse, has been constructed beside the GEKKO XII laser at the Institute of Laser Engineering, Osaka University, Japan. The GEKKO-LFEX laser facility enables the creation of materials having high energy density, which do not exist naturally on the earth and have an energy density comparable to that of stars. High-energy-density plasma is a source of safe, secure, environmentally sustainable fusion energy. Direct-drive fast-ignition laser fusion has been intensively studied at this facility under the auspices of the FIREX (Fast Ignition Realization EXperiment) project [1]. There are three potential difficulties in the fast ignition scheme, "unstopable" , "shut-in" , and "diverging" of relativistic electron beams. Research is underway to address these three difficulties.

Since fast electrons are scattered and stopped by strong electric field of highly ionized high-Z (i.e. gold) ions, a low-Z cone is being studied in an effort to reduce energy loss of the fast electrons in the cone tip region [2]. We have identified diamond-like carbon (DLC) as a potential cone material for the fast-ignition scheme [3]. It was found in a previous experiment that electron beams diverge during transport with an angle of 100 deg. [4]. Active control is required to focus the relativistic beams toward the fusion fuel. One candidate scheme is to apply an external magnetic field parallel to the beam direction in the fuel [5]. When the magnetic flux density exceeds 1 kT, relativistic electrons are trapped by the magnetic field lines and lateral transport of the electrons is strongly suppressed. We use a laser-driven capacitor-coil target [6] to generate 1 kT of the magnetic field instead of the conventional magnetic field generation scheme. We have developed several tens keV Kα [7] and a few MeV x-ray spectrometers with measured absolute sensitivity to provide more quantitative information about generation and transport of the relativistic electron beam in the fast ignition plasma [8]. The above ideas to enhance energy coupling efficiency of fast-ignition were tested with the new diagnostics.

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X-ray emission spectroscopy of well-characterized, NLTE Nb and W plasmas

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ABSTRACT

Accurate calculations of multicharged ion population dynamics in plasmas not in local thermodynamic equilibrium (NLTE) are of paramount importance for understanding and diagnosing their radiative properties. As NLTE plasmas constitute a large majority of laboratory plasmas encountered in x-ray driven fusion, x-ray laser research and laser-plasma x-ray sources, the modeling of their ionization dynamics is crucial for applications. In the past years, NLTE collisional-radiative models, have widely progressed in the calculation of spectra emitted by multi-charged high-Z ions, but several discrepancies still remain. Benchmarking by well-diagnosed experiments is thus needed for the validation of such codes. The present experiment brings an important contribution to this objective, by measuring the x-ray emission of Nb and W plasmas whose hydrodynamic parameters are simultaneously measured by two additional diagnostics, namely time-resolved Thomson scattering and rear-face self-emission.

In the experiment, we irradiated Nb and W dots with the two frequency doubled, 1.5 ns duration LULI2000 beams to reach an intensity on target of about $2 \times 10^{14}$ W/cm². The focal spot was 400 µm in diameter so that the microdot was overfilled, producing a surrounding plastic plasma which partially tamped the lateral expansion of the Nb (or W) plasma, thus reducing the lateral gradients. A conical crystal spectrometer allowed the measurement of the Nb L-shell and W M-shell emission, in the 2.55-2.9 keV spectral range. Time-resolved Thomson scattering measured the electronic density and temperature, and the rear-face self-emission diagnostic measured the shock speed. These hydrodynamic measurements allow to constrain the 1-D MULTI hydrocode. The atomic physics code FLYCHK is then used as a post-processor of the hydrodynamic code, to reproduce the experimental x-ray spectra. We are also performing calculations with the 2-D hydrocode FCI2 and with the atomic physics code AVERROES to have deeper insight in the experimental measurements. The results of these analyses will be presented.
Instability and turbulence in laser-driven shock-induced counterflowing shear experiments

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ABSTRACT

Isolation of shear-induced instability and turbulence production under high-energy-density conditions constrains models relevant to integrated high-energy-density experiments such as inertial confinement fusion applications or scaled astrophysical problems. An experiment [1] fielded at the Omega Laser Facility [2] comprised a series of targets which used multiple shocks to create high-speed shear between regions at equal pressure in which mixing associated with shear instability could be diagnosed.

This experimental campaign uses laser ablation in a 1 mm scale target to initiate strong shocks which induce fast (~ 70 km/sec) post-shock flow speeds. These post-shock flows are arranged to form a shear interface in a counterflowing geometry providing both a doubling of shear (to 140 km/sec) and an equilibration of the high post-shock pressures across the interface. After the post-shock transients saturate, a developing Kelvin-Helmholtz instability laterally spreads a thin layer of aluminum placed at the interface. The temperature of the materials are approximately 20 eV, and the Mach number of the post-shock flows in the experiment is around 2 on each side of the shear layer.

The experiment is conducted without imposed perturbations seeded onto the interface, which retains a characteristic broadband roughness of order 1 micron. We report finding substantial evidence of turbulent mixing of our dense layer, spanning well over a hundred microns (over five times the initial occupation region of tracer material). Comparison between RAGE [3] simulations both utilizing and omitting turbulent transport models are used to argue that the spreading of material is due primarily to turbulent effects. The data compare favorably to the turbulent simulations. The experimental Reynolds number is estimated around $4 \times 10^5$.

Additionally, radiography in the orthogonal direction captures the onset and evolution of the instability. Early in time, a dominant wavelength corresponding to a most unstable mode is extracted from the data. Later in time, nonlinear effects and a transition to diffuse turbulent structures are observed. The observed time of transition, about 10 ns after the onset of shear, agrees roughly with Zhou's criteria [4] for the development of a turbulent cascade.

REFERENCES

Effects of ion kinetic physics on thermonuclear burn in inertial fusion hot spots

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ABSTRACT

Recent work by Molvig et al. [1] has led to renascent interest in how thermonuclear fusion reactivity may be modified in finite assemblies of fuel. In such systems, modifications to simple hydrodynamic descriptions of the fuel are required and fuel ions in the tails of the ion distribution functions may be depleted substantially by proximity to a boundary, a problem with potential relevance to predicting thermonuclear burn yield in inertial confinement fusion experiments.

In this talk, recent work on this problem will be presented, including analytical results and computational studies using kinetic particle-in-cell (PIC) simulations with the VPIC code [2]. Results from the model of Movig et al. [1] will be compared with PIC calculations employing a binary collision model between plasma particles and lossy walls. Inferred reaction rates as a function of temperature and distance from the boundary will be shown and compared with those found from various theoretical models. It will be shown that while the Molvig et al. “Knudsen distribution function” provides an upper bound to the size of the reactivity modification, a more complete theory is likely to be required to accurately capture these loss effects. Various improvements to the theory will be presented and comparisons made to recent direct-drive Omega experiments.

Recent work on a new model for fusion reactivity of very low rho-R assemblies of thermonuclear fuel will be shown. In such assemblies, reacting ions within the fuel are effectively collisionless, thus necessitating a nonlocal treatment of the ion kinetics. A new, semi-analytic model will be presented with unique experimental signatures that might explain anomalies in recent inertial fusion experiments.

Work performed under the auspices of the U.S. Dept. of Energy under contract W-7405-ENG-36 by the Los Alamos National Security, LLC, Los Alamos National Laboratory.

REFERENCES

Collisionless shocks in laser produced plasmas

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ABSTRACT

Collisionless shocks are nonlinear plasma structures that convert the kinetic energy of a supersonic flow into the thermal energy of a compressed subsonic flow. In the absence of Coulomb collisions, such shocks are mediated by the collective electromagnetic interactions in plasma. As a byproduct, collisionless shocks also accelerate non thermal particles, generate and amplify magnetic fields, and exchange energy between ions and electrons. I will discuss the outstanding issues in plasma physics that governs the structure of collisionless shocks and their ability to accelerate particles. Guided by large scale ab-initio kinetic simulations of shocks, we can now predict the collective processes involved in shock formation in different regimes of flow speed, composition, and magnetization. This physics is now testable with laboratory experiments at high-energy density facilities. I will discuss the physical constraints that need to be satisfied by such experiments and will present our current progress at creating collisionless shocks on the Omega laser.
Reconnections of ultra-strong magnetic fields in laser produced plasmas


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ABSTRACT.

Recent laser driven magnetic reconnection (LDMR) constructed with self-generated B fields has been experimentally and theoretically studied extensively [1-5], where more than Mega-Gauss strong B fields are spontaneously generated in high-power laser-plasma interactions, which located on the target surface and produced by non-parallel temperature and density gradients of expanding plasmas. For the properties of short lived and strong B fields in laser plasmas, laser driven magnetic reconnection opened up a new territory in a parameter regime not covered before. In this talk we will present the recent LDMR experimental results performed on Shenguang and Gekko laser facilities, which are aimed to understand the basic physical processes, such as particle accelerations, scale of diffusion region, and guide fields effects et al which are also strongly interested in astrophysics plasma environments.

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Laboratory Experiments of Magnetic Field in the Universe

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ABSTRACT.

In astronomy and astrophysics a magnetic field plays essential roles in various phenomena, however, it is highly difficult to measure the magnetic field in astrophysical plasmas; one of the most uncertain quantities in astrophysical observations is the magnetic field. Laboratory experiments can be a complementary tool to investigate the magnetic field in the Universe. Laboratory astrophysics is a relatively new but rapidly growing field [1-3]. We report our recent efforts on model experiments of the magnetic field generation and/or amplification in the Universe with high-power lasers. The magnetic field generation from the null field condition has been investigated analytically, numerically and experimentally. The Biermann effect has been demonstrated in a laboratory [4] and the Weibel instability will be tested by the world largest laser, the NIF [5]. Recent numerical study has suggested that the Kelvin-Helmholtz instability can generate a D.C. magnetic field [6]. We have reported the Kelvin-Helmholtz turbulence associated with collisionless shocks [7]. A magnetic field can be generated in the turbulence. Another candidate for the magnetic field generation from the null field is the relativistic origin of seed magnetic field and volcity [8]. We are planing to verify these effects in model experiments. We also report the experimental results of magnetic field amplification in supernova remnants via Richtmyer-Meshkov instability.

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A platform to study magnetic field amplification of laser driven shocks due to induced turbulence

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ABSTRACT

Misaligned pressure and temperature gradients associated with asymmetrical shock waves generate currents which seed magnetic fields (Biermann battery process). These fields could then be further amplified by increasing the vorticity and turbulent motions. Studies of such phenomena have been conducted at the Rutherford Appleton Laboratory and scaled to astrophysical conditions (e.g., protogalactic structure formation) using magnetohydrodynamic scaling techniques. Shock waves were driven in a 1 mbar Argon gas filled chamber from ablation of 500 µm Carbon rods using 300 J of 527 nm, 1 ns pulse light. A plastic grid was positioned 1 cm from the target to drive turbulence with outer scale ~1 mm (the size of the grid opening). An induction coil, located 2 cm from the grid, was used to measure the magnetic field while optical diagnostics were used to track the fluid flow.
Radiation pressure acceleration of ions from ultrathin high Z targets

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ABSTRACT
Ion acceleration driven by the enormous radiation pressure exerted by ultra-intense lasers is currently attracting a substantial amount of experimental and theoretical attention due to its superior scaling, compared to the so-called TNSA mechanism, in terms of ion energy and laser-ion conversion efficiency. In this prospective, the 'Light Sail' (LS) regime, where, in a sufficiently thin foil, the whole laser-irradiated area is detached and pushed forward by the Radiation Pressure, is particularly promising. Through a series of experimental campaigns employing Vulcan Petawatt laser, the light-sail regime of RPA-LS mechanism has been systematically explored. While the faster energy scaling of the RPA-LS mechanism, compared to TNSA mechanism, has been demonstrated experimentally in our previous campaign [1], acceleration of narrow band heavy ion spectra was further investigated in recent follow-on campaigns at the Vulcan Petawatt. One of the striking results obtained from the recent experiment was the observation of narrow band peaked feature in spectrum of bulk target ions, accelerated from ultrathin high Z foils at a peak intensity in excess of $10^{20}$ W/cm². Other ion species from the target contaminants, such as carbon and oxygen, showed similar narrow band features at comparable energies/nucleon, suggesting whole foil acceleration along the forward direction. Systematic parametric scans were carried out by varying laser and target parameters, which not only underpinned the RPA scaling, but also provided further insights on achieving a stable RPA drive.

REFERENCES

Laser Plasma Ion Acceleration at Peking University

Peking University, China

ABSTRACT

Target normal sheath acceleration (TNSA) is the predominant mechanism leading to the emission of multi-MeV, high-quality ion beams. Radiation Pressure Acceleration is more efficient, especially in Phase Stable regime. In order to improve the laser energy transmission efficiency, a ultra-high intensity, ultra high contrast laser pulse with steep front is required. By both 3D particle-in-cell (PIC) simulation and analysis, a plasma lens with near critical density is proposed. When the laser passes through the plasma lens, the transverse self-focusing, longitudinal self-modulation and prepulse absorption can be synchronously happened. If the plasma skin length is properly chosen and kept fixed, the plasma lens can be used for varied laser intensity above 10^{18} \text{W/cm}^2. The plasma lens can be implemented by a micron-scale glass cone irradiated by the prepluse with precisely controlled timing before the main pulse. Simulation shows by combining the cone target and DLC target, both acceleration efficiency and proton energy can be about 3 times higher than in RPA regime and 6 times higher than in TNSA regime. It shows 180 MeV proton beam can be generated at laser intensity of 10^{20} \text{W/cm}^2.

A project called Compact LA plasma Accelerator (CLAPA) is approved recently by Chinese Ministry of Science and Technology (MOST), it will aim at ion acceleration and applications, such as ion cancer therapy, proton imaging and diagnostic for high energy density plasma.

REFERENCES:
Fast Electron Transport and Spatial Energy Deposition into Imploded High Density Plasmas using Cu-Doped CD Shell Targets

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ABSTRACT.
Understanding fast electron transport and spatial energy deposition in high-density plasmas is extremely important for fast ignition (FI) inertial confinement fusion. We have, for the first time, characterized fast electron spatial energy deposition in integrated cone-guided FI experiments by measuring fast electron induced Cu K-shell fluorescence emission using Cu doped CD shells attached to the Au cone. This work used the OMEGA laser (3ω, 18 kJ) for fuel assembly, and a high intensity OMEGA EP beam (1ω, 10 ps, 0.5 - 1.5 kJ, I peak > 10¹⁹ W/cm²) focused onto the inner cone tip to produce fast electrons similar to previous FI heating experiments¹. The timing delay between the OMEGA EP beam and the OMEGA driver beams was varied from 3.65 ns to 3.85 ns. This range covers the instant of peak neutron yield until the cone-tip breakout time as observed in previous FI experiments¹. A spherical crystal imager (SCI) was used to image the Kα radiation from the Cu dopant atoms in the imploded plasmas initiated by supra-thermal electrons from the OMEGA beams as well as the fast electrons produced from the OMEGA EP beam. A calibrated Zinc Von Hamos (ZVH) x-ray spectrometer, tuned for measuring Cu K-shell spectrum, provided the total Kα yield measurement, was used to infer energy coupling from the OMEGA EP beam to the compressed core. The escaped fast electron energy spectra were monitored by magnetic spectrometers at several angles. Experimental results showed a significant enhancement (up to 60%) in the total Kα yield from the joint shots compared to that in the driver only implosion case. Fast electron induced Kα yield also increased with the EP beam energy. Fast electron produced Cu Kα emission recorded on the SCI diagnostic was found 100 µm back from the cone tip, which is consistent with the extent of the preplasma created inside the cone by the intrinsic pre-pulse of the EP beam. The measured electron energy spectrum also showed a hotter than ponderomotive scaling temperature. These results are then compared with the latest integrated shots using the high contrast (two orders of magnitude higher than previously used) OMEGA-EP beam. The experiments are being modelled using LSP for fast electron generation and transport with the fuel assembly provided from DRACO simulations.

REFERENCES
General Model of Conversion Efficiency in Ultraintense Laser-Overdense Plasma Interactions

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ABSTRACT.

Ultraintense laser interaction with matter is characterized by two modes of the laser ponderomotive force: the steady-state component, which can generate high-fluence, low-emittance ‘hole punching’ ions; and the oscillatory component, which excites a relativistic fast electron current. By controlling and optimizing the modes in which the light is absorbed, one may enable applications such as compact GeV-scale particle accelerators[1], approaches to fast ignition inertial confinement fusion, and medical proton oncology[2]. Yet, to date, a general framework treating both populations on equitable theoretical footing has not been developed. In this presentation, we outline a fully-relativistic absorption model based on conservation of energy and momentum that describes both modes of light coupling on a unified, first-principles basis for the first time. By allowing both the fast electron beam and the hole punching ions to be energetically significant, we derive a strict lower limit on light absorption as a function of laser intensity and target density. Expressions for the laser conversion efficiencies into each kinetic mode are derived. Results from the model are shown to be in good agreement with high resolution one-dimensional particle-in-cell simulations, and high energy density physics applications are highlighted.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-630157.

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Experimental studies of ion charge equilibrium in the warm dense matter regime.

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ABSTRACT.

We present a recent experiment performed on the 100TW ELFIE (LULI, Ecole Polytechnique) laser system. We measured, at several projectile energies, the charge-state distribution of heavy carbon ion beams after passing through either cold or isochorically-heated WDM with temperature of 1 eV. Our results were then compared to various empirical models as well as a collisional-radiative atomic model. This successful experiment can be viewed as a proof of principle which opens a way for future experiments dealing with other ions interacting with WDM under higher temperatures.

REFERENCES

Ultra-High-Contrast Laser Acceleration of Relativistic Electrons in Solid Targets

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ABSTRACT.

The cone-guided Fast Ignition\textsuperscript{[1,2]} (FI) approach to Inertial Confinement Fusion (ICF) requires relativistic electrons to deposit tens of kilojoules of energy within an imploded fuel core to initiate fusion burn. To minimize the energy, and thus the cost of the laser, the coupling of laser to electron energy should be maximal. Using FI-surrogate cone-wire targets, we investigate the advantages of ultra-high-contrast lasers through experiments on the Trident laser at LANL, which maintains a (prepulse) intensity below $10^{11}$ W/cm\textsuperscript{2} until $<0.1$ ns before the peak intensity of $5\times10^{19}$ W/cm\textsuperscript{2}. This contrast level greatly reduces the amount of material, known as preplasma, ablated prior to the main pulse interaction and increases the coupling of electrons into the solid target.

Using Cu K\textalpha{} emission, we find that coupling of laser-to-relativistic-electron energy into the 40 μm diameter wire is increased by a factor of 2.7x at high-contrast as compared to the low-contrast Titan Laser (LLNL) using identical targets. Simulations using the particle-in-cell code LSP\textsuperscript{[3]} model the full-scale laser interaction and quantitatively reproduce the experimental results. The strong quantitative agreement between experiment and simulations gives us confidence in our modeling techniques and allows information about the electron spectrum to be inferred. By modeling several different preplasma levels, the simulations show two major benefits of preplasma reduction leading to the increased coupling observed experimentally. First, low preplasma means that electrons are accelerated closer to the solid target allowing more of them to be captured by the small solid angle of the wire. Second, the short-scale of the preplasma does not allow non-linear effects (e.g. filamentation, hole-boring) to grow, thus creating a smooth electron profile. Additionally, the investigation of various preplasma levels gives an understanding of how preplasma influences the electron spectrum.

This work gives encouragement that upgrades in laser contrast are worth the significant effort required for their realization, by showing expectation of increased coupling. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Studying High-Energy-Density Plasmas with Nuclear Diagnostics


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ABSTRACT.

Significant progress has recently been made in developing advanced nuclear diagnostics for the OMEGA laser facility and the National Ignition Facility (NIF). Both self-emitted fusion products and backlighting nuclear particles have been measured and used to study a large range of basic physics of high-energy-density (HED) plasmas. The highlights of these works are manifested by numerous recent publications [1-8]. For ignition science in inertial-confinement fusion (ICF) experiments, for example, this work has helped advance our understanding of kinetic effects in exploding-pusher ICF implosions and our understanding of NIF capsule implosion dynamics and symmetry. For basic physics in HED plasmas, our research as contributed to the understanding of basic nuclear plasma science, the generation and reconnection of self-generated spontaneous electromagnetic fields and associated plasma instabilities, high-Mach-number plasma jets, and charged-particle stopping power in various laser-produced HED plasmas. We will present details of this research.

REFERENCES

Influence of overlapping high-intensity laser beams on mega-ampere electron transport

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ABSTRACT.

The production of stable, collimated, energetic, and high density electron beams inside solid is of primary importance for the Fast Ignitor (FI) concept for Inertial Confinement Fusion (ICF) and for the generation of laser-based secondary particles and radiations. High-power laser facilities that will explore the FI concept are planned to comprise many bundled laser beams to produce the electron or ion beams required to heat and ignite the pre-compressed fusion core. The actual propagation of ultra-high intensity (UHI) laser-induced extreme currents is strongly influenced by dynamically changing self-induced fields inside matter.

We experimentally demonstrated that the electron transport and subsequent secondary particle generation are improved when two UHI laser beams interact with plasmas at an angle with respect to each other, compared to a single beam irradiation. Simulations performed using state-of-the-art collisional PIC simulations suggest that surface magnetic fields play an important role to produce a collimated electron beam. The experiment was conducted at the Vulcan TAW laser facility at the Rutherford Appleton Laboratory in the UK. Each optical laser pulses, of ~1 ps duration, contained ~ 50 J energy on target.

In this poster, we discuss the dynamically changing surface magnetic fields and their role on mega-ampere electron beam propagation.
X-ray phase contrast x-ray imaging for relativistic plasma research using FEL radiation

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ABSTRACT.

X-ray free electron laser facilities have started in operation recently in USA and in Japan. Those facilities have already provided versatile unique scientific achievements. European counterpart, the European XFEL facility is now under construction which will provide photon energies up to 24 keV, pulse duration down to 2 fs, allows diagnosing ultra-fast structural dynamics inside truly bulk matter.

Among other applications, coherent imaging of solid-density plasmas interacting with an ultra-high intensity (UHI) laser (> 10¹⁸ Wcm⁻²) will allow visualising the mega-ampere current transport that is a cornerstone of relativistic plasma science. Applications include the inertial confinement fusion and other many applications using secondary generated bright particles and radiations.

Besides other unique x-ray diagnostic methods, the x-ray phase contrast imaging is one of the most interesting methods which fully benefit from coherent nature of the XFEL. The phase contrast imaging will provide refractive index maps of solid samples that were modified by the energetic electron transport and subsequent extreme field generation. Such measurement requires stringent condition for x-rays such as high coherency, monochromaticity, diverging beam, high photon number and short-pulse duration.

In this poster session, we’ll show how to realize such measurement at the European XFEL facility.
Time-resolved x-ray Thomson scattering on laser-driven targets

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ABSTRACT.

Free electron laser facilities enable new pump-probe experiments to characterize warm dense matter, i.e. systems at solid-like densities and temperatures of several eV. Especially, the femtosecond free electron laser pulses allow the investigation of details of the laser-matter interaction, e.g. the generation of non-equilibrium plasmas at ultra-short time scales, the subsequent equilibration of electron and ion temperatures, and the thermal relaxation on the picosecond time scales. This can be realized within pump-probe experiments where a short-pulse laser irradiates a target that is subsequently probed with brilliant x-ray radiation. For such pump-probe experiments, we calculate the scattering spectrum considering the full density and temperature dependent dynamic structure factor throughout the target. The temporal evolution of the density and temperature profiles are derived from particle-in-cell or radiation-hydrodynamic simulations which can be performed for the relevant target materials and laser parameters. This method can be applied to various pump-probe scenarios by combining optical lasers, soft and hard x-ray sources.
Arrival time diagnostic using free carriers generation induced by X-ray FEL

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ABSTRACT.

With the advance of few-femtosecond FEL pulses, the possibility to explore ultrafast processes becomes possible. This is especially important if one wants to explore the ongoing (electron) dynamics of WDM during the early stage of its creation, e.g. with short-pulse optical lasers.

Synchronization between optical lasers and X-ray pulses are still challenging and limited to shot-to-shot fluctuations of their respective arrival time (the so-called « jitter »). We report the development of a "measure-and-sort" approach using a versatile single-shot diagnostic based on ultrafast free-carrier generation in optically transparent materials. Studies have been performed in the hard X-ray regime at LCLS and in the VUV-soft X-ray regime at FLASH.

At LCLS, we have demonstrated that the change of the optical properties is strong enough to allow such measurements in the hard X-ray regime. By correlating two independent measurements, we demonstrate unambiguously a sub-10 fs rms error in reporting the optical/X-ray arrival time. The single shot error suggests the possibility of reaching few femtoseconds resolution [1]. At FLASH, we have also shown the possibility to extract the FEL pulse duration from such a timing tool. We have performed FEL pulse duration measurements at two distinct FEL wavelengths, 41.5 nm and 5.5 nm [2]. In both cases, we demonstrate the possibility of a non damaging mode allowing to operate the timing tools as an online diagnostic.

REFERENCES

Dynamical properties of warm and hot dense matter: First principles Langevin molecular dynamics study

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ABSTRACT

Dynamical properties of warm and hot dense matter are challenging work in both theories and experiments. By introducing the electron-ion collisions induced friction (EI-CIF), we construct first-principles Langevin molecular dynamics, which can be extended into the hot dense regime up to the temperature of 1000 eV [1-2]. The validation of this method is verified by comparing the results from experiments, path-integral Monte Carlo method and so on. Within the framework of this method, the equation of state and dynamical structures under the conditions from giant planet core core to solar interior [3-4]. The dynamical behaviors of warm and hot dense matter are very complicated but interesting, showing the characters of the flowing electron bubbles and dynamical ionic clusters [5].

Besides, the quantum nuclear effects of light elements such as H are investigated using path integral molecular dynamics, showing the significant effects of equation of state, ionic structures, electric conductivities, diffusions and viscosities. This effect is always neglected before but the results indicate its significance in warm dense regime.

REFERENCES

Pressure Ionization and Plasma Phase Transition in High Energy Density Matter

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ABSTRACT.

The report presents new results of investigation of “pressure ionization” and phase transition of high energy matter generated as a result of multiple shock compression in the megabar pressure range. High energy plasma states were generated by single and multiple shock compression and adiabatic expansion of solid, liquid, porous and low-density foams (aerogels) samples. The highly time-resolved diagnostics permit us to measure thermodynamical, transport and radiative properties of high pressure condensed matter in a broad region of the phase diagram. These data in combination with exploding wire conductivity measurements demonstrate the ionization rate increase up to ten orders of magnitude as a result of compression of degenerate plasmas at \( p \sim 10^4 - 10^7 \) bars. Shock compression of \( \text{H}_2, \text{D}_2, \text{Ar}, \text{He}, \text{Kr}, \text{Ne}, \) and \( \text{Xe} \) in initially gaseous and cryogenic liquid state allows measuring the electrical conductivity, Hall effect parameters, equation of state, and emission spectra of strongly nonideal plasma. Thermal and pressure ionization of such exotic states of matter is the most prominent effects under the experimental conditions.

It was shown that plasma compression strongly deforms the ionization potentials, emission spectra and scattering cross-sections of the neutrals and ions in the strongly coupled plasmas. Comparison of the data obtained with theoretical models (percolation, Mott transition, Ziman and Lorenz approach etc.) is presented. In contrast to the plasma compression experiments the multiple shock compression of solid \( \text{Li} \) and \( \text{Na} \) shows “dielectrization” of these elements. Theoretical estimations of the dielectrization pressure range for some elements at ultramegabars are presented and compared with the experiments.

The “plasma” phase transition phenomena are analysed on the base of shock experiments and quantum Monte-Carlo simulations.
Analytical linear theory of propagation of inhomogeneities in two plates system.

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ABSTRACT.

In this work collision process of iron impactor with velocity 5 km/s and aluminum target are considered. Initial field of density non-uniformities is existed in impactor, perturbations of pressure are absent, i.e. there is initial field of entropy wave in the target. The Mie-Gruneisen equation of state is applied for all materials. Initial perturbations of hydrodynamics values aluminum plate are absent.

Shock wave propagates in plate after impact, and perturbations generates after its front. They connect with initial inhomogeneities of impactor. The breakup of shock wave on material boundaries and multiple wave reflection accompany this process. The approach similar to [Dyakov, 1954] is used in this work. It consists of small parameter linearization of hydrodynamic equations and further interpretation of inhomogeneities field like a set of sound and entropy-vortex waves.

In this work we considered first and second order of small-parameter expansion. In the second order is showed that small-parameter expansion approach is incorrect in some initial entropy wave incident angles areas.

Also numerical calculations of this task on complex of applied programs TIS are considered. This complex designed for numerical calculations of solid state deforming mechanical and hydro-gasdynamics. Numerical scheme is physical processes separation and movable Euler meshes.

REFERENCES

Consideration of elastic properties in laser-induced shock-wave propagation in nickel

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ABSTRACT

Ultrashort shock waves in nickel films generated by femtosecond laser pulses were studied using two-temperature hydrodynamics with consideration of elastic properties of material. The results of simulations were compared with experimental data [1] on maximum rear surface velocity and extension and with MD simulations [2]. It is shown that consideration of elastic properties of nickel lead to a good agreement with experiment and MD simulations whereas pure hydrodynamic simulations lead to significantly later and much larger rear side displacements.

REFERENCES

Quartz standard for Equation of State experiments: Recent Advances and Implications for ICF

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ABSTRACT

Megabar shocks waves in warm dense fluid Silica (SiO2) can be accurately tracked by interferometric Doppler velocimetry (VISAR) and self-emission pyrometry (SOP). The extensive 12éterminatio dataset available on shocked SiO2 enables its use as a standard for Equation of State (EOS) measurements. In the past 12éterm, the quartz standard has been used to produce high quality, high accuracy data on a wide variety of materials using lasers or magnetically accelerated flyer plates. In addition, the shock-front self 12étermin and 12étermi reflectivity have also been absolutely calibrated allowing the use of SiO2 as an in-situ reference. However, as our understanding of warm dense fluid SiO2 improves, some of the data referenced to quartz need to be revised.

We will review 12éterm advances on our understanding of the quartz standard and the important implications for the 12étermination of important properties of materials used in current and proposed ICF designs such as CH polymers and Hydrogen.
The preliminary simulation of magnetically driven loading processes for equations of state of materials

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ABSTRACT.
A large magnetic field is produced in the region of a short circuit load, i.e. the gap between the anode and cathode, as the intensified current pulse is flowing through it. If the magnetic pressure is exerting on a drive plate, a pressure wave is created and transferred into the sample, in which an isentropic compression is caused. If it is exerting on a flyer plate, the flyer plate is accelerated up to a high velocity, and intended to collide with a target for material equation of state and/or impact dynamics research. That is magnetically driven loading technology. The primary Test Stand (PTS, 8-10MA, ~90ns) for Z-pincho studies is under testing and will shortly be used in wire-array implosion, as well as in isentropic compression and flyer plate acceleration. It is necessary to develop the ability to simulate the magnetically driven loading processes, and to study the magnetic field evolution processes.

First based on the quasi-stationary magnetic field theory, the magnetic fields was calculated in the gap, and then the configuration of the short circuit load might be determined according to the magnitude and uniformity of the magnetic field on the drive plate or flyer plate. For the square configuration of the electrodes, the magnetic field on the drive plate is in proportion to the linear current density. Then it can be calculated and used as a boundary condition of magnetic field evolution. The pressure wave, caused by the Lorentz force \( \mathbf{j} \times \mathbf{B} \), transported in the drive plate, and then into the sample to produce isentropic compression. The processes can be simulated by means of Zeus-2D code. The obtained results reveal that a shock wave will develop in the sample for a certain current with the increase of total thickness of the drive plate and sample. So the thickness of the sample need accurately designed.

In the process of flyer plate acceleration, the drive current is flowing through the plate all the time. The drive magnetic field on the flyer plate would be obviously affected by the motion of the plate. For the square configuration of the electrodes, the simulation domain of the flyer plate acceleration in 2D is a quarter of its cross section. It includes the cathode, flyer plate, the space, through which the plate is accelerated, and the anode. The circuit equation is coupled to the MHD calculation. Thus the drive magnetic field was self-consistently solved. The simulated results show that the distribution of the magnetic field agree roughly with calculated result based on the quasi-stationary magnetic field theory, and that the flyer plate is accelerating, while the cathod is squeezed. In the future, more effort would be needed in the accurate electrode equation of state, the calculation of the magnetic vector potential, and the electric resistivity of the flyer plate for better results.

For deeply understanding the process of magnetically driven loading, it is necessary to know the physical mechanism of magnetic field evolution and its influence factor, as well as the trend in the evolution with the increase of drive current.

REFERENCES
DFT calculation of reflectivity from dense xenon plasma flat surface

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ABSTRACT

Reflectivity is calculated from the front of strong shock wave in xenon for the conditions of the unique measurements \cite{1-3}, the satisfactory theory for which is not yet available. The reflection coefficient is calculated by the Fresnel formula. The imaginary part of the dielectric function is evaluated using the Kubo-Greenwood formula. The real part is obtained by the Kramers-Kronig transformation. Quantum molecular dynamics simulation and VASP are used as in \cite{4}. However as opposed to Desjarlais, some improvement of the formalism is introduced. The better agreement with the results for the wavelength 1064 nm \cite{1} is obtained for both absolute values and density dependence. No arbitrary width correction of the energy gap between bound and free states like in \cite{4} is made. Additionally to \cite{4}, wavelengths 532 and 695 nm are also treated. The average discrepancy between the calculated and measured values in all the 16 experimental points for the whole range of the densities and wavelengths studied is about 4\%. The value of the discrepancy reaches several times only for 3 points (1064 nm, 0.51 g/cm\textsuperscript{3}), (694 nm, 0.53 g/cm\textsuperscript{3}) and (532 nm, 1.1 g/cm\textsuperscript{3}) at the border of the experimental range studied. However the discrepancy is of such an irregular character that one is able to interpret it as an uncertainty of the measurement. The dependencies of the reflection coefficient on an incident angle are calculated and compared with the experiment \cite{3} as well. Contrary to \cite{5,6} it is assumed in all the calculations, as in \cite{4}, that the shockwave front has no width, what is similar to the experimental conditions.

REFERENCES

Stochastic dislocation dynamics and renormalization group

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ABSTRACT.

For the description of dislocation dynamics under shock wave loading of solids the model based on KPZ SPDE with random scalar field associated with dislocation density is suggested. We choose the Gaussian distribution of noise. The two points correlator of noise is chosen in turbulent form (power law). Such choice is motivated by the fact that the dislocation system is far from equilibrium. Beta functions of parameters of the system are computed in one loop approximation. Critical exponents are also determined at the fixed points and are computed in one loop approximation in Wilson's epsilon expansion method. We describe the phase diagram of the system that depends on space-time dimensionality and parameters of two points noise correlation function. We also discuss the effective potential of the system. The appearance of condensate and emergence of none perturbative scale parameter (dimensional transmutation) are demonstrated. Besides of direct interest associated with the dislocation dynamics description this system is an interesting toy model for the turbulence.
The effect of approximation to evaluate atomic-configuration probabilities on ionization balance and opacities of dense plasmas.

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ABSTRACT

Average-atom models enable one to simulate thermodynamic, optical, and transport properties of pure elements and mixtures in a wide range of temperatures and densities on the same theoretical footing [1]. Among those, a model formulated by D.A. Liberman [2] is known to be one of the most advanced average-atom models and therefore is widely employed in practice. Starting from Liberman’s model, we developed a RESEOS code [3] that was originally intended for the calculations of equations of state. Recently, the RESEOS code has gained a capability of calculating LTE-plasma opacities in the context of the proposed generalization of the superconfiguration approach [4]. This generalization enables one to effectively allow for the occupation-number fluctuations of some atomic subshells when the detailed accounting of those is not much significant.

We compare ion-charge distributions and opacities calculated with the atomic-configuration probabilities utilizing either zeroth-order average configuration energies (found by summing over all one-electron energies of the relevant orbitals), or those additionally allowing for the first-order electron-electron corrections.

The comparisons show that the use of a single orbital-energy set for the zeroth-order configuration energies of all ionic species of a given chemical element (being equivalent to the binomial distribution for configuration probabilities) overestimates the widths of ion-charge distributions at relatively low temperatures. At low material densities, this is likely to lead to incorrect values of monochromatic and Rosseland mean opacities. Plasma-density effects however improve the quality of the binomial distribution for the opacity calculations.

REFERENCES

Isentropic compression of dense hydrogen

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ABSTRACT

We perform ab initio calculations for the equation of state of dense liquid hydrogen and deuterium using quantum molecular dynamics simulations based on finite-temperature density functional theory. This extensive data set allows us to determine specific density-temperature tracks which are essential for the analysis and interpretation of high pressure experiments. In particular we calculate the cold curve, the principal Hugoniot curve, Hugoniot curves for precompressed states, and isentropes [1]. Especially, we report on extreme conditions that have been probed in recent quasi-isentropic shock compression experiments [2-5]. Important effects such as dissociation and the subsequent nonmetal-to-metal transition have to be treated adequately in this context. High pressures up to the multi-Mbar region are also relevant for the deep interior of Jupiter, Saturn and of Jupiter-like exoplanets. Based on our ab initio data we give new predictions for the isentropes of such planets. These results will motivate proposals for new compression experiments at the National Ignition Facility (Livermore), the Linear Coherent Light Source (Stanford), the future European X-ray Free Electron Laser (Hamburg) or other high-pressure platforms where such extreme states of matter can be probed.

REFERENCES

Thermodynamic functions of the heated electron subsystem in the field of cold nuclei

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ABSTRACT.

The paper presents electronic heat capacities and thermal pressures calculated for aluminum and tungsten at densities in the case when the temperature of electrons is finite (a few electron-volts) and nuclei are cold. Calculations were done with the all-electron full-potential linear muffin-tin orbital method (FP-LMTO) and compared with data obtained with the Liberman’s average-atom model and the Vienna Ab-initio Simulation Package code (VASP) which uses pseudopotentials. It is shown that results obtained with different approaches qualitatively agree within the ranges of electron temperatures and densities under consideration, and quantitatively agree within 10% in most cases. A detailed analysis of the obtained results is presented.
Atomistic simulation of defects formation in nuclear materials by swift heavy ions.

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ABSTRACT

At moving of the swift heavy ion (e.g. Xe ion - the typical fission fragment), the defect formation takes place in nuclear materials. The heavy ion creates defects by way of elastic nuclear collisions and through the interaction with electron subsystem [1-3]. There is a large interest in understanding of the mechanisms of defect formation. In this work, the atomistic simulation of defect formation due to the swift heavy ion irradiation is performed for various nuclear materials (U, U-Mo, UO\(_2\)). The two-temperature atomistic model with explicit account of electron pressure and electron thermal conductivity is used [3]. This two-temperature model describes ionic subsystem by means of molecular dynamics while the electron subsystem is considered in the continuum approach. The interaction between ions is simulated by the developed interatomic potentials [4, 5] The various mechanisms of defects formation are examined. The radiation track in bulk forms as the large accumulation of defects in investigated materials. However the surface track forms like ablation process. The comparison to the experimental data is performed.

REFERENCES

Two-temperature thermal conductivity of warm dense aluminium and gold.

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ABSTRACT.
Warm dense matter (WDM) can be attributed to the state of matter at near-solid densities and temperature between 1 eV and 100 eV. Theoretical modeling of WDM is extremely difficult due to electron degeneracy and strong ion-ion coupling. It cannot be modelled either as classical plasma or solid. Nevertheless a large number of studies showed that density functional theory (DFT) can be successfully applied to simulate characteristics of WDM (e.g. see \cite{1}). The calculations of thermal conductivity in metals with hot electrons (temperature of electrons is significantly higher than the temperature of ions) are conducted in \cite{2,3}. The necessity of evaluation of thermal conductivity with hot electrons comes from femtosecond laser physics \cite{4,5}. The laser energy is absorbed by the electrons during the laser pulse. They are heated to a few eV or higher. Then the energy is transferred from the hot electrons to the ions. The mass of the electron is substantially less than the mass of typical ion therefore the relaxation in electronic subsystem occurs much faster than relaxation between hot electrons and ions. Thereby one can consider both electronic and ionic subsystems to be in the state of thermodynamic equilibrium and the system can be represented consisting of hot electrons and cold ions. The simulation of laser interaction with the metal target is carried out at two-temperature approximation. These simulations require the thermal conductivity, which depends both on the electron temperature and the ions temperature. The calculations became complicated because the heating of electrons transforms the electronic structure, which in turns leads to a change in the physical properties of the material \cite{4-6}. In this paper ab-initio calculations of the thermal conductivity of aluminum and gold via Kubo-Greenwood formula in the two-temperature case is carried out. The advantage of this approach over the methods developed in \cite{2,3} is the absence of fitting coefficients and the ability to go beyond the approximation of the ideal Fermi-Dirac gas, which allows to calculate the thermal conductivity of d-metals \cite{7}.

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Convergent ablation experiments in gas-filled rugby hohlraum with uniform and laminated ablators

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ABSTRACT.

The nominal design for implosion experiments with the Laser MegaJoule (LMJ) relies on a rugby-shaped hohlraum, which present significant advantages in terms of LPI mitigation [1], coupling efficiency and symmetry control with a 1/2-1/2 energy balance [2]. The increased x-ray flux on capsule in rugby hohlraum compared to a classical cylindrical hohlraum was moreover confirmed by enhanced nuclear performances and more ablated mass [3]. It is nevertheless important to acquire convergent ablation measurements [4] to assess the implosion velocity, key metric for implosion performance. Convergent ablation experiments with gas-filled rugby hohlraums were therefore performed for the first time on the OMEGA laser facility. A time resolved 1D streaked radiography of capsule implosion is acquired in the direction perpendicular to hohlraum axis, whereas a 2D gated radiography is acquired at the same time along the hohlraum axis on a x-ray framing camera. The implosion trajectory has been measured for various kind of uniformly doped ablators, including germanium-doped and silicon-doped polymer (CH), at two different doping fraction (2 % et 4 % at.). It has in fact been emphasized that Si-doped ablators are more efficient than Ge-doped ones at NIF scale [5]. Our experiments aimed also at comparing the implosion performance of uniformly doped and laminated ablators [6]. A laminated ablator is constituted by thin alternate layers of undoped and doped CH. It has been previously demonstrated in planar geometry that laminated ablators could mitigate Rayleigh Taylor growth at ablation front [7]. Our results confirm that the implosion of a capsule constituted with a uniform or laminated ablator behaves similarly, in accordance with post-shot simulations performed with the CEA hydrocode FCI2.

REFERENCES

Hotspot ignition criterion of inertial confinement fusion

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ABSTRACT.
Inertial confinement fusion (ICF) is an approach to fusion by using the inertia of the fuel mass to provide confinement, which is possible to be realized in the laboratory. In indirect drive hotspot ignition scheme, a capsule is imploded by the radiation field converted by laser energy in hohlraum. Then, hotspot can be formed and ignition can be achieved. Ignition criteria such as ignition threshold factor (ITF)\(^2\), generalized Lawson criterion (GLC)\(^3\) and experimental ITF (ITFX)\(^4\) have been presented to predict the ignition status and evaluate target performance, and have been applied in current target designs\(^5\). In this report, we note that the radiation free path is usually smaller than the thickness of high density fuels and bremsstrahlung radiation energies deposit in the shell to heat the fuel. Through simple derivation based on the hotspot dynamic model of S. Atzeni\(^6\), we can analytically define the time from stagnation to ignition and a criterion composite of hotspot areal density, fuel areal density and hotspot ion temperature. The exponents of the criterion are determined by fitting a number of simulations of assembled targets (as shown in Fig.1). Our criterion has been used to characterize the target performance in target parameter optimization (as shown in Fig.2).

![Fig.1 The criterion fitting result](image1)

![Fig.2 Evaluating target performance.](image2)

REFERENCES
A new ignition scheme using hybrid indirect-direct drive for inertial confinement fusion.

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ABSTRACT.

Recently, the National Ignition Facility (NIF) is able to deliver 1.9 MJ of 0.35-μm ultraviolet light at 500 TW. However, the National Ignition Campaign (NIC) experiments on it are facing challenges. Besides laser plasma instabilities (LPI), two major issues in implosion dynamics exist: (1) a strong rarefaction wave generated from the radiation ablating region seriously decreases the ablation pressure and limits the ability of increasing implosion velocity; (2) hydrodynamic instabilities are more severe than predicted causing hot spot asymmetry and material mixing.

In this report, a new hybrid indirect-direct-drive ignition scheme is proposed: a cryogenic capsule encased in a hohlraum is first compressed by indirect-drive x-rays, and then accelerated and ignited by both direct-drive lasers and x-rays. The hybrid drive can create a double-ablation-front structure (consisting of a radiation ablation front and an electron ablation front) and a higher density plateau is newly formed between the two ablation fronts, which reduces the rarefaction at the radiation ablation front and greatly increases the drive pressure. As compared with conventional indirect drive, numerical simulations show that the hybrid drive can implode the capsule with a higher velocity (~4.3 x 10⁷ cm/s) and a much lower convergence ratio (~25). It is also found that the hybrid-drive scheme is insensitive to the intrinsic low-mode drive asymmetries, and more importantly, it features low level of hydrodynamic instability growth, which benefits target fabrication and ignition robustness. Laser plasma instabilities need to be investigated in the future.

Fig. 1: Schematic of the hybrid-drive ignition target configuration

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The modification of ignition threshold factor due to the low-mode shell areal density asymmetry.

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ABSTRACT.

The work investigates the low-mode areal density asymmetry of the main fuel in the ignition capsule implosions. A suite of 200 two-dimensional simulations with radiation flux asymmetry are run with the radiation hydrodynamic code LARED-S, and the simulation results make up a data base for the study. It is found that the low-mode drive asymmetry could leading to large areal density variation of the main fuel, and the areal density asymmetry may be a major contributor to performance degradation. It is because that large areal density perturbation can break up the capsule shell and significantly reduce the temperature and stagnation pressure of the hot spot. In the low-mode asymmetric cases especially P2 mode, there is no direct correlation between the perturbations of areal density and hot spot boundary. So the hot spot shape term of the ignition threshold factor could not adequately represent the areal density perturbation. A modification of the ITF formalism is carried out, and a term of the low-mode areal density perturbation fraction is introduced into the formalism. By scaling the data base of the marginal capsules, the power law of the areal density perturbation term is determined. The modified ITF formalism can more effectively characterize the margin of the capsule designs.

REFERENCES

Hydrodynamic simulation of two symmetrically converging plane thermonuclear burn waves

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ABSTRACT
Two approaches to inertial confinement fusion are well-known. The first is based on loading of a target by a single driver providing sufficiently high values of density and temperature [1]. Under such approach, the burn wave arises in the target volume. The second so-called fast ignition approach is based on using two drivers [2, 3]. The first driver compresses the target up to the density of about \(10^3 \rho_s\), where \(\rho_s\) is the normal density of the solid fuel, while the second driver provides for fast rise of temperature. In this case, the burn wave arises near the target boundary and propagates inside the target. Laser-accelerated beams of electrons [3] and protons [4, 5] as well as heavy ion beams [6] are considered as a driver for the fast heat of the high-density fuel. Both theoretical estimates and simulation results show that burn waves propagating inside the target are possible for certain values of beam parameters.

In the present work, we study 2 symmetrically converging plane burn waves at relatively small values of initial density \(\rho_0 = \rho_s\) and \(5\rho_s\). The 1D problem on simultaneous symmetrical action of 2 identical laser beams on a plane layer of DT fuel [7] is considered. The sufficiently large value of the layer half-width \(H = 5\) cm is chosen, so that \(H\rho_s \approx 1\) g/cm\(^2\). For the problem, one can obtain the burn wave propagating inside the target using the model of total absorption of laser radiation in the point with the critical density that is without taking into account the epithermal particles, which heat the domain of supercritical density. It is necessary to choose the sufficiently large intensity \((5 \cdot 10^{15}\) W/cm\(^2\)) and action time \((400\) ns) of laser radiation to reach the ion temperature in the target corona of about \(20\) keV and the sufficiently small laser wavelength \((0.25\) μm) to avoid too small density of the corona. Note also that in all our computations the target ignition occurs only after at least the first arrival of the shock wave reflected from the symmetry plane to the ablation front.

The equations of 1-velocity 2-temperature hydrodynamics are considered. The equation of state of hydrogen is used. Electron and ion heat conduction, self-radiation of plasma, and plasma heating by laser radiation as well as by α-particles are taken into account.

In our simulations, either of the two burn waves moving to the symmetry plane generates before itself the compressing velocity profile with the slope angle increasing in time. As a result, the relatively cold fuel before the wave is rapidly compressed up to \(50\rho_s\) and \(500\rho_s\) at \(\rho_0 = \rho_s\) and \(5\rho_s\), respectively. One can assume a similar property of converging burn waves in cylindrical and spherical geometries.

REFERENCES
On inertial electrostatic confinement fusion based on nanosecond vacuum discharge

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ABSTRACT

The generation of energetic ions and DD neutrons from microfusion at the interelectrode space of a low energy (~ 1 J) nanosecond vacuum discharge with deuterium-loaded Pd anode has been demonstrated earlier [1]. To understand better the physics of fusion processes the detailed particle-in-cell (PIC) simulation of the discharge experimental conditions have been developed using a fully electrodynamic code KARAT [2]. The principal role of a virtual cathode (VC) and the corresponding single and double potential well formed in the interelectrode space are recognised. The calculated depth of the quasistationary potential well (PW) of the VC is about 50-60 kV, and the D⁺ ions being trapped by this well accelerate up to energy of few tens keV that provides DD nuclear synthesis under head-on D⁺ collisions (the partial review of experimental data and modelling results related are presented at [3]). PIC modeling allows to identify the scheme of small-scale experiment [1] with a rather old branch of plasma physics as inertial electrostatic confinement fusion (IECF) (see [2-4] and refs therein). In particular, ions in the potential well may undergo high frequency (~80 MHz) harmonic oscillations accompanied by a corresponding regime of oscillatory DD neutron yield. This value of high frequency ion oscillations observed coincides with extrapolation of expressions obtained for IECF scheme with periodic oscillating plasma spheres (POPS) [4]. At the chosen scheme of IECF based on miniature vacuum discharge [1,2] we have very small size of VC, r_VC ~ 0.1 cm, and rather deep PW like ϕ ≈ 50 kV. Thus, both PIC simulations and experiment [3] illustrate efficient scaling of the fusion power density (~ ϕ²θ²/r⁴_VC) under decreasing of r_VC [4] (θ - compression level of ions subsystem). Remark, the anode erosion may provide the partial fulfillment of PW by deuterium clusters also (interelectrode ensembles). The total trapping of fast ions D⁺ by cluster ensembles observed in experiment would increase the neutron yield essentially (up to ~ 10⁷/4π) [1,2]. Meanwhile, at very initial stage of discharge when the voltage is applied and autoelectron beam extracting from cathode irrigates the surface of porous deuterium-loaded Pd anode, the limiting case r_VC → 0 accompanied by DD syntheses is realizing also (integrated multichannel microreactor) [3].

REFERENCES
Thermal conductivity measurements at CH/Be interface under ICF-relevant conditions by refraction-enhanced x-ray radiography

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ABSTRACT.

Transport properties near the fuel-ablator interface at the edge of an ICF capsule are important for modeling the growth of hydrodynamic instabilities, which determines the mix level in the fuel and thus is critical for successful ignition [1]. A novel technique, time-resolved refraction-enhanced x-ray radiography, is developed to study thermal conductivity at the interface [2]. Experiments using OMEGA laser have been carried out for CH/Be targets isochorically heated by x-rays to measure the evolution of the density gradient at the interface due to thermal conduction. The sensitivity of this radiographic technique to discontinuities enabled observation of shock/rarefraction waves propagating away from the interface. The radiographs provide enough constraints on the temperatures, densities and scale lengths in CH and Be, respectively. Preliminary data analysis suggests that the thermal conductivities of CH and Be at near solid density and a few eV temperature are higher than predictions by the commonly used Lee-More model. Detailed analysis and comparison with various models will be presented.

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.

REFERENCES

Numerical Modeling of the Sensitivity of Indirect Drive Inertial Confinement Fusion Implosions to Low-Mode Flux Asymmetries

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ABSTRACT.

The sensitivity of inertial confinement fusion implosions, of the type performed on the National Ignition Facility (NIF) \cite{1}, to a low-mode flux asymmetry described by the Legendre polynomial $P_4$ is investigated numerically. It is shown that large-amplitude, low-order mode shapes, resulting from low-order flux asymmetries, cause spatial variations in capsule and fuel momentum that prevent the deuterium and tritium (DT) “ice” layer from being decelerated uniformly by the hot spot pressure. This reduces the transfer of implosion kinetic energy to internal energy of the central hot spot, thus reducing the neutron yield by up to a factor of 15. Furthermore, synthetic gated x-ray images of the hot spot self-emission are used to show that $P_4$ shapes were unquantifiable for DT layered capsules using the (then) existing NIF diagnostics. Instead the positive $P_4$ asymmetry “aliases” itself as an oblate (or “pancaked”) $P_2$ in the x-ray images – a feature observed in many NIF implosions. Simulations are used to demonstrate that correction of this apparent $P_2$ distortion by applying additional flux at the capsule equator \cite{2} can create a highly distorted fuel configuration while the resultant x-ray self-emission images appear both round and self-consistent from both orthogonal experimental diagnostic directions, giving the false impression that the implosion is spherical.

New diagnostics have recently been fielded on the NIF using an X-ray backlighter to reveal the shape of the cold, dense fuel. As predicted by these simulations, these backlit NIF implosions showed that a large $P_4$ asymmetry was occurring in tandem with “excessive” equatorial drive causing the implosion to be prolate (or “sausaged”), while the image from the hot spot X-ray self-emission was near round.

Simulation indicate that long wavelength asymmetries may be playing a significant role in the observed yield reduction of NIF DT implosions relative to detailed postshot two-dimensional simulations.

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A physical system to study nonlinear coupling between laser radiation and matter under extreme conditions.

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ABSTRACT.

During the implosion of a target in the ignition confinement fusion (ICF) scheme, various physical processes take place, including both creation of warm dense matter (WDM) and strong nonlinear coupling between laser radiation and matter, possibly leading to parametric instabilities [1]. The understanding and modelling of these physical processes is important to control the ICF. In order to improve our knowledge of these processes, a physical benchmark system and the associated theoretical and numerical studies are proposed [2].

This physical benchmark system consists of the interaction of a dielectric nanoparticle, embedded in the bulk of a transparent material, with an intense and short laser pulse. Due to the finite size of the target and the possible large production of electrons in the conduction band, large electric field enhancement may be induced inside the particle [3,4]. Since ionization rates also depend on the instantaneous electric field, a strong time-dependent connection between electron production and field enhancement may take place. Such a connection is shown to possibly lead to a nonlinear temporal increase in the free electron density relevant from an avalanche process, called optical avalanche, similar to the one induced by electron impact ionization. However, the present build-up in the electron density clearly exhibits more nonlinear features than traditional collisional avalanche which induces an exponential growth of the density: when the optical avalanche is engaged, the temporal electron evolution exhibits an explosive behavior.

This physical benchmark system may induce a plasma at solid density whose laser heating may lead locally to matter under extreme conditions relevant from WDM. Nonlinear coupling between laser radiation and matter may further take place under such conditions.

REFERENCES

The first data from the Orion laser; measurements of the spectrum from hot dense plasma.

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ABSTRACT.

The newly commissioned Orion laser system has been used to study dense plasmas created by a combination of short pulse laser heating and compression by laser driven shock, using the nanosecond and sub-picosecond laser beams available at the facility. The plasma density was systematically varied between 1 g/cc and 10 g/cc by using aluminium samples buried in plastic or diamond sheets. The aluminium was heated to electron temperatures between 500 eV and 700 eV allowing the plasma conditions to be diagnosed by emission spectroscopy of the aluminium K-shell. These were inferred from comparison with a variety of codes, including FLY and FLYCHK spectra and from radiation-hydrodynamic simulations. The time-resolved aluminium X-ray emission was recorded using a spectrometer coupled to an ultrafast X-ray streak camera, with additional time-integrated spectrometers recording onto image plate. By using different materials to tamp the aluminium and shock compression to alter the sample density, a systematic study of the change in the aluminium spectrum with density was carried out. The K-shell spectra show evidence of the lowering of the ionization potential, where the data are in reasonable agreement with FLY and FLYCHK when using the standard treatment of ionization potential depression proposed by Stewart and Pyatt. The data have also been compared to more sophisticated models and the results are presented.
The Vishniac instability in supernova remnants revisited

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ABSTRACT.

The so-called Vishniac instability (VI) has been discovered theoretically by Ethan T. Vishniac in 1983 [1] and it has been developed more accurately in a further work published in collaboration with Dongsu Ryu four years later [2]. According to these papers, the VI corresponds to the growth of a deformation, up to its disruption, of the front of a blast wave, produced by a supernova, that propagates in the circumstellar medium and the interstellar medium. This instability (actually named “overstability” after Vishniac) is therefore supposed to take place in supernova remnants (SNR), however, in opposition to Rayleigh-Taylor instabilities (RTI) that occur in SNR also, astronomical observations have not yet clearly evidenced VI. In addition, the latest numerical simulations, including the calculation of the time evolution of the nonlinear regime of the VI, did not show either strong deformations of the blast wave or disruptions of its front [3]. On the other hand, although recent experiments achieved on laser facilities about VI have produced unstable blast waves [4], the experimental growth rates do not really correspond to Vishniac – Ryu theoretical predictions. As a consequence, the existence of the VI may still appear questionable. For these reasons, a first theoretical clarification to this problem has been performed [5] and the situation does not look so obvious. As expected, for accelerating blast waves, the shell experiences RTI and the growth rate varies like the square root of the mode, $l$, for $l$ large enough. Nevertheless, in the opposite case (decelerated blast wave) RTI occur too due to internal unstable modes and, in both situations, it is difficult to distinguish RTI and VI because the growth rates might have the same order of magnitude. The work presented in this conference is an extension of [5] including small modes behaviors in the limit $l=0$ (radial modes) and the results shown in [1-2] are not recovered. We also do not obtain those derived in 2005 by Kushnir et al. [6] although these authors have revisited VI and they do not agree with Vishniac - Ryu calculations.

REFERENCES

Formation of radiatively cooled, differentially rotating, supersonic plasma flows in z-pinch experiments.

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ABSTRACT.

The aim of this work is to develop an experimental platform from which to study high energy density plasma phenomena relevant to astrophysical accretion disks. The approach taken is complementary to laser driven work proposed by Ryutov [1] and builds upon our previous experience inducing rotation in z-pinch systems [2].

To form rotating plasma the experiment makes use of ablation flows from a cylindrical wire array z-pinch. The toroidal magnetic field generated by current flowing through the array drives the wire ablation towards the array axis. The current is also passed through opposing coils above and below the array generating a cusp magnetic field at the wires. The radial component of the cusp field produces an azimuthal component of the Lorentz force which introduces angular momentum to the system.

Results from the first experiments in this configuration on the Imperial College MAGPIE (1.5MA, 250ns) will be presented. Using multi-frame optical and XUV cameras we observe the formation of a hollow rotating disk ~3mm diameter. Laser interferometry was used to measure the plasma density distribution (~10¹⁸ cm⁻³). Analysis of the Thomson scattered spectrum provides information on the disk temperature and velocities (~45kms⁻¹); measurements of the radial profile of the rotation velocity showing evidence for differential rotation. The results are compared with numerical simulations of this experimental configuration [3] produced using the GORGON code.

REFERENCES

Similarity properties and scaling laws of astrophysical radiation hydrodynamic and magnetohydrodynamic flows

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\textbf{ABSTRACT.}

The magnetic field plays an important role in astrophysical environments and is the source of many physical processes encountered in various high-energy astrophysical environments \cite{1,2} (reconnection, accretion \ldots). The capability to produce in laboratory radiation hydrodynamic flows submitted to intense magnetic fields is a real opportunity in order to progress in their modelling. The similarity properties of these plasmas have already been the subject of different works \cite{3,4,5}. In this work we propose to extend the study of the similarity properties and the development of scaling laws to new regimes of radiating magnetized plasmas. We also discuss the possibility to produce flows similar to astrophysical ones in laboratory with current powerful facilities.

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Radiation hydrodynamic accretion flows in magnetic cataclysmic variables: theoretical models, numerical simulations and laser experiments

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ABSTRACT.

Magnetic cataclysmic variables are binary systems containing a highly magnetized white dwarf which accretes matter from a late type Roche-lobe filling secondary star [1]. The presence of intense magnetic field, radiation and hydrodynamics implies a rich range of behaviors at different spatial and time scales. The radiation collected from these objects mainly comes from an unresolved area near the white dwarf surface, named the accretion column. Thus, the possibility of reproducing these phenomena in laboratory is a real opportunity to increase our understanding of the physics of accretion processes [2,3]. In this work we will review the theoretical, numerical and experimental progress which has been made recently on the physics of accretion shocks in magnetic cataclysmic variables.

REFERENCES

New similarity concepts for high-energy density physics: Application to radiation hydrodynamic flows

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ABSTRACT.

The study of similarity properties of high-energy density flows is a fundamental problem of laboratory astrophysics. Recently the similarity properties of radiation hydrodynamic flows have been studied\cite{1,2} and different scaling laws have been developed. These studies are based on the homothetic and dimensional groups which are specific symmetric group. In this works we propose to use other symmetry properties of radiation hydrodynamics flows \cite{3,4} to define new scaling laws. We apply the different similarity concepts on astrophysical radiation hydrodynamic flows (radiative shocks and ablative waves). Numerical simulations will be presented in order to illustrate the theoretical results.

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\end{itemize}
Simulation of laser produced radiative shock waves

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ABSTRACT.

We present a study of laser produced radiative shocks in a Xenon gas made with the 2D simulation code ARWEN \cite{1}. The time evolution of the plasma is computed using a conservative multimaterial hydrodynamic method while we use a multigroup radiation transport package to get the plasma radiative properties. Finally we include an adaptive mesh refinement scheme that allows us to obtain high resolution where the properties change more abruptly.

Also we will present recent developments in the calculation of equation of state and opacity tables suitable for including in simulation codes to study laboratory astrophysics as well as other processes like ICF and FI or X-ray secondary sources. We have improved the original QEOS model \cite{2} to fit the available experimental data and molecular dynamics simulations. For opacity calculations we use the code BiGBART \cite{3} in LTE conditions, with self-consistent data generated with the Flexible Atomic Code. Non-LTE effects can be approximately taken into account by means of the improved RADIOM model \cite{4}, which makes use of existing LTE data tables.

REFERENCES

Interaction of the Type Ia Supernovae ejecta with a secondary star orbiting in a compact orbit

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ABSTRACT

Nowadays we do not really know what the nature of the progenitor of Type Ia supernovae is. One of the preferred scenarios invokes an exploding white dwarf located in a binary system. This work presents the simulation of some aspects of the interaction between the Supernovae ejecta and the secondary star in the laboratory:

• Are the gross features of the interaction similar to that of large scale astrophysical simulations?

• Analyze the hydrodynamics around the hole that is created in the ejecta because of the shielding effect of the secondary star (usually a sun like star).

• Analyze the gross features of the geometry of the ensuing supernova remnant. What is the impact of the hole on the remnant geometry?

The basic setting of the experiment could be similar to that of Kang et al. (2001) but using a two-density solid sphere located on the rightmost part of the box. As the real averaged velocity of the supernova ejecta is ~8500 km/s and the achieved velocity in the lab. is more than a factor ten lower the results will be qualitative but still useful to interpret the large scale simulations.

For the simulations, we use our own code ARWEN, a 2D AMR multi-material radiation fluid dynamic code.

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ABSTRACT.

The aim of the POLAR project is to simulate, in the laboratory, the accretion shock region of a binary system of a late sequence star transferring matter to a highly magnetised (B~10-230 MG) white dwarf. Investigation into hydrodynamic scaling laws¹ have shown that laboratory experiments can be related to astrophysical phenomena by matching particular dimensionless parameters. These assure that the physical properties that describe viscous transport, magnetic field diffusion, thermal diffusion and radiation are equivalent in both the laboratory and astrophysical systems.

The POLAR experiment at Orion will utilise high intensity laser pulses, ~3,500 TWcm², to drive a flow of plasma down a tube which will impact on a quartz obstacle. In the region behind the obstacle, a reverse shock will form, which will be probed with multiple diagnostics available on the Orion system; including DANTE, X-ray Thomson Scattering and X-ray Radiography, to extract values for electron temperature, density, shock velocity etc.

We have performed both 1D and 2D radiative hydrodynamics simulations to predict the properties of the plasma flow and then construct synthetic images of the predicted diagnostics results. Comparison with previous experimental data will also be briefly discussed.

REFERENCES

Cosmic shocks and magnetic fields: an experiment at GEKKO

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ABSTRACT.

Understanding the creation of magnetic fields in plasma shockwaves is important for explaining processes such as cosmic ray acceleration and the origin of galactic magnetic fields. As part of an on-going experimental campaign, we used the GEKKO-XII laser facility to produce shockwaves in low pressure nitrogen gas. We explored how the presence of a static background magnetic field affects the field generation mechanisms. We found that the imposition of this background field appeared to increase the magnitude of the transient shockwave-associated magnetic field.

REFERENCES

Observation of astrophysically-relevant Weibel instability in counterstreaming laser-produced plasmas

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ABSTRACT.

The Weibel instability [1,2] is among the few known processes which generates magnetic field de novo in astrophysical and laboratory plasmas. It is believed to be a key ingredient in many astrophysical systems, particularly in collisionless shocks driven by astrophysical explosions such as supernova remnants [3] and gamma ray bursts [4,5], which are in turn of interest as sites of cosmic ray acceleration. Here we present laboratory tests of this process through observations of the Weibel instability generated between two counterstreaming, supersonic, laser-produced plasma flows, conducted on the OMEGA EP laser facility at the University of Rochester Laboratory for Laser Energetics. The counterstreaming plasmas were produced with oblique irradiation of a pair of parallel CH targets by UV laser pulses (0.351 μm, 1.8 kJ, 2 ns). The Weibel-generated electromagnetic fields were probed with an ultrafast proton beam [6], generated with a high-intensity laser pulse (1.053 μm, 800 J, 10 ps) focused to >10¹⁸ W/cm² onto a thin Cu disk. The proton beam traversed the interaction region of the two ablation plumes and was detected in a stack of radiochromic film. Growth of a striated, transverse instability is observed at the midplane as the two plasmas interpenetrate, which is identified as the Weibel instability through agreement with analytic theory [2] and particle-in-cell simulations. These laboratory observations directly demonstrate the existence of this astrophysical process, and pave the way for further detailed laboratory study of this instability and its consequences for particle energization and shock formation.

REFERENCES

Radiative Shocks driven by Supersonic Magnetized Plasma Flows

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ABSTRACT.

Experimental studies of the radiative shocks formed in the interaction of the supersonic magnetized plasma flows with ambient plasma will be presented. The experiments are scalable to astrophysical flows in that the critical dimensionless numbers such as the plasma collisionality, the plasma beta, the Reynolds number and the magnetic Reynolds number are all in the astrophysically appropriate ranges.

The magnetized plasma streams [1] are created by ablation of metal foils (e.g. Al) by 1.4MA, 250ns current pulse on the MAGPIE z-pinch facility at Imperial College. The plasma flows are sustained for ~400ns, propagate with velocities of ~100km/s, have electron densities of ~10^{18} cm^{-3} and are self-collimated by the advected toroidal magnetic fields. The radiative shocks are formed in the process of collision of these flows with a target object or with a second, counter-propagating plasma stream. We find that the presence of the magnetic fields in these experiments is dynamically significant, and that the compression of the magnetic fields in the shocks noticeably affects the shock structure. The experimental results will be compared with computer simulations.

Results of experiments investigating formation and properties of radiative shocks in noble gases (Ne, Ar, Kr, Xe) at \rho \sim 10^{-5}g/cc will be also presented. The shocks propagate with velocity of ~50km/s and this velocity is supported for ~300ns. Measurements of the electron density profiles obtained using laser interferometry show the development of the well-formed radiative precursors, extending for up to ~10mm in the case of higher atomic number gases. The simultaneous measurements of the post-shock electron densities allowed determining how the effective compression in the shock and the shock width scale with the atomic mass of the gas (the rate of radiative cooling). The development of cooling instabilities in the post-shock plasma is observed in these experiments and the results will be compared with theoretical models.

REFERENCES

Studies of Magnetic Reconnection and Shocks driven by high power lasers

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ABSTRACT

Recent research of laboratory astrophysics driven by high power lasers at the Institute of Physics, Beijing is presented. Magnetic reconnection (MR) is believed to play an important role in many different plasma phenomena including solar flares, star formation, and other astrophysical events. The loop-top x-ray source in solar flares is one of the most famous observation evidences for MR model. Mega-gauss (MG) magnetic fields could be generated in hot, high-density plasmas by irradiating a solid target with high-power laser beams. During the laser pulse the magnetic field is quasi-steady and approximately “frozen” in the plasma expanding laterally. Based on this quasi-steady state of the magnetic field, we reconstruct the topology of magnetic reconnection in laboratory by using Shenguang II laser facility. The similar results of loop-top x-ray source in solar flares are observed. By applying the scaling law of magnetohydrodynamics they found the physical parameters of both systems have highly similarity. Most astronomical and astrophysical shock waves are collisionless, which means that the shocks are not formed by coulomb collisions. This paper presents our experimental as well as theoretical investigations of shock waves induced in the interaction between two counter-streaming laser-produced plasmas. Jet generation, propagation and instabilities are also observed.
Highly Radiative Shock Experiments

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ABSTRACT.

We performed laboratory experiments in connection to astrophysical phenomena, with the help of 1D and 2D laser/matter interaction radiative codes. Such experiments provide a unique opportunity to validate models and numerical schemes. Indeed shock waves are ubiquitous in astrophysics, arising in most circumstances and they are difficult to model theoretically or computationally because of important complications due to radiative effects [1]. Experiments can directly probe the shock physics and provide validation for radiative hydrodynamic codes.

During the last three years, we generated on GEKKOXII highly radiative shocks (RS) having much higher velocities than previous data obtained on LULI2000 [2, 3]. Recently, we performed a LIL experiment with up to 12 kJ on target. Here we investigated RS propagating in different gases (krypton and argon), in addition to traditional RS obtained with same conditions in xenon gas [4].

In this paper, we will present the main experimental results and the difference on the RS behavior between these experimental campaigns driven on two different lasers. The laser intensity was roughly the same between 5 x 10¹⁴ to 1 x 10¹⁵ W/cm², but the pulse durations were completely different (4 times longer on LIL). Consequently, the shock velocity recorded is almost equivalent, in the range [100-150] km/s, the radiative precursor development presents a notable different behavior. All used diagnostics are visible, like interferometry or VISAR, self-optical pyrometry, 2D snapshot imagers and so on, providing measurements of the shock and precursor velocities, temperature, electronic density an 2D shock front shape. We will compare experimental results with numerical simulations obtained by 2D radiative codes.

REFERENCES

Numerical studies on the magneto-hydrodynamical evolutions of Richtmyer-Meshkov instability

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ABSTRACT.

The Richtmyer-Meshkov instability (RMI) is of crucial importance in a variety of applications including astrophysical phenomena and laboratory experiments [1]. The RMI occurs when an incident shock strikes a corrugated contact discontinuity separating two fluids with different densities [2]. Because of the corrugation of the interface, the surface profiles of the transmitted and reflected shocks are also rippled. The RMI is driven by the vorticity left by these rippled shocks at the interface and in the fluids [3].

We have investigated the evolution of a magnetic field associated with the RMI by using two- and three-dimensional MHD simulations [4]. In terms of the field amplification, the importance of “laminar stretching” driven by the RMI at the interface is successfully demonstrated. In our single-mode analysis, an incident shock propagating through a light fluid is considered to encounter a contact surface of a heavy fluid. When the interface is spatially corrugated, the RMI takes place and a mushroom-shaped structure develops in the density profile. An ambient magnetic field is initially supposed to be uniform and subthermal. Our numerical results for various situations suggest that the RMI is an efficient mechanism of the amplification of the interstellar magnetic fields. The main conclusions are summarized below.

1. The fluid motions associated with the RMI strengthen an ambient magnetic field by many orders of magnitude. This phenomenon can be seen in a wide range of the initial parameters. The amplification factor is almost independent from the Mach number of the incident shock and the initial field direction, so that it could occur even for the cases with a weak shock and/or a small density jump. Therefore we can conclude that the RMI is a robust mechanism of the ambient field amplification.

2. The amplified magnetic field is saturated when the magnetic pressure becomes comparable to the thermal pressure after the shock heating. This is because of the suppression of the RMI through the Lorentz force of the amplified magnetic field. If the Mach number of the incident shock is larger than about 50, we can expect at least more than 100-fold enhancement of the initial field. Thus the RMI can be a promising origin of the interstellar strong fields observed at the shock of supernova remnants [5].

REFERENCES
Simulations of HED laboratory astrophysics experiments of nested jets and accretions shocks in cataclysmic variables with the FLASH code

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ABSTRACT.

In this poster, we will present 2D radiation hydrodynamics simulations using the FLASH code used to interpret recent laboratory astrophysics experiments performed on the LULI2000 laser facility. Two sets of experiments were obtained recently (POLAR and nested jets) and are discussed here.

In the POLAR project [1], we study the accretion shocks in magnetic cataclysmic variables (mCVs). These are binary systems containing an accreting magnetic white dwarf which accretes matter from a secondary star. Due to the intense magnetic field, the accreted matters is guided by the magnetic field lines and falls with supersonic velocity onto the white dwarf surface, creating a reverse radiative shock. We will present recent experiments aiming at studying the shock formation and dynamics, and compare them to simulations.

In a second experiment, we focused on the nested outflows occurring in the collimation of an astrophysical jet due to ambient media of lower density, like winds [2]. In a similar approach, the experimental results will be shown and discussed on the base of FLASH code simulations.

REFERENCES

Reverse Shocks in Colliding Magnetised Plasma Flows
Driven by Inverse Wire Array Z Pinches

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ABSTRACT.

Radiatively cooled shocks have applicability to a range of astrophysical phenomena, from the interaction of young star jets with interstellar media, to solar winds and accretion phenomena. These systems combine the physics of radiation and hydrodynamics in a non-trivial manner, and are therefore of great interest to simulate in the laboratory.

The experiments presented here utilize ablation plasma flow from an inverse wire array z pinch setup [1] at the MAGPIE facility, as a platform for studying the structure of radiative shocks in quasi 1-D geometry. Trajectories of ablation streams from individual wires of the array are controlled by wire positioning to create a parallel and sufficiently uniform flow which is directed towards planar surface obstacles. These plasma streams contain frozen-in magnetic field oriented perpendicular to the flow velocity.

The inverse wire array setup provides a good diagnostic access to measure the shock parameters. Plasma flow velocity was measured with a Thomson scattering diagnostic at several spatial positions in the upstream flow and across the shock, simultaneously with measurements of the distribution of the electron density from laser interferometry (532 and 355nm). A twelve-frame fast optical camera was used to measure dynamics of the shock formation. Miniature inductive magnetic field probes were used to diagnose the advected magnetic field in the flow.

Experiments show formation of a well-defined standing shock in the flow interacting with a planar (~5x10mm) Al foil positioned perpendicular to the flow. The measurements of the plasma parameters show a supersonic and super-Alfvénic flow in the upstream region, with plasma beta, calculated using the ram pressure of the flow, exceeding unity ($\beta\sim10$). It is observed that the shock is formed at distance of ~2mm from the foil and this large separation from the obstacle surface is consistent with support of the shock by compression of magnetic field. In some of the experiments Thomson scattering diagnostic shows in the upstream region the presence of ions reflected from the shock.

REFERENCES

High-resolution absorption spectroscopy of photoionized silicon plasma, a step toward measuring the efficiency of Resonant Auger Destruction

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ABSTRACT

A remarkable opportunity to observe matter in a regime where the effects of General Relativity are significant has arisen through measurements of strongly red-shifted iron x-ray lines emitted from black hole accretion disks. The lines are believed to originate from the photoionized plasma in the close proximity to the black hole. The spectra carry encoded information about the physical structure of the disk and thus, the black hole itself. However, decoding this unique information requires an accurate spectrum formation model. A major uncertainty in the spectral models is the efficiency of Resonant Auger Destruction (RAD), in which fluorescent K\(\alpha\) photons are resonantly absorbed by neighbor ions. The absorbing ion preferentially decays by Auger ionization, thus reducing the emerging K\(\alpha\) intensity. The RAD process has been proposed as the reason that K\(\alpha\) lines from L-shell ions are not observed in iron spectral emission from some black hole accretion disks, but the question remains why such lines are observed from silicon plasma surrounding other accretion powered objects. Are the observations different because the RAD efficiency is different, or are the differences due to the structure of the accretion flow? To help answer this question, we are investigating photoionized silicon plasmas produced using intense x-rays from the Z facility. The incident x-ray spectral irradiance is determined with time-resolved absolute power measurements, multiple monochromatic gated images, and a 3-D view factor model. The charge state distribution, electron temperature, and electron density are determined using space-resolved backlit absorption spectroscopy. These measurements are strengthened by the fact that the high spectral resolution and the narrow lines arising from the photoionized plasma enable the observation of detailed energy level structure. The measurements constrain photoionized plasma models and set the stage for future emission spectroscopy directly investigating the RAD process.

++Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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Enhanced information-reference system SPECTR-W³ for plasma spectroscopy and other applications in the EU project “Virtual Atomic and Molecular Data Center”

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ABSTRACT

The Spectr-W³ information-reference system was developed in 2001–2010 and implemented as an online Web resource [1] providing free access to the relevant factual atomic database. The information accumulated in the Spectr-W³ atomic database contains over 450,000 records and includes the experimental and theoretical data on ionization potentials, energy levels, wavelengths, radiation transition probabilities, and oscillator strengths, and the parameters of analytical approximations of electron-collisional cross-sections and rates for atoms and ions. To date, the Spectr-W³ atomic database is the largest factual database in the world, containing the information on spectral properties of multicharged ions.

In the course of implementation of the EU collaborative project “Virtual Atomic and Molecular Data Center” (VAMDC) [2,3], fully-functional direct access to the Spectr-W³ database from the VAMDC data-request portal [4] was provided. This capability was realized by creating substantially rearranged and extended version of the Spectr-W³ database and special-purpose program tools, thus enabling one to bring the requested atomic data to a unique representation in line with the international standard for atomic, molecular, and particle surface interaction data exchange XSAMS (eXtensible Schema for Atoms, Molecules, and Solids) [5,6] in a modest query processing time from the VAMDC portal.

VAMDC project was funded under “Combination of the Collaborative Projects and Coordination and Support Actions” funding scheme of the Seventh Framework Program of EU. Call topic: INFRA-2008-1.2.2 Scientific Data Infrastructure. Grant Agreement number: 239108.

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Plasma particle-in-cell simulations of pair production experiments using a high-Z target

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ABSTRACT.
Recent progress in high intensity lasers is allowing the experimental investigation of high-energy plasma phenomena under the influence of quantum electrodynamics (QED) effects [1-4]. One available example is the positron measurement carried out on a thin gold target and high intensity laser [5-7]. Aiming at the numerical investigation on such experiments, we have developed a new simulation scheme including both collective plasma dynamics and stochastic QED reactions. The developed simulation scheme consists of (1) a Particle-in-Cell scheme [8] for relativistic plasma dynamics, (2) a Conservative semi-Lagrangian scheme [9] for hard photon transport and (3) a Monte-Carlo scheme for the QED reactions. Considered QED reactions are Bremsstrahlung and pair production in a high-Z nuclear field [10]. Under experimental condition, these reactions are characterized by an extremely low transition rate and a macroscopic number of potential seed particle. Fluid description of hard photons is employed in a multi-dimensional phase space to capture the small fraction of photon emission as a continuous quantity. The QED reactions are described as momentum/energy exchange processes between plasma (super-particle), hard photons (fluid) and particle pairs (test particles). A test simulation of positron production in a thin solid target is performed by means of the developed simulation scheme. Simulation results successfully show a series of plasma and QED processes leading to positron ejection from the target. Seed particles for the QED reaction are high-energy electrons accelerated by the pulse laser in the low-density pre-plasma at the target front. These electrons penetrate into the target with higher density and result in pair production mediated by hard-photon emission. It is also confirmed that positron acceleration due to the electrostatic field at the target rear side dominantly characterizes the positron energy distribution.

The developed simulation scheme is a promising computational approach for full-scale simulation studies of pair production experiments using high-Z targets. We will discuss the controlling mechanism of the positron energy spectrum, the ejection angle distribution and the laser-to-positron energy conversion rate based on the simulation results.

REFERENCES
Electron beam generation by direct laser acceleration from over critical density plasma.

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ABSTRACT.

In the frame of the fast ignition (FI) scheme of inertial confinement fusion, several methods are proposed to heat the core plasma. Direct heating (super-penetration) is one of the promising methods owing to the simple target and laser geometry [1]. In this scheme, most of the laser energy is transferred to electron energy at the critical density interface. It is therefore crucial to reach a proper understanding of the electron generation mechanism and laser propagation in such plasmas having density close to critical density. However, reaching such understanding in fast ramping plasma where the density varies quickly from vacuum to overdense is difficult due to the interplay of other mechanisms affecting the laser propagation before it reaches the critical density layer. This motivated us to investigate the characteristics of the fast electron generated from slightly over critical, and, most important, uniform, density plasmas. For this, we used, as the laser interaction medium, tube targets filled with C\textsubscript{15}H\textsubscript{20}O\textsubscript{6} foam with ultra low density (~5 or 20mg/cc). The target is attached to a thin Cu foil on one side in order to produce a burst of X-rays through the irradiation of the Cu foil by a long pulse laser (I = 10\textsuperscript{14}W/cm\textsuperscript{2}, t = 1ns ). The X-rays heat the foam and create within the tube a uniform plasma over several hundred microns. The plasma generation is simulated using 1D hydro-radiative simulations (CHIC), showing the generation of homogeneous N\textsubscript{c} and 4N\textsubscript{c} plasmas [2]. A High intensity laser pulse (I=10\textsuperscript{19}W/cm\textsuperscript{2}, t=300fs) irradiates from the other side the tube target. The resulting fast electrons were observed with an electron spectrometer and an imaging plate (IP) stack. The electron divergence was observed to be around 20deg (FWHM) when using the tube target. Comparatively, when using a standard foil target (i.e. with a ramped density), the divergence was measured around 53deg (FWHM). From these data, it is found that the electron divergence generated from the tube target decreases comparing with that of from the foil target. To study this difference, simulations using the 2D particle-in-cell code FISCOF are conducted [3]. Details of experimental and simulation results will be presented.

REFERENCES

To acquire more detailed radiation drive by use of ‘quasi-steady’ approximation in atomic kinetics.

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ABSTRACT.

In current routine 2D simulation of hohlraum physics, we adopt the principal-quantum-number (n-level) average atom model (AAM) in NLTE plasma description. However, the detailed experimental frequency-dependant radiative drive differs from our n-level simulated drive, which reminds us the need of a more detailed atomic kinetics description. The orbital-quantum-number (nl-level) average atom model is a natural consideration, however the nl-level in-line calculation needs much more computational resource. By distinguishing the rapid bound-bound atomic processes from the relative slow bound-free atomic processes, we found a method to build up a more detailed bound electron distribution (nl-level even nlm-level) using in-line n-level calculated plasma conditions (temperature, density, and average ionization degree). We name this method ‘quasi-steady approximation’ in atomic kinetics. Using the plasma condition (temperature, density, and average ionization degree) calculated under n-level atomic model, we re-build the nl-level bound electron distribution (Pnl), and acquire a new hohlraum radiative drive by post-processing. Comparison with the n-level post-processed hohlraum drive shows that we get an almost identical radiation flux but with more fine frequency-dependent spectrum structure which appears only in nl-level transition with same n number (⊿n=0). This may have more use in building an even more sophisticated radiation drive in simulation of experiment design or ignition target design.
Stimulated Raman scattering in ICF relevant plasmas

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ABSTRACT.

In the indirect-drive scheme for inertial confinement fusion (ICF), laser beams propagate throughout an inhomogeneous under-dense plasma. In such plasmas the laser light is reflected via stimulated scattering off plasma waves; SRS is the scattering off electron plasma (or Langmuir) waves. It is now well established that parametric instabilities such as stimulated Raman Scattering (SRS) are detrimental for ICF.

In recent experiments performed at the NIF \cite{1} high levels of SRS reflectivity were measured (up to 50\% on some quads). These levels are far more elevated than predicted by linear theories (linear Landau damping). However, they can be partially explained by kinetic effects as the parameter \( k \lambda D \) is quite high (> 0.25) in ICF relevant plasmas. Thus Landau damping could be reduced resulting in an increase of reflectivity (kinetic inflation) \cite{2}. Combined with inhomogeneity, the autoresonance \cite{3} mechanism could also appear and enhance SRS in these kinetic plasmas.

The investigation of SRS with PIC simulations is very complicated in large plasmas (3 mm) on long time scale (1 ns) particularly when a multi-dimensional model is needed. Nevertheless, good results are expected with a non linear wave coupling model which describes the resonant energy exchange between three coupled waves: the incident laser beam, the reflected electromagnetic and Langmuir waves.

In this poster session we will present the first results obtained with a new three wave coupling code designed to simulate SRS in ICF relevant plasmas. The idea is first to reproduce known results, and then to complete the physics with new models of kinetic effects. These models will probably be introduced with \textit{ad hoc « coefficients »} in the Langmuir wave equation. The results given by this code will be confronted with experimental data gathered during the last LIL campaign.

REFERENCES

\cite{1} Siegfried H. Glenzer et al. “First implosion experiments with cryogenic thermonuclear fuel on the National Ignition Facility” in Plasma physics and controlled fusion 54, 045013 (2012).
Spectral properties of buried targets heated by fast electrons

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ABSTRACT.

In the past few years, several experiments [1, 2, 3] using Ultra High Intensity lasers (10¹⁷ - 10¹⁹ W/cm²) have demonstrated the possibility to heat a layer of material to very high temperatures (hundreds of eV) with densities close to solid. It is of particular interest to study these plasma conditions to constrain theoretical models of dense plasma equations of state or radiative opacities. To achieve this goal, in our case for spectral opacity measurements, plasma conditions (temperature, density, LTE/NLTE) have to be well determined.

This poster will present a model of electronic heating to illustrate the general scheme of the heating processes in this experiment. In addition, to demonstrate the capability to limit hydrodynamic expansion by using buried-layer targets, MULTI [4] simulations will be presented. Despite high densities, LTE conditions have not been demonstrated yet and it is an open question for our series of experiments.

Preliminary results of a first experiment performed on ELFIE at the LULI laser facility will be presented. In this experiment, we measured K-shell emission of a well-understood material such as aluminium to infer the expected range of temperatures. The spectra were first measured from the front (laser) side of the target, using a time integrated Von-Hamos spectrometer. Secondly emission was measured from the rear side using a picosecond resolution X-ray streak camera coupled to a toroidal spectrometer. Different targets as well as laser conditions have been tested to infer effects on the heating process.

REFERENCES

Ion acceleration from thin solid foils using the APOLLON laser system

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ABSTRACT.

The 10-PW APOLLON laser, due to be operational in 2015, will deliver 150 J in 15 fs pulses, leading to focused intensities up to 2x10^{22} W/cm^2. This will permit to achieve a novel laser-matter interaction regime where both electrons and ions are accelerated to relativistic energies. These particle (and the related photon) sources will open new perspectives in a variety of fields encompassing fusion science, high-energy density physics, nuclear physics, astrophysics and medicine [1].

This poster is concerned with the properties of the ion beams expected to be generated by the APOLLON laser during the first years of operation. Using the particle-in-cell code CALDER, we have performed 2-D simulations of the laser-driven ion acceleration taking place in thin solid carbon foils coated with nanometer proton layers on their (steep-gradient) front and rear surfaces. Collisions and Synchrotron-like radiation loss have been assumed negligible. In the case of linearly-polarized, ultra-high contrast pulses of intensities 5x10^{21} - 1.8x10^{22} W/cm^2 impinging at normal incidence, the maximum proton (~250 MeV) and carbon (~1.8 GeV) energies are obtained for 100-200 nm-thick targets giving rise to comparable laser transmission and reflection (~30-50%) [2,3]. Under such optimal conditions, the carbon and hydrogen ions are accelerated by a combination of `leaky´ radiative pressure and rear-side sheath field. The proton energy distribution is flat-shaped with two peaks at the low- and high-energy ends (at ~30 MeV and ~230 MeV, respectively). For the less efficient, 500-1000 nm-thick targets, the fastest ions are seen to originate from the front surface: they are first driven by the radiative pressure and then further accelerated by the rear-side sheath field. This mechanism yields lowered final energies (~100-150 MeV) compared to the optimal configuration. Finally, the sensitivity of the source performance to non-ideal laser contrast (leading to significant preplasma) is gauged.

REFERENCES

Modeling of transport of laser-driven proton beam in solid density targets.

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¹University of California, San Diego, USA
²General Atomics, San Diego, USA

ABSTRACT.

We recently conducted an experiment with the TRIDENT laser (75 J, 0.6 ps) at Los Alamos National Laboratory using novel targets to study transport and isochoric heating in solid material by a laser-generated high-intensity proton beam. Protons from a spherically-curved foil focused into a planar transport foil of varied atomic number (Z) and thickness. The XUV emission from a rear Au layer coated on the transport foil indicated a clear dependence of spot size and peak brightness on the material properties. The emission brightness decreased with Z, but so did the spot size with the Cu and Au transport foil targets producing very tightly confined emission profiles (as small as 44 µm) compared to the Al and CH cases (as large as 180 µm and filamented in some cases). This indicates proton beam transport and heating dynamics are substantially altered from the low beam intensity cold target case. To investigate this matter we studied intense proton beam ($n_{beam} \sim 10^{17}$ p/cm³, $T_{beam} \sim$MeV) interaction with solid-density targets via hybrid fluid particle-in-cell (PIC) simulations using the large-scale plasma (LSP) code. In this regime, the cold target is rapidly heated by the proton beam into partially ionized warm-dense and/or hot-dense plasma states. However, we found ion stopping calculation of LSP for solid density and low temperature condition is inaccurate. Correctly modeling this interaction requires careful inclusion of target ionization, equation of state, and a robust stopping model. To this end, a new ion stopping-power calculation module covering both these warm and hot dense regimes has been implemented in LSP. In this module, both the contributions from bound electrons and free electrons are calculated into the total stopping power of charged ions by using respectively the Bethe formula and plasma free electron term. Therefore, the ion stopping power of the targets varying with its temperature and ionization can be dynamically described, i.e. with the rising ionization during the interaction, stopping power decreases for low energy particle range while increasing for high-energy range [1-4]. Using this new module, the above experimental observations have been explained; further the dependences of beam-plasma interactions on the beam intensities and target materials and initial temperatures have been systematically studied.

REFERENCES

The Origin of Super-Hot Electrons from Intense Laser Interactions with Solid Targets having Moderate Scale Length Preformed Plasmas

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The results of a numerical study investigating the acceleration mechanism for super-hot electrons by an intense laser interaction with moderate scale length preformed plasma are described. We find that a simple mechanism that we call loop-injected direct acceleration (LIDA) is overwhelmingly dominant in the acceleration of the hottest electrons. Results from recent experiments at the newly commissioned SCARLET laser facility (15 J, 30fs, peak intensity of 5 x 10^21 W/cm²) are also presented.

The particle-in-cell code LSP [1] is used to model a 100J, 175fs, peak intensity 6 x 10^20 W/cm² laser in 2D Cartesian geometry. The laser interacts with a solid density Al target with a L=3um scale length preformed plasma. We identify several features of direct laser acceleration by investigating particle tracks; we have also found that electrons with the largest energies require the simple three-step mechanism we have called LIDA which is sketched in Figure 1. In (a), the incoming laser (red) heats the region (pink) near the critical surface (dashed black) expelling electrons along the green trajectories. The electrons that will become super-hots follow looping trajectories (black arrows in (b)) which are shaped by large quasi-static fields (magnetic field indicated in yellow). In (c), LIDA electrons are injected into the intense region of the laser pulse and directly accelerated until they escape into the target with large energy.

We also discuss results and relating physics of recent experiments using the SCARLET laser. Flat targets with an array of ~10um long normally oriented front-surface wires are expected to enhance hot electron generation, in a mechanism similar to that observed by Kluge, et al. [2].

REFERENCES
QED-PIC: A Simulation Tool for 10PW Laser-Plasma Interactions

C.P. Ridgers

University of York

ABSTRACT.

Next-generation 10PW lasers will create strong enough electromagnetic fields to access non-linear quantum electrodynamics (QED) processes. The standard particle-in-cell (PIC) simulation approach is inadequate for describing the resulting QED-plasmas and a new approach (QED-PIC) must be adopted. The defining feature of a QED-plasma is the strong feedback between microscopic QED emission processes and macroscopic collective plasma effects. The inherently multi-scale nature of this feedback provides a challenge for QED-plasma simulation. We will show that this problem may be surmounted by coupling a Monte-Carlo code describing the QED processes to a standard PIC code resulting in our new QED-PIC algorithm. We predict that such QED-PIC codes will be the workhorse simulation codes for next generation laser-plasma physics.
Modeling of collisionless electron-ion shocks and application to laser-driven shock generation

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²CEA, Saclay, INSTN, F-91191 Gif-sur-Yvette, France

ABSTRACT.

Ab initio kinetic simulations of electron-ion collisionless shocks are now made possible by supercomputers, hence paving the way to a quantitative modeling of the high-energy physics of gamma-ray bursts, pulsar wind nebulae, supernova remnants [1,2]. We have performed 2D particle-in-cell (PIC) simulations of the electromagnetic instabilities developing in nonrelativistic counterstreaming electron-ion flows, whose nonlinear evolution results in the shock formation. These results are of interest for assessing the feasibility of generating shocks using high-intensity lasers [3]. The experimentally accessible plasma parameters will be explored in the framework of relativistic kinetic linear theory, pointing out the dominant instabilities at play. This analysis will be then used for interpreting 2D PIC simulations of relativistic laser-driven shocks in dense plasmas. The influence of the laser (spot size, amplitude) and plasma (density, collisions) parameters on the shock properties will be studied. Finally, the PIC simulation results will be compared to a Hamiltonian model of the saturation stage of the ion Weibel instability accounting for both magnetic and electric trapping effects, highlighting the crucial role of the electron dynamics in the evolution of the system. The quantitative estimates of the nonlinearly perturbed electron and ion distribution functions will allow us to predict the electrostatic field associated to the saturation stage, which mostly contributes to the electron heating and, therefore, the destabilization of the ion beams [4].

REFERENCES

Resonant absorption and double Auger and photoionization effects on evolution dynamics of charge state distribution in atom interaction with ultra-intense x-ray pulses

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ABSTRACT.

Strong-field physics is expanding from the long-wavelength regime into the short-wavelength region due to technological advancement of x-ray free-electron lasers such as the Linac Coherent Light Source (LCLS) [1]. Understanding the x-ray absorption mechanisms at a fundamental level is the basis of any further investigations and essential for all types of applications. The first experiment at the LCLS carried out by Young et al. [2] revealed that sequential K-shell single-photon ionization mechanism dominates the interaction in the electronic response of a free neon atom to ultra-intense x-ray pulses. Inner-shell resonant absorption (IRA) is the physical origin of the large discrepancies found between the theory and experiment at 1050 eV, where the rates of K-shell resonant absorption 1s-4p of Ne⁶⁺ and 1s-3p of Ne⁷⁺ are larger than the direct single-photon ionization rates by more than one order of magnitude. Besides IRA effects, double Auger decay (DAD) [3] and double photoionization (DP) also play a role in the x-ray interaction with matters. To investigate these effects, we developed a detailed level accounting (DLA) method on the relevant atoms in the time-dependent rate equation (TDRE) formalism [4]. The IRA effects are shown in Fig. 1 and the effects of double Auger decay and double photoionization are shown in Fig. 2.

Fig. 1 IRA effects on charge state distribution

Fig. 2 The effects of DAD and DP on charge state distribution

REFERENCES

Assessing the predictive capability of the CRASH radiation-hydrodynamics simulation code.

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ABSTRACT.

The overarching goal of the Center for Radiative Shock Hydrodynamics (CRASH) is to assess and improve the predictive capability of the CRASH simulation code [1], using a combination of experimental data and statistical analysis. Within this project, we specifically focus on laser-driven radiative shock experiments in the high-energy-density regime. The aim is to predict the radiative shock structure in three-dimensional elliptical shock-tube nozzle with our simulation code [2]. This code is first validated and calibrated with experimental results obtained for straight shock tubes and circular nozzles. In this presentation, we evaluate the performance of our predictive model.

The CRASH simulation code is a parallel block-adaptive-mesh Eulerian code for high-energy-density plasmas. In the implementation, we have incorporated radiation models with either a gray or a multigroup method in the flux-limited-diffusion approximation. The HYPRE preconditioner is used to improve the radiation implicit solver. The electrons and ions are allowed to be out of temperature equilibrium and flux-limited electron thermal heat conduction is included. The CRASH code does also incorporate a laser package with 3D ray tracing [3], resulting in improved energy deposition evaluation. The CRASH code has also the option to perform radiative shock simulations under the assumption of non-LTE.

In our canonical experimental set-up, used for the calibration and validation of the CRASH code, a 1ns, 3.8kJ laser pulse irradiates a 21 micron beryllium disk, driving like a piston a shock into a xenon-filled plastic tube. The electrons emit radiation behind the shock. This radiation from the shocked xenon preheats the unshocked xenon. Photons traveling ahead of the shock will also interact with the plastic tube, heat it, and in turn this can drive another shock off the wall into the xenon. The X-ray radiographs of the simulated radiative shock evolutions can be validated against those obtained from shock tube experiments at the Omega high-energy-density laser facility.

This work was funded by the Predictive Sciences Academic Alliances Program in DOE/NNSA-ASC via grant DEFC52-08NA28616 and by the University of Michigan.

REFERENCES

High ratio quasi-adiabatic compression conic implosion high energy density device

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ABSTRACT.

Implosion is the most practical way to produce a near equilibrium high energy density state in a laboratory. Liquid driving conic implosion [1] has been explored to create bright cavitation luminescence with temperature up to a few thousand Kelvin. To extend to the realm of high energy density physics, we proposed a device with much lower initial gas pressure and a method to produce high vacuum conveniently without using a vacuum pump. The principle was proved in a simpler device, but we are constructing a new one using lead-bismuth eutectic as the driving liquid. Preliminary investigation shows there would be no problem to reach $10^5$ bar and $10^5$ Kelvin. The over heated gas (warm dense plasma) is used to accelerate a metal bullet, thereby we shall be able to estimate the peak pressure. We hope we can reach $10^6$ bar with minor improvements. The scheme is also applicable to magnetic target fusion ideas.

REFERENCES

Design and manufacturing of Laser Targets

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GEPI, Observatoire de Paris, CNRS, Université Paris Diderot, Meudon, France

ABSTRACT

Within the Instrumental Pole of GEPI of Paris Observatory, we realize specific targets for radiative shocks, accretion shocks or plasma jets similar to young stellar jets, which are simulated in laboratory by interacting a powerful laser with the pusher of targets. The experiments are connecting to astrophysical studies leaded at the Paris Observatory in collaboration with LULI at Ecole Polytechnique and CEA/DIF.

However, this particular approach of high-energy-density laboratory astrophysics requires target manufacturing with very accurate metrology, insuring both the development of the expected phenomenon and the experimental reproducibility.

In this poster, we show various kinds of targets which were realized by our team during the last ten years.
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