51st Anomalous Absorption Conference

June 18-23, 2023

The Westin Monache Resort, Mammoth Lakes, CA

Sunday, June 18

Registration & reception – The Westin

5:30 – 7:00 pm	Registration
6:00 – 8:00 pm	Welcome reception

Monday, June 19

Morning session I – the Village Lodge
Chair: Siegfried Glenzer

8:30 – 8:50 am	Introduction / welcome	*Organizing committee*
8:50 – 9:20 am	Overview of Cross-Lab Polar Direct Drive Wetted-Foam High-Yield Efforts (**invited**)	*Mark Schmitt*
9:20 – 9:40 am	Optimization of Polar Direct Drive Illumination for Mega- Joule Laser Facilities	*Duncan Barlow*
9:40 – 10:00 am	Machine-assisted optimization and scaling of NIF capsule implosions	*Paul Schmit*
10:00 – 10:20 am	Influences of Laser-Driven and Shock-Driven Preheat on 3D-printed Porous Media	*Ryan Lester*
10:20 – 10:40 am	**Coffee break**	

Morning session II – the Village Lodge
Chair: Jackson Williams

10:40 – 11:10 am	New insights into NIF's burning plasma regime from neutron spectroscopy (**invited**)	*Aidan Crilly*
11:10 – 11:30 am	Interpreting Signatures of Ignition and a-heating in Neutron Spectra from High-Yield Experiments on the National Ignition Facility	*Alastair Moore*
11:30 – 11:50 am	Nuclear imaging capabilities at the National Ignition Facility	*Mora Durocher*
11:50 – 12:10 pm	Demonstration of a high repetition rate laser-driven neutron source in a pitcher-catcher scheme	*Griffin Glenn*
12:10 – 12:30 pm	Analysis of NIF polar-direct-drive exploding pushers for the development of a radiochemistry mix diagnostic	*Diego Lonardoni*

Lunch – the Westin

12:30 – 1:30 pm	**Lunch**

LA-UR-23-25161

Overview of Cross-Lab Polar Direct Drive Wetted-Foam High-Yield Efforts*

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Collaborative efforts across the Laboratories are underway to investigate the feasibility to achieve high nuclear yields using a liquid DT-wetted layer capsule directly driven by the National Ignition Facility's (NIF's) current laser capabilities[1]. Ideally, the capsule will be composed of a thin plastic shell enclosing a thick annular matrix layer that contains the liquid DT fuel. Comparisons across several simulation codes indicate that a high level of laser absorption can occur that drives a central gas pocket convergence of 15 enabling higher levels of gain and the potential to robustly ignite (using the current laser energy available at NIF). High laser absorption is consistent with previous polar direct drive (PDD) MJ-class NIF experiments where >95% capsule absorption of the laser drive energy was achieved using a 5 mm diameter capsule[2]. Moreover, fielding of a PDD cryogenic capsule filled with liquid hydrogen was recently demonstrated at NIF[3] and fabrication efforts using 3D printing techniques are making progress. Additional physics experiments are planned for both NIF and Omega to field liquid hydrogen wetted-foam capsule implosions and investigate in detail the effects of the heterogeneous matrix/fuel layer on both laser ablative drive, shock propagation and concomitant fuel compression. An overview of these multi-Laboratory efforts will be presented.

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[1] R. E. Olson *et al.*, *Phys. Plasmas* **28**, 122704 (2021).
[2] M. J. Schmitt, et al., https://meetings.aps.org/Meeting/DPP22/Session/JO04.13.
[3] G. E. Kemp, private communication regarding NIF shot N230131-002.

Optimization of Polar Direct Drive Illumination for Mega-Joule Laser Facilities

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The National Ignition Facility (NIF) has achieved ignition[1] using an indirect drive approach to inertial confinement fusion (ICF) where a roughly 1mm spherical target was compressed to less than 0.1mm by x-rays. Stable compression requires highly uniform, spherical illumination, which is achieved by indirect drive with the use of a cylindrical hohlraum. Laser light enters the hohlraum at the poles and is converted to thermal x-rays before driving the target. The hohlraum helps to improve irradiation uniformity, but at the cost of laser-target coupling efficiency when compared to a direct-drive (DD) approach. Due to its efficiency, DD is a promising candidate when moving beyond ignition towards a future energy source. However, testing DD at ignition scales is challenging as the mega-joule laser facilities (National Ignition Facility, NIF and Laser Méga-joule, LMJ) are configured with beams entering the target chamber in the polar region for indirect-drive, and so require optimization to enable DD compatible illumination. The NIF features: 48 quads entering from different ports with independent pointing, power balance, wavelength tuning and defocusing; and the quads may be split to 192 beams with individual pointing offsets. A polar direct-drive (PDD) scheme has already been tested on the NIF[2], however there are a large number of possible beam configurations and evaluating them currently requires expensive experimental/computational methods, so it is likely not the optimal solution. In addition, the use of beams as diagnostics or changes to the target/implosion dynamics requires manual re-optimization and different configurations are required for solid targets, conventional hotspot ignition, and shock ignition.

This talk presents the use of Bayesian optimization and genetic algorithms for efficient evaluation within the PDD parameter space for the NIF. It creates highly uniform illumination configurations in the presence of temporally varying plasma and laser plasma interactions (LPI), such as cross-beam energy transfer[3]. The procedure is presented in comparison to a current NIF PDD configuration[2] which was used on several solid target experiments[4]. 3D radiation-hydrodynamic simulations highlight the new configuration's benefits in drive uniformity and ablation pressure. The process is currently being applied to aid in the design of future experiments for both the NIF and LMJ.

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[1] Abu-Shawareb, H., et al. Physical Review Letters 129.7 (2022): 075001.
[2] Hohenberger, M., et al. Physics of Plasmas 22.5 (2015): 056308.
[3] Colaïtis, A., et al. Journal of Computational Physics 443 (2021): 110537.
[4] Ceurvorst, L., et al. Review of Scientific Instruments 93.10 (2022): 105102.

Machine-assisted optimization and scaling of NIF capsule implosions*

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The recent achievement of ignition in inertial fusion experiments on the National Ignition Facility[1] (NIF) has inspired a surge of interest in answering two fundamental questions. First, what design options exist to increase target performance within present-day facility and target-fabrication capabilities? Second, given multiple NIF facility upgrade proposals currently under consideration, what performance increases may be achievable based on our current understanding of target and driver risk profiles?

To help address both questions, we describe a set of capsule implosion design tools utilizing designer-guided, machine-assisted iterative optimization to rapidly assess the scaling and optimization of both demonstrated and novel implosion scenarios for the NIF. In one application of these tools, we identify a minimum set of design input variations and output performance metrics needed to generate hydrodynamically equivalent implosions of ignition-scale designs at arbitrary capsule ablator scales and DT fuel layer thicknesses. We then assess the performance scaling of demonstrated ignition designs mapped over a broad range of ablator, fuel, and driver energy scales. In another application, we explore the constrained optimization of present-day ignition-scale implosions and identify design variations that could increase yields by factors of several while maintaining or improving upon the implosion risk profiles of demonstrated designs, including susceptibilities to hydrodynamic instabilities and mix. Finally, we explore the task of generating equivalent implosions under a transformation of capsule ablator and dopant materials as a starting point to explore the benefits and tradeoffs of alternate ablators while maintaining strong physics connections to demonstrated designs on the NIF.

* This work was performed under the auspices of the U.S. DOE by LLNL under contract DE-AC52-07NA27344.

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[1] H. Abu-Shawareb *et al.*, "*Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment,*" Phys. Rev. Lett. **129**, 075001 (2022).

Influences of Laser-Driven and Shock-Driven Preheat on 3D-printed Porous Media

Presenter R. S. Lester
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Mixing of materials in porous media can cause a significant impact on fusion yield as previously demonstrated by the NIF MARBLE[1] Campaign. Initially, the reactants are separated, with deuterium in the lattice struts and a tritium gas fill in the voids. Lattice parameters such as the strut thickness and relative pitch, provide a control for the mix parameters in the experiment. Los Alamos National Laboratory's (LANL) BOSQUE project looks to understand better how the mix[2] of the reactants and shell materials impact the fusion burn and resultant yield on various laser platforms.

xRAGE's[3] Eulerian hydrodynamics and adaptive mesh refinement provide the unique ability to study the impacts of multiscale features of complex lattice structures. This modeling provides the ability to measure shock front variations as the wave progresses through a given media. Initial conditions of the lattice are essential to accurately model mix and burn measured by experiment. Preheat was found to perturb these initial conditions during MARBLE[1] by effectively eliminating the foam pores before the shock had a chance to start the compression and mixing process, thus motivating the study of potential sources and sensitivities.

This study will aim to uncover how the sensitivities due to sources of preheat such as laser driven hard x-rays, hot electrons, and radiative shock effects alter the structure of the two-photon polymerization (2pp) lattice. We will explore various experimental setups and laser platforms as well as radiographic measurements of shock position and disk expansion to estimate preheat due to shock and preheat due to laser drive respectively.

*This work was performed by the Los Alamos National Laboratory, operated by Triad National Security, LLC for the National Nuclear Security Administration (NSSA) of the U.S. Department of Energy (DOE) under Contract No. 89233218CNA000001.

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[2] B. M. Haines et al., "Observation of persistent species temperature separation in inertial confinement fusion mixtures," Nat. Commun. 11, 544 (2020)
[3] M. Gittings et al., "The RAGE radiation-hydrodynamics code," Comput. Sci. & Discov. 1:015005 (2008).

New insights into NIF's burning plasma regime from neutron spectroscopy

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In ICF experiments, measured neutron spectra contain a wealth of information on the ion velocity distributions throughout the DT fuel. Common to all the spectral features is dependence on microscopic scale reaction kinematics, mesoscopic scale local ion velocity distributions and macroscopic scale hydrodynamic motion. Neutron spectroscopy therefore can give unique insight into the behaviour of the fusing and bulk ions throughout the fuel during fusion burn.

The most prominent and commonly analysed features are the DT and DD fusion peaks. The shapes of these peaks encode the relative and centre of mass velocity distributions of the fusion reactants. Munro[1] provided an energy moments-based approach for Maxwellian ion distributions. Crilly et al.[2] extended this approach to arbitrary distributions. This analysis allows ion kinetic features to be characterized and departure from Maxwellians to be identified. Recent burning plasma experiments from the NIF[3] have shown primary neutron spectra inconsistent with Maxwellian ion velocity distributions.

Backscatter neutron spectroscopy is a diagnostic technique which can be used to infer the scatter averaged ion velocity moments[4]. Since the scattering rate is proportional to the ion number density, this measurement is weighted towards the DT fuel shell. For burning plasma experiments on the NIF, backscatter neutron spectroscopy was used to infer that the dense fuel was expanding and heated at the time of peak neutron production. These are key signatures of ignition and burn-propagation.

As neutron yields have increased, the high energy neutron ($E > 15$ MeV) spectrum has recently become measurable on nTOF spectrometers. These high energy neutrons are created by D and T ions which have been knocked on to high energies by fusion products such as alphas and neutrons. Therefore, the spectra can be used to learn about high energy ion distributions which are affected by scattering cross sections, stopping power and profile effects.

References:

[1] – Munro, 2016 Nucl. Fusion 56 036001
[2] – Crilly et al., 2022 Nucl. Fusion 62 126015
[3] – Hartouni et al., 2023 Nature Physics 19, 72–77
[4] – Crilly et al., 2022 Physics of Plasmas 29 062707

Interpreting Signatures of Ignition and α-heating in Neutron Spectra from High-Yield Experiments on the National Ignition Facility*

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Laser-indirect-drive inertial confinement fusion (ICF) experiments at the National Ignition Facility (NIF) demonstrated ignition in December 2022 achieving fusion neutron yields in excess of 3 MJ[1]. In these burning and igniting plasmas energy deposited by α-particles generated in the T(d,n)α fusion reaction plays the central role in heating the fuel to achieve a sustained thermonuclear burn.
In the hydrodynamic picture, α-heating increases the temperature of the plasma, leading to increased reactivity because the mean ion kinetic energy increases; for a thermal plasma the ion temperature is related to the mean ion kinetic energy through the Maxwell-Boltzmann energy distribution. In fusion plasmas the ion kinetic energy distribution is encoded in the neutron spectrum[2].
Using neutron time-of-flight spectroscopy measurements we study the relationship between the ion temperature (measured by the variance in the neutron kinetic energy spectrum) and the ion mean kinetic energy (measured by the shift in the mean neutron energy) for DT fusion plasmas. A departure from the relationship expected for thermal plasmas is observed when the plasma begins to burn[3]. Understanding the cause of this departure from hydrodynamic behavior could be important for achieving robust and reproducible ignition. LLNL-ABS-848537.

[1] to be submitted to Physical Review Letters
[2] Crilly et al.,*'Constraints on ion velocity distributions from fusion product spectroscopy'* (2022) Nuclear Fusion **62** 126015; https://doi.org/10.1088/1741-4326/ac90d5
[3] Hartouni et al.,*'Evidence for suprathermal ion distribution in burning plasmas'* (2022) Nature Physics **19** 72-77; https://doi.org/10.1038/s41567-022-01809-3

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Nuclear imaging capabilities at the National Ignition Facility

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The Nuclear Imaging System (NIS), located at the National Ignition Facility (NIF), captures neutron, X-ray and gamma-ray images of Inertial Confinement Fusion (ICF) driven implosions. From these images, implosion information can be extracted to assess fusion performance. Today, the nuclear imaging suite consists of three nearly orthogonal lines of sight (LoS) allowing 3D reconstruction of neutron source distributions. Furthermore, two of those LoS are equipped to capture gamma-ray images which can help characterize the remaining ablator of the fuel capsule. This talk will cover NIS neutron, X-ray and gamma-ray image reconstruction capabilities and show how NIS can provide critical information on the mechanisms that may limit implosion performance.

Demonstration of a high repetition rate laser-driven neutron source in a pitcher-catcher scheme*

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High-flux, high repetition rate (HRR) pulsed neutron sources with short pulse durations are essential for investigating neutron-induced damage processes in materials used in fusion energy science. One method to achieve both high peak and high average neutron fluxes is to use laser-driven neutron sources employing HRR-compatible targets in a pitcher-catcher neutron generation setup. Ambient-temperature liquid jet targets[1] are well-suited for this purpose, as they can support HRR operation at petawatt-class lasers[2] while also enabling in-situ optimization of the laser-target interaction by tuning the jet orientation and thickness.

In this study, we implemented an ambient-temperature H_2O and D_2O microjet target at the ALEPH laser facility (400 nm, 45 fs, 5 J, 0.5 Hz), acquiring ~2000 laser shots. We placed a 1.5 mm thick beryllium converter with an on-axis pinhole 3.9 cm behind the liquid target, which enabled simultaneous ion beam characterization and neutron beam production. Measurements were taken with and without the converter in place, quantifying the neutron flux generated by the converter source. We found that neutron yields in the target-normal direction were higher when using D_2O rather than H_2O, indicating a contribution from deuteron breakup reactions. The neutron flux demonstrated in this study makes these neutron sources highly efficient for studying stationary systems. Further scaling to high-energy, high-power laser systems will provide access to even higher fluxes necessary for single-shot pump-probe experiments.

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[2] F. Treffert et al., Applied Physics Letters **121**, 074104 (2022)

Analysis of NIF polar-direct-drive exploding pushers for the development of a radiochemistry mix diagnostic

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During the deceleration phase of an inertial confinement fusion (ICF) implosion, instability growth can lead to mixing between the ablator material and the thermonuclear fuel.[1] Mixing is undesirable, as it reduces the performance of the capsule. One method to diagnose mixing is to study the x-ray emission from the burning fuel.[2] However, double shell[3] and pushered single shell[4] designs for the National Ignition Facility (NIF) render this technique ineffective because they involve a high-Z shell surrounding the fuel that is opaque to x-rays. A possible alternative mix diagnostic involves measuring the interaction of alpha particles, produced during the thermonuclear burn, with the ablator material.[5] The Radiochemical Analysis of Gaseous Samples (RAGS) facility at NIF allows for quantitative measurements of α-induced reactions.

We present the results of an investigation using Boron-doped Beryllium ablator polar-direct-drive exploding pusher (PDXP) shots at NIF. Radiation-hydrodynamics calculations were performed in 1D to optimize the capsule design, and a charged-particle transport post-processor was developed to study α-induced reactions on the ablator material. An initial B-Be PDXP target (N201115-011) was fielded on the NIF, and nitrogen from the $^{10}B(\alpha,n)^{13}N$ reaction was measured by RAGS for the first time in an ICF implosion, validating the feasibility of the radiochemistry approach.[6] Several successive B-Be PDXP shots have been fielded on the NIF, providing additional constraints on the platform. Detailed 1D and 2D radiation-hydrodynamics calculations were performed to study the interplay between simulated laser drive, laser-plasma interaction, heat conduction models and implosion dynamics, shape asymmetry, and thermonuclear/radiochemistry yields. The ongoing computational and experimental analysis suggests that radiochemistry can provide a practical diagnostic for ICF dynamics.

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[2] T. Ma *et al.*, Phys. Rev. Lett. **111**, 085004 (2013).
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Monday, June 19 (cont'd)

Plenary evening session – the Village Lodge
Chair: John Moody

7:00 – 8:00 pm	The Underpinning for FLUX—Fourth generation Laser for Ultrabroadband eXperiments (**plenary**)	*Dustin Froula*

Poster session – the Village Lodge
8:00 – 10:00 pm

Raman gap and collisional absorption	*Ido Barth*
Modeling experiments that probe beam spray thresholds and exploring bandwidth mitigation	*Tom Chapman*
Modeling of the Jupiter Laser Facility with Virtual Beamline (VBL++) code	*Marie-Louise d'Astanières*
Coupling nonlinear CBET effects to radiation- hydrodynamic modeling of ICF/HED experiments via laser ray tracing	*Lauren Green*
Simulated Gamma-Ray Imaging of NIF Capsule Implosions	*John Kuczek*
Modeling self-generated-magnetic-field effects on X-ray emission from laser-driven Kr plasma	*Luis Leal*
Laser-Plasma Interactions for X-ray Radiographic Imaging: An Update	*Scott Luedtke*
Peculiar Profiles in the Subscale 'BigDipper' Campaign on the NIF	*Ryan Nora*
Momentum deposition by beam bending results in bow shock generation in ICF plasmas	*Wojciech Rozmus*
A mid-beta booster for proton beams	*Davide Terzani*
Design of Planar Heterogeneous Ablation Experiment on OMEGA	*Blake Wetherton*
PIC Simulations of Autoresonant Beatwave Excitation	*Jonathan Wurtele*

The Underpinning for FLUX—Fourth generation Laser for Ultrabroadband eXperiments*

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Recent direct-drive implosions on the OMEGA Laser Facility have demonstrated hot-spot pressures capable of producing a burning plasma when increasing the laser's energy to 2.15 MJ while scaling the target hydrodynamically and maintaining the 140 Mbar of ablation pressure achieved on OMEGA [1]. However, direct-drive experiments on the NIF have demonstrated that cross-beam energy transfer limits the achievable ablation pressure with narrowband lasers to ~75 Mbars [2], while maintaining the laser intensities ($<10^{15}$ W/cm^2) below the thresholds for hot electron generation. Simulations suggest 220 Mbars of ablation pressure is sufficient for high-gain robust ignition [3] and can be achieved using broadband ultraviolet lasers with wavelengths less than 530 nm [4].

The Fourth generation Laser for Ultrabroadband eXperiments (FLUX) [5], was created to demonstrate the laser technologies for a broadband inertial confinement fusion driver and to study the effects of bandwidth on laser-plasma instabilities. Broadband optical parametric amplification developed for ultrashort pulse lasers, was adapted to produce spatially coherent and temporally incoherent laser-pulses suitable for laser fusion. A novel sum frequency generation was invented to efficiently convert the 1054-nm high-bandwidth pulses to the ultraviolet ($\Delta\omega/\omega>1.5\%$, >12 THz).

The OMEGA LPI Platform was designed to isolate uncertainties in the plasma conditions from laser-plasma instability physics by using Thomson scattering, including measurement of the electron distribution functions [6], to characterize the plasmas. Initial experiments on this platform used the Tunable OMEGA Port 9 (TOP9) beam to understand the limitations in modeling cross-beam energy transfer with linear gain models [7]. The FLUX beam will use the same beam path on OMEGA allow the study the effects of bandwidth on laser-plasma instabilities, including cross-beam energy transfer, filamentation, two-plasmon decay, and stimulated Raman/Brillouin scattering.

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Raman gap and collisional absorption*

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One of the long-standing puzzles observed in many laser-plasma experiments is the gap in the Raman backscattering spectrum. This gap is characterized by the absence of backscattered light between some critical wavelength and twice the incident laser wavelength. The latter is associated with the absolute Raman instability from the quarter-critical density surface. Supported by particle-in-cell (PIC) simulations, it is suggested that the gap can result from the collisional damping of the backscattered light. A linear analysis of the competition between the Raman growth rate and the damping rate in a non-homogenous plasma predicts the gap's existence and width as a function of the system's parameters. The theory is compared with PIC simulations and past experiments.

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

Modeling experiments that probe beam spray thresholds and exploring bandwidth mitigation*

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Recent experiments at the Omega Laser Facility [D. Turnbull *et al*., Phys. Rev. Lett. **129**, 025001 (2022)] have carefully studied the spraying of laser light as it propagates through underdense plasmas of relevance to inertial confinement fusion experiments. In these experiments, frequency redshits of the transmitted light were measured that exceed estimates based on the Dewandre shift caused by the plasma expansion alone. Such redshifts are a signature of forward Brillouin scattering. Here, these experiments are modeled using three-dimensional simulations that describe the necessary absorption, backscattering, filamentation, and forward scattering of the laser light. The phase plate of the experimental beam is reproduced numerically, allowing for a direct comparison with the experimentally measured transmitted beam spot and frequency. The impact of various bandwidth-based mitigation techniques is explored in anticipation of further upcoming experiments.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344 and funded by LDRD 22-ERD-042.

Modeling of the Jupiter Laser Facility with Virtual Beamline (VBL++) code*

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The Jupiter Laser Facility (JLF) at LLNL is a mid-scale laser facility, with three different laser platforms: Janus (Target Area 1), Titan, and COMET. To help the facility and its users better understand the laser performance, a model of Janus and Titan has been developed using the Virtual Beamline ++ code (VBL++), which was initially developed by LLNL to model the National Ignition Facility beamlines and predict their performance.

The VBL++ code allows the user to place components on an optical chain and define their specific properties. The code then propagates the beam from a source through the different optics. The user can place checkpoints along the beamline to access any desired properties of the beam, such as beam energy, fluence, phase, or field, at a specific point.
Using this method, the user can test different input properties to reach a desired output pulse.
The simulations were run on different scenarios to understand the effect of some imperfections in the beamline on the output such as spots on the optics, misaligned optics or backscatter damage.

* This work was performed under the auspices of the U.S. Department of Energy under Contract No. DE-AC52-07NA27344

Coupling nonlinear CBET effects to radiation-hydrodynamic modeling of ICF/HED experiments via laser ray tracing

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Cross beam energy transfer (CBET) is an important energy redistribution mechanism in direct drive and indirect drive ICF/HED experiments performed on large-scale laser facilities. In order to model these experiments accurately, it is essential to include feedback from the laser-plasma instabilities on hydrodynamics. Nonlinear effects from ion trapping and secondary instabilities can cause CBET gain to deviate from linear theory predictions typically used in laser ray tracing codes. In this work, we developed a new CBET formulation in Mazinisin[1] a laser ray-tracing code developed by LLE, that includes effects of saturation in a physics-based nonlinear CBET model and evolving plasma conditions from simulations using the LANL Eulerian radiation hydrodynamics code xRAGE. We performed simulations to test the implementation of the nonlinear CBET model using settings and results from experiments[2] at the LLE OMEGA laser facility. These experiments observe CBET saturation due to ion heating, which is not represented in a time-dependent manner by the linear model alone. We will compare results from linear and nonlinear CBET models and discuss the conditions necessary for improving the agreement between simulations and experiments.

[1] J. A. Marozas et. al., "*Wavelength-detuning cross-beam energy transfer mitigation scheme for direct drive: Modeling and evidence from National Ignition Facility implosions,*" Phys. Plasmas **25**, 056314 (2018).
[2] A. M. Hansen et. al., "*Cross-Beam Energy Transfer Saturation by Ion Heating,*" Phys. Rev. Lett. **126**, 075002 (2021).

Simulated Gamma-Ray Imaging of NIF Capsule Implosions

Presenter J. J. Kuczek, N. M. Hoffman, B. M. Haines, W. Daughton, B. J. Albright, J. P. Sauppe, K. D. Meaney, V. Geppert-Kleinrath
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Gamma-ray imaging of burning inertial confinement fusion capsules give information on where the ablator is during the final stages of the implosion[1]. Neutrons formed from fusion processes generate gamma-rays through inelastic nuclear scattering in the carbon ablator of the capsule. The ablator areal density (rhoR) can be inferred through gamma-ray detection if the capsule's total neutron yield is measured[2,3].

Capsule implosions on the National Ignition Facility (NIF) have recently achieved ignition[4]. Repeat experiments of igniting shots have achieved much lower yields than expected. Degradation mechanisms, such as voids in the capsule and fill tube geometry, are a leading theory as to why there is such variability in the repeats. Recent simulation work has shown that capsule defects lead to collections of small jets in the shell that reduce overall compression of the DT fuel[5,6]. Generation of synthetic gamma-ray images from clean/degraded capsules and varied fill tube geometry simulations could prove useful when comparing against experimental data. We present high resolution 2D simulations using radiation-hydrodynamics code xRAGE[7] of NIF shots N211024 and N211107 with the inclusion of the fill tube. Synthetic gamma-ray images are produced through post processing of xRAGE output. We compare simulated rhoR and gamma-ray images with experiments.

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[4] H. Abu-Shawareb et al, "Lawson criterion for ignition exceeded in an inertial fusion experiment", PRL, **129**, 075001 (2022)
[5] B. M. Haines et al, "A mechanism for reduced compression in indirectly driven layered capsule implosions", Phys. Plasmas, **29**, 042704 (2022)
[6] B. M. Haines et al, "Robustness to hydrodynamic instabilities in indirectly driven layered capsule implosions", Phys. Plasmas, **26**, 012707 (2019)
[7] M. L. Gittings et al, "The RAGE radiation-hydrodynamics code", Comput. Sci. Discov., **1**, 015005 (2008)

Modeling self-generated-magnetic-field effects on X-ray emission from laser-driven Kr plasma*

Presenter L. S. Leal, G. E. Kemp, P. J. Poole, A. Campos, M. Tabak, Y. Ping, K. Carpenter, C. A. Walsh, K. Widmann, and M. J. May
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A variety of X-ray sources ranging from the 1 -30 keV photon range are in development at Lawrence Livermore National Laboratories[1]. Well characterized emission from X-ray sources is important for various applications from imaging HED experiments to studies in X-ray interactions with materials. One major platform shot at the National Ignition Facility (NIF) is a gas pipe filled with under-dense Krypton (Kr) gas that uses NIF lasers to heat the Kr gas and generate high fluence X-rays that can be measured using DANTE spectrometer.

This poster focuses on the modeling of the Kr gas-pipe target using HYDRA simulations including laser-generated magnetic fields and studies the effect of magnetohydrodynamic (MHD) terms on the plasma and the simulated X-ray emission and spectra. Notably the laser-generated fields raise the simulated temperatures of the Kr plasma, which leads to better agreement between experiments in time-resolved X-ray emission for energies from 1-7 keV and Differential Emission Measure weighted temperatures. Varying the model used for magnetized transport has a noticeable effect on the X-ray Emission. An OMEGA experiment that simplifies magnetic field geometry and similar to foil experiments investigating MHD transport[2] has been proposed to better characterize the magnetized transport effects that are important for X-ray emissions.

*This work conducted under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under DE-AC52-07NA27344. IM# LLNL-ABS-848875

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[1]M. May, *et. al,* "Development of high intensity X-ray sources at the National Ignition Facility", Physics of Plasmas **25**, 056302 (2018)
[2] P. T. Campbell, *et. al*, "Measuring magnetic flux suppression in high-power laser-plasma interactions", Physics of Plasmas **29**, 012701 (2022)

Laser-Plasma Interactions for X-ray Radiographic Imaging: An Update*

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Novel MeV x-ray sources based on high-power short-pulse lasers have the potential to revolutionize radiography with their small spot size, short pulse duration, low cost, and flexibility. In this poster, we report an update on Los Alamos's theoretical and experimental efforts to develop this technology. Using particle-in-cell and Monte-Carlo particle-transport codes, we simulate electron acceleration in short-pulse laser experiments with a variety of targets and calculate photon spectra resulting from bremsstrahlung radiation in a high-Z converter. We present preliminary results from a recent experimental campaign on the Texas Petawatt laser which studied intensity scaling and performance of various bare and coated tantalum targets.

*Work performed under the auspices of the U.S.~DOE by Triad National Security, LLC, and Los Alamos National Laboratory. This work was supported the LANL Laboratory Directed Research and Development program. High-performance computing resources were provided by LANL's Institutional Computing program. Experiments on the Texas Petawatt laser were supported by LaserNetUS.

Peculiar Profiles in the Subscale 'BigDipper' Campaign on the NIF*

Presenter R. C. Nora[1], A. Kritcher[1], R. H. H. Scott[2], V. Smalyuk[1], A. Zylstra[1]
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We report on the results of the 'BigDipper' subscale experimental campaign on the National Ignition Facility (NIF). The BigDipper scheme is a Shock-Augmented Ignition Approach[1] on conventional hot spot ignition and seeks an enhancement in compression by reducing the laser drive after peak power is reached for a short period of time before ramping back up to peak power. Simulations have shown the resulting drive imparted upon the capsule may lead to mitigation of the n+1 shock and/or enhanced compression at stagnation due to a late time pressure wave.

The subscale NIF campaign was based on a previous high-density-carbon subscale experiment and utilized two symcaps to verify the hohlraum response before culminating in a layered tritium-hydrogen-deuterium (THD) implosion. The two symcaps established the radiation hydrodynamic simulations to be in good agreement with experimental observations of the radiation temperature via the DANTE diagnostics, but differed in that the experimental stagnated profiles were prolate (as opposed to being round). The final shot in this series applied what we had learned from the symcaps to generate a (hopefully round) THD implosion which resulted in a yield-over-preshot-1D of ~50% and DSR-over-preshot-1D of ~90% but remained prolate. We will show integrated hohlraum calculations investigating the reason behind these peculiar profiles.

* This work was performed under the auspices of the U.S. DOE by LLNL under contract DE-AC52-07NA27344.
R. H. H. Scott, et al., "Shock-Augmented Ignition Approach to Laser Inertial Fusion," Phys. Rev. Lett. **129**, 195001 (2022)

Momentum deposition by beam bending results in bow shock generation in ICF plasmas

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High energy randomized laser beams interacting with flowing plasmas can produce a plasma response that leads to beam bending and, by momentum conservation, to slowing down of the plasma flow velocity [1]. For incoming plasma flow, with a velocity slightly greater than sound speed, the plasma response to a ponderomotive force exerted by speckled laser beams is the strongest, such that slowing down the flow to subsonic velocities leads to the formation of a shock. Recent OMEGA experiments demonstrated the shock formation due to ponderomotive and thermal coupling of the laser to the expanding plasma [2].

In this poster, we will detail a theoretical understanding of the momentum deposition, including the effect of temporal smoothing, present more results of hydrodynamic simulations, describe properties of the shocks, and discuss different ways of shock detection as well as an assessment of its impact on the laser plasma coupling. Simulations have shown large density and velocity jumps for the LEH parameters on NIF. The necessary condition for the shock to be formed is the presence of sonic velocity in the transverse flow across the laser beam. We will specify the required power and size of the interacting beams. The interaction of the expanding gold plasma in a hohlraum glint experiment will also be examined for shock generation.

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[2] C. Bruulsema, invited talk, AAC 2023.

A mid-beta booster for proton beams*

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Laser Plasma Acceleration of electron beam enables the production of high-energy and high-quality electron beams in ultra-compact setups, with a record-breaking 8 GeV beam produced in a 20 cm plasma capillary discharge[1]. While the idea of extending the same concept to the acceleration of ion beams is alluring, trapping an ion beam into the accelerating phase of a plasma wave is still a challenge. In fact, the group velocity of a laser driver in a plasma with a density typically used for acceleration (i.e., $10^{17}cm^{-3} \leq n_0 \leq 10^{19}cm^{-3}$) is on the order of $v_g \simeq c$. Due to its high rest mass, such ion (e.g., proton) velocity corresponds to a kinetic energy of several GeVs. However, the typical ion energy obtained from a compact laser-plasma source is $\mathcal{E}_{kin} \lesssim 100MeV$. Here, we explore the possibility of post-accelerating an ion beam produced in a compact laser-plasma source (e.g., a Magnetic Vortex Accelerator stage[2]) using the "snowplow" electric field of an intense laser pulse propagating in a near-critical density target[3]. The electron sheet that accumulates in front of the laser pulse generates an electric field on the order of $\mathrm{E} \geq 10\mathrm{TV/m}$, that yields GeV energy gains within a $\Delta z \simeq 100\ \mu m$ solid target, eventually reaching a sufficient energy for a subsequent beam injection into a Laser Wakefield Accelerator. Tapering of the target density is studied and employed as a mean to reduce the ion beam dephasing.

* This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, and used the computational facilities at the National Energy Research Scientific Computing Center (NERSC).

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[3] Liu, B., M. Shi, M. Zepf, B. Lei, and D. Seipt. 2022. "Accelerating Ions by Crossing Two Ultraintense Lasers in a Near-Critical Relativistically Transparent Plasma." *Physical Review Letters* **129** (27), 274801 (2022).

Design of Planar Heterogeneous Ablation Experiment on OMEGA*

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Ablation of heterogeneous material is not well understood and will play an important role in the implosion of targets such as the Polar Direct Drive- Wetted Foam concept[1] that employ advanced fabrication techniques. To this end, we are designing an experiment in a simplified planar configuration on the OMEGA platform which will drive a shock through the target by ablating a heterogeneous medium of two-photon-polymerization (2PP) 3D-printed lattice and liquid deuterium, where shock propagation speed and planarity of the shock structure relative to lattice morphology will be measured. To make sure the bulk of the ablation occurs in the heterogenous medium, we explore several options for front window material and thickness to minimize burnoff time, thereby maximizing ablation of the desired heterogenous material beneath. Results of initial 1D and 2D simulations of shock propagation will be presented. We anticipate presenting updates on current progress in modeling and design.

*This work is supported by LANL LDRD project 20230034DR.

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PIC Simulations of Autoresonant Beatwave Excitation*

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Autoresonant excitation of plasma and ion waves using frequency-chirped ponderomotive drives has been proposed as a method to excite beatwaves [1] and photonic structures [2] in plasmas. The method offers some advantages: the drive itself does not need to be intense and the excitation is large amplitude and robust to jitter in the plasma density. The original explorations of this technique were based on numerical solution of fluid models and analytic theory. Here we (see also [3]) we employ one-dimensional and two-dimensional PIC codes (SMILEI [4]) to investigate kinetic effects and laser depletion. We introduce a negative frequency chirp in the laser with the higher frequency such that the beat frequency of the lasers passes through resonance with the plasma frequency during the simulation. Our findings demonstrate that, as in the fluid case, autoresonant phase-locking to the beat-wave lasers can be achieved, thereby exciting a large-amplitude, high-phase-velocity plasma wave. The amplitude can exceed the Rosenbluth-Liu limit [5]. Regions of agreement and disagreement with fluid studies are explored. Similar to the fluid model, autoresonant excitation is seen to be robust to effects such as density jitter, and it exhibits a threshold behavior as seen in analytical calculations.

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*Work partially supported by the Berkeley-France Fund.

Investigating hypotheses regarding opacity experiments and theory comparisons above electron densities of $2x10^{22}cm^{-3}$

Presenter *H. M. Johns[1]*, R. F. Heeter[2], T. S. Perry[1], C. Fontes[1], Y. P. Opachich[2], M. Hohenberger[2], T. Urbatsch[1], on behalf of a large team
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This year the Opacity-on-NIF[1] and Opacity-on-Z[2] campaigns are working towards quantitative and rigorous comparisons between our measured opacity data for iron and theory at multiple conditions. This work falls under the seven-lab National Opacity Program (LANL, LLNL, SNL, NNSS, GA, LLE, UT Austin). While qualitative agreement exists at (T_e ~ 156eV, N_e ~ $7x10^{21}cm^{-3}$) [3] significant disagreements remain for higher densities (N_e ~$2x10^{22}cm^{-3}$). High backgrounds continue to be a problem for NIF for higher temperatures T_e (~180eV). These conditions are highly relevant for HED regimes but at higher temperatures and densities (≥180eV, $3x10^{22}cm^{-3}$) these opacities become relevant for the solar CZ boundary problem [4].

This talk will focus on the Opacity-on-NIF side of the above work. We will include details on the status of the current platform [1] as well as temperature [5] and density [6] measurements. Significant efforts have been expended to assess hypotheses regarding causes of the disagreements between theory and Opacity-on-NIF at (T_e ~ 156eV, N_e ~ $2x10^{22}cm^{-3}$), which is qualitatively similar to disagreements observed between Z data and theory at (~180eV, ~$3x10^{22}cm^{-3}$). This presentation will update the community on these NIF developments.

1. T.S. Perry, R.F. Heeter, Y.P. Opachich, et al, "Progress toward NIF opacity measurements", *High Energy Density Physics* ***35,*** *100728 (2020)*
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3. R. Heeter, T. Perry, H Johns, et al, "Iron X-ray Transmission Near 150eV Temperature using the National Ignition Facility: First Measurements and Paths to Uncertainty Reduction", *Atoms* ***6,*** *57, (2018)*
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5. Y. P. Opachich, E. S. Dodd, R. F. Heeter, et al, "DANTE as a primary temperature diagnostic for the NIF iron opacity campaign", Review of Scientific Instruments 92, 033519 (2021)
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Tuesday, June 20

Morning session I – the Village Lodge
Chair: David Strozzi

8:30 – 9:00 am	Investigating hypotheses regarding opacity experiments and theory comparisons above electron densities of 2x10^22cm-3 (**invited**)	*Heather Johns*
8:50 – 9:20 am	Inverse Bremsstrahlung Coulomb logarithm for non-Maxwellian Electron Distribution Functions	*Mark Sherlock*
9:20 – 9:40 am	Reduced thermal conductivity due to inverse bremsstrahlung absorption	*Nathaniel Shaffer*
9:40 – 10:00 am	Hot-electron preheat mitigation and scaling in polar-direct-drive inertial confinement fusion implosions at the National Ignition Facility	*Andrey Solodov*
10:00 – 10:20 am	Cross-beam energy transfer in conditions relevant to direct- drive implosions on OMEGA	*Khan Linh Nguyen*
10:20 – 10:40 am	**Coffee break**	

Morning session II – the Village Lodge
Chair: Matthew Edwards

10:40 – 11:10 am	High-energy proton beams generated from plasma in laser contrast insensitive 3D printed log-pile structures (**invited**)	*Sergei Tochitsky*
11:10 – 11:30 am	Direct measurements of peak laser intensity via electron scattering from high-intensity laser pulses	*Andrew Longman*
11:30 – 11:50 am	Laser harmonic generation with tunable orbital angular momentum using a structured plasma target	*Holger Schmitz*
11:50 – 12:10 pm	BELLA iP2: The Short Focal Length Beamline for High Energy Density Research at High Repetition Rates at the BELLA PW	*Lieselotte Obst-Huebl*
12:10 – 12:30 pm	Ionization injection and acceleration in a dephasingless laser wakefield accelerator	*Kyle Miller*

Lunch – the Westin

12:30 – 1:30 pm	**Lunch**

Inverse Bremsstrahlung Coulomb logarithm for non-Maxwellian Electron Distribution Functions

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Abstract

We provide analytic expressions for the effective Coulomb logarithm for inverse bremsstrahlung absorption which predict an increase in the absorption by as much as ≈30% over previous estimates. The calculation of the collisional absorption rate of laser energy in a plasma by the inverse bremsstrahlung mechanism usually makes the approximation of a constant Coulomb logarithm. We dispense with this approximation and instead take into account the velocity-dependence of the Coulomb logarithm, leading to a more accurate analytic approximation for the absorption rate valid in both classical and quantum conditions. In contrast to previous work, the laser intensity enters into the Coulomb logarithm. For a Maxwellian electron distribution the absorption rate is enhanced by ≈1-4% above previous estimates. In most laser-plasma interactions the electron distribution function is super-Gaussian [A.B. Langdon, Phys. Rev. Lett. **44**, 575 (1980)], and we find the absorption rate under these conditions is increased by as much as ≈30% compared to previous estimates.*

*This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344. Release LLNL-ABS-848920.

Reduced thermal conductivity due to inverse bremsstrahlung absorption*

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We present the results of Vlasov–Fokker–Planck simulations which demonstrate that a plasma being heated by inverse bremsstrahlung absorption also experiences a reduced thermal conductivity compared to Spitzer-Härm theory. The effect is analogous to the so-called "Langdon effect," through which the absorption of high-intensity laser distorts the bulk electron energy distribution and nonlinearly reduces the inverse bremsstrahlung heating rate.[1] In the present case, however, it is the tail electron population that is depleted relative to a Maxwell-Boltzmann distribution, which leads to reduced thermal conductivity. Such an effect has been previously theorized, but final predictions were not useful from a modeling perspective, since they relied on knowing the shape of the distribution function, typically in terms of a super-Gaussian exponent[2]. We show that the conduction electrons do approximately have such a shape, but the exponent is distinct from that of the bulk. Our approach also includes a correct treatment of electron-electron scattering, which is critical for quantitative accuracy. For conditions relevant to laser-direct-drive ICF designs, the actual conductivity can be lower than the Spitzer-Härm value by as much as 40%. We distill our results into a simple analytic fit that can be readily implemented in any radiation-hydrodynamics code.

*This work was supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 and by ARPA-E BETHE Grant Number DE-FOA-0002212.

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Hot-electron preheat mitigation and scaling in polar-direct-drive inertial confinement fusion implosions at the National Ignition Facility*

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Target preheat by super-thermal electrons from laser–plasma instabilities is a potential concern for direct-drive inertial confinement fusion. Polar-direct-drive (PDD) surrogate plastic implosion experiments were performed at the National Ignition Facility (NIF) to quantify preheat levels at ignition-relevant scale and develop mitigation strategies.[1] The experiments were used to infer the hot-electron temperature, energy fraction, divergence, and to directly measure the radial hot-electron energy deposition profile inside the imploding shell. Preheat scaling with the incident laser intensity and the target size at ignition-relevant scale has been obtained. It is shown that a thin mid-*Z* Si layer buried in the ablator or a Si-doped outer layer strongly mitigate the growth of laser-plasma instabilities and reduce preheat. Implosion analysis indicates that the higher laser absorption efficiency is another beneficial effect of Si. The Si layer should be kept thin to minimize the radiation preheat and utilize the larger ablation efficiency of the innermost lower-*Z* layer in the ablator. This provides a promising hot-electron preheat-mitigation strategy that can expand the ignition design space to higher intensity. The experiments show that hot-electron preheat can be acceptable in future cryogenic DT, ignition-scale PDD implosions on the NIF for on-target intensities up to 10^{15} W/cm^2.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

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Cross-beam energy transfer in conditions relevant to direct-drive implosions on OMEGA (*)

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In cross-beam energy transfer (CBET), the interference of two laser beams ponderomotively drives an ion-acoustic wave that coherently scatters light from one beam into the other. This redirection of laser beam energy can severely inhibit the performance of direct-drive inertial confinement fusion (ICF) implosions. To assess the role of nonlinear and kinetic processes in direct-drive-relevant CBET, the energy transfer between two laser beams in the plasma conditions of an ICF implosion at the OMEGA laser facility was modeled using particle-in-cell simulations. For typical laser beam intensities, the simulations are in excellent agreement with linear kinetic theory, indicating that nonlinear processes do not play a role in direct-drive implosions. At higher intensities, CBET can be modified by pump depletion, backward stimulated Raman scattering, or ion trapping, depending on the plasma density.

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High-energy proton beams generated from plasma in laser contrast insensitive 3D printed log-pile structures

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Laser-produced ion beams from 1 μm laser-plasma interactions have been a focus of high-energy density physics studies for several decades. Traditionally, these beams have been accelerated via the target normal sheath acceleration (TNSA) mechanism, which has scaling of the maximum kinetic energy of protons $E_p \propto \sqrt{I}$, where I is the laser intensity. To enhance TNSA via increase in coupling efficiency of radiation into hot electrons, beyond the ponderomotive potential of the laser, the current trend is to utilize very thin ~100-200 nm foils. For the nanofoils, as was shown experimentally, a relativistic induced transparency and associated flux of super-thermal electrons can result in increase in proton energy up to 100 MeV. However, survival of such an ultrathin target irradiated by a laser prepulse becomes a true limiting factor in wide usage for this approach.

To develop a robust method for ion acceleration in PW laser-solid interactions, we explore a novel target design, 2PP-printed log-pile microstructures. Usage of a relatively thick low-density target (~10-50λ, where λ is the laser wavelength) improves the absorption of the laser energy and facilitates generation of a relativistic plasma with electron temperature, $T_e \geq 1$MeV for which TNSA can be enhanced and sheath lifetime extended. In experiments at OMEGA EP PW laser facility, we detected high-energy ≥75 MeV, spatially round proton beams containing ~10^9 particles/MeVxSr. Measurements show that finite contrast due to the picosecond/nanosecond prepulse, characteristic for the PW glass laser system, doesn't affect acceleration process making such 3D printed microstructures a viable platform for reproducible laser-driven particle accelerators.

Direct measurements of peak laser intensity via electron scattering from high-intensity laser pulses

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With the increasing number of petawatt laser systems being developed worldwide, and laser intensities now surpassing the 10^23W/cm^2 barrier, we are entering a new regime of laser-plasma interactions. However, a direct measurement of these extreme laser intensities has yet to be made and is currently only inferred from indirect methods. An open question remains: how can we directly determine the peak intensity of a high-power, high-intensity laser system[1]?
In this work we report on a direct method of measuring the peak laser intensity using electron scattering from background vacuum pressures. The measurement is completely independent of the laser energy, pulse duration, and focal spot shape giving a high degree of accuracy compared to standard methods. We will present results on two recent experiments demonstrating a high precision, direct measurement of the peak intensity of the Scarlet laser at The Ohio State University, and the VEGA3 PW beam at the CLPU laser facility in Salamanca, Spain[2].
The experimental results will be compared with analytic and numerical models showing an excellent agreement between all three. Additionally, we will show how it is possible to measure other laser parameters in addition to the peak intensity through this method including, but not limited to, focal spot spatial aberrations[3].

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, Laserlab Europe V Grant No. 871124, and from Junta de Castilla y Leon, Grant No. CLP087U16, National Science Foundation Grant # PHY2010392, Natural Sciences and Engineering Research Council of Canada Grant # RGPIN-2019-05013, and the LaserNetUS initiative.

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Laser harmonic generation with tunable orbital angular momentum using a structured plasma target

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In previous studies of spin-to-orbital angular momentum (AM) conversion in laser high harmonic generation (HHG) using a plasma target, one unit of spin AM is always converted into precisely one unit of OAM [1,2]. Here we show, through analytic theory and numerical simulations, that we can exchange one unit of SAM for a tunable amount of OAM per harmonic step, via the use of a structured plasma target. The target absorbs the difference in total AM between that of n fundamental photons and the outgoing n-th harmonic photon. We introduce a novel way to analyze the frequency, spin and OAM content of the harmonic radiation which provides enhanced insight into this process. The prospects of structured targets for HHG with high-order transverse modes will be discussed.

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BELLA iP2: The Short Focal Length Beamline for High Energy Density Research at High Repetition Rates at the BELLA PW

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The new high-intensity iP2 beamline at the BELLA PW laser system enables frontier capabilities in High Energy Density Science (HEDS), including accessing exciting new regimes of ion acceleration. This system provides a focal spot of ~3 µm diameter, resulting in on-target peak intensities of $> 5\times10^{21}$ W/cm^2. The high laser pulse repetition rate capability (up to 1 Hz), if paired with innovative, replenishable target systems, will increase the particle flux for applications and allows for the collection of large data sets, enabling adequate statistical analysis of the results. We have implemented a double plasma mirror to improve the temporal contrast of the laser pulse before target interaction. These capabilities uniquely enable a series of scheduled experiments to study advanced ion acceleration mechanisms, investigate fundamental plasma processes relevant for Inertial Fusion Energy (IFE), and develop innovative plasma-based technologies with societal benefits, such as in radiation therapy. The iP2 beamline is accessible to users through LaserNetUS and was recently commissioned at high power with up to 17 J laser pulse energy. Proton beams were generated in the target normal sheath acceleration (TNSA) regime with cutoff energies up to 40 MeV. In this contribution we present the iP2 facility and recent ion acceleration results.

This work was supported by the U.S. Department of Energy (DOE) Office of Science, Offices of Fusion Energy Science (FES), LaserNetUS, and High Energy Physics. S. Hakimi was supported by the U.S. DOE FES Postdoctoral Research Program administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by Oak Ridge Associated Universities (ORAU) under Contract No. DE-SC0014664.

Ionization injection and acceleration in a dephasingless laser wakefield accelerator*

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The viability of laser wakefield accelerators for use in next-generation x-ray free-electron lasers or linear colliders is limited by dephasing, diffraction, and pump depletion. Spatiotemporally structuring the laser pulse using an axiparabola and echelon can overcome these limitations by producing an intensity peak that travels at the vacuum speed of light in a plasma over distances unconstrained by diffraction.[1] Here, we present particle-in-cell simulations that show ionization injection and acceleration of a 16-pC electron beam to a maximum energy of 1.6 GeV over 16 dephasing lengths (1.1 cm) using 3 J of laser energy (normalized vector potential of $a_0 \approx 2$). The highest-energy electron bunch contains 1.7 pC with an energy spread of 0.7% and divergence of 1.5 mrad. Stable propagation is obtained by masking the inner portion of the axiparabola, accelerating the focus to compensate the changing spot size, and offsetting the density profile so that $P/P_{\text{crit}} \lesssim 0.5$ for the inner core of the laser pulse. A more stable intensity peak and wake structure can be achieved by extending the focal region even further.

*This work conducted under the auspices of the Office of Fusion Energy Sciences under Award Number DE-SC00215057, the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

[1] J. P. Palastro, J. L. Shaw, P. Franke, D. Ramsey, T. T. Simpson, and D. H. Froula, "Dephasingless Laser Wakefield Acceleration," Physical Review Letters **124(13)**, 134802 (2020).

Tuesday, June 20 (cont'd)

Plenary evening session – the Village Lodge
Chair: Pierre Michel

7:00 – 8:00 pm	Proton-Driven Fast Ignition as a Route to Inertial Fusion Energy (**plenary**)	*Debbie Callahan*

Poster session – the Village Lodge
8:00 – 10:00 pm

Mitigating parametric instabilities with broadband laser light in direct-drive inertial-confinement-fusion plasmas	*Jason Bates*
Modeling of Laser-Plasma Interaction with the WarpX Exascale Code	*Alex Huebl*
Initial shape measurements of the inner shell of a Double Shell implosion with high-energy x-rays	*Paul Keiter*
Structure of a collisional plasma shock front in an extended hydrodynamics frame	*Olivier Larroche*
Effect of small magnetic fields on stimulated Raman scattering in the kinetic, strongly-driven regime	*Roman Lee*
Backscatter SBS relative cross-calibration of FABS Q31B (B318) and SLTD (37-94) at NIF	*Nuno Lemos*
Implementing field ionization models in VPIC for laser- target interaction simulations	*Brandon Medina*
X-Ray Spectroscopy of Mid-Z Tracers to Estimate Wall Mix in NIF Gas Pipe Experiments Relevant to MagLIF	*Henry Meyer*
Characterization of a plasma diffraction grating with equal pump and probe wavelengths	*Victor Perez-Ramirez*
Modeling of Halfraum-Driven Physics Experiments in an Eulerian Radiation-Hydrodynamics Code	*Joshua Sauppe*
Particle-in-cell simulations high-frequency hybrid instability (HFHI) dominated rescattering relevant to inertial fusion energy (IFE)	*Frank Tsung*
Development of a short pulse neutron source for multimodal radiography applications	*Jackson Williams*
Designing Thomson scattering diagnostics of unstable plasmas using particle-in-cell simulations	*Audrey Farrell*

Proton-Driven Fast Ignition as a Route to Inertial Fusion Energy

Debra Callahan, Pravesh Patel, Wolfgang Theobald, Stefano Atzeni, Matthias Brönner, Todd Ditmire, Paul Gibbon, Andrea Hannasch, Javier Honrubia, Charlie Jarrott, Alfonso Mateo Aguarón, Markus Roth, Lorenzo Savino, Olena Turianska, Xavier Vaisseau, Florian Wasser, Sero Zähter, Marc Zimmer
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Recent successes on the National Ignition Facility (NIF) laser [1-3] have renewed interest in inertial fusion as a potential source of clean energy. The challenge is to take the results from NIF and improve on the science and technology needed for a fusion energy power plant. A power plant will require a robust G ~100, rather than the G = 1.5 achieved on NIF, with high repetition-rate and low cost for the laser and targets.

Proton-driven fast ignition [4] is an alternate method for inertial fusion that holds promise for the high gain needed for a fusion power plant. In proton fast ignition, the compression and ignition are done in a two-step process. In the first step, nanosecond long-pulse laser beams compress the fuel around a re-entrant cone. Powerful picosecond short-pulse laser beams are then focused in a second step onto a hemispherical foil inside the cone and produce an intense proton beam, which is focused into the dense fuel to heat a small volume of the fuel to ignition conditions to initiate propagating burn.

Increased coupling of the laser energy to the target is one way to increase target gain. To reduce the complexity of the laser, we will use 2ω laser for the compression step rather than 3ω used on NIF and Omega. Control of laser-plasma instabilities (LPI) at 2ω is an important topic to address for our design. We will discuss our initial design concept, methods for mitigating LPI, and trade-offs that can be made between LPI, Rayleigh-Taylor instability, and required short pulse laser energy. We will also discuss future plans to fill the gaps in our knowledge.

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Mitigating parametric instabilities with broadband laser light in direct-drive inertial-confinement-fusion plasmas*

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It has long been recognized that broadband laser light has the potential to control parametric instabilities in inertial-confinement-fusion (ICF) plasmas. In this poster, we present results from LPSE simulations that estimate the bandwidths required to mitigate the three predominant classes of instabilities in direct-drive ICF implosions, namely, cross-beam energy transfer (CBET), two-plasmon decay (TPD), and stimulated Raman scattering (SRS). We find that for frequency-tripled, Nd:glass laser light, a bandwidth of 8.5 THz can significantly increase laser absorption in a direct-drive target by suppressing CBET, while 13 THz is needed to also mitigate absolute TPD and SRS on an ignition-scale platform. None of the glass lasers used in contemporary ICF experiments, however, possess a bandwidth greater than 1 THz and reaching larger values requires the use of an auxiliary broadening technique such as optical parametric amplification or stimulated-rotational-Raman scattering. An arguably superior approach is the adoption of an argon-fluoride (ArF) laser as an ICF driver. Besides having a broad bandwidth of 10 THz, the ArF laser also possesses the shortest wavelength (193 nm) that can scale to the high energy and power required for ICF—a feature that helps to suppress parametric instabilities even further. We show that these native properties of ArF laser light are sufficient to eliminate nearly all CBET scattering in a direct-drive target and also raise absolute TPD and SRS thresholds well above those for broadband glass lasers. The effective suppression of parametric instabilities with broadband lasers would have an enormous impact on the field of ICF because it would allow the use of thicker, lower-aspect-ratio pellets that are more resistant to hydrodynamic instabilities and therefore require less precision in their fabrication and laser illumination uniformity to achieve high-yield implosions.

*This work was conducted under the auspices of the U.S. Department of Energy (NNSA/ARPA-E/FES)

Prefer poster session

Modeling of Laser-Plasma Interaction with the WarpX Exascale Code*

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The study of kinetic effects in laser-plasma interactions (LPI), strong field generation and acceleration of particles requires a coordinated effort in modeling, theory and experimentation. In this presentation, we show results of full 3D modeling with the WarpX electromagnetic particle-in-cell code for applications in LPI and laser-ion acceleration. In particular, we will present recent breakthroughs in high-fidelity modeling using advanced algorithms and Exascale-class supercomputers[1] to resolve the target physics of over-critical and near-critical targets for the acceleration of electrons and ions.

We show modeling results for experimental campaigns in LaserNetUS at the newly commissioned high-intensity beamline at the Lawrence Berkeley National Laboratory BELLA Center, interaction point 2 (iP2).[2] There, an intense PW laser pulse of 30 fs length, focused to a few microns in diameter spot size interacts with a near-critical density (NCD) target to generate energetic ion beams via the Magnetic Vortex Acceleration (MVA) mechanism. We compare with the study of interactions with overdense targets for established ion acceleration mechanisms (such as TNSA, RPA) and draw connections to applications of WarpX in IFE, e.g., the applicability of modeling for proton-driven fast ignition schemes.

*This work was supported by the U.S. DOE Office of Science, LaserNetUS, Offices of High Energy Physics and Fusion Energy Sciences (FES), and used resources at Lawrence Berkeley National Laboratory (DE-AC02-05CH11231), NERSC (FES-ERCAP0024250), and OLCF (DE-AC05-00OR22725). S. Hakimi was supported by the U.S. DOE FES Postdoctoral Research Program administered by the ORISE (DE-SC0014664). WarpX was supported by the Exascale Computing Project (17-SC-20-SC) and the CAMPA Collaboration, a project of the U.S. DOE Office of Science ASCR and HEP Offices, Scientific Discovery through Advanced Computing (SciDAC) program.

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[2] S. Hakimi, L. Obst-Huebl, A. Huebl et al., "*Laser–solid interaction studies enabled by the new capabilities of the iP2 BELLA PW beamline,*" Physics of Plasmas **29**, 083102 (2022).

Initial shape measurements of the inner shell of a Double Shell implosion with high-energy x-rays*

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Double shell capsules provide a complementary and alternative path to the single shell inertial confinement fusion (ICF) approach. Generically, a double shell capsule consists of an outer shell, a medium between the shells and a high-Z inner shell filled with DT fuel. Double shell targets rely on effectively transferring the kinetic energy of the outer shell to the inner shell to compress the DT fuel. To measure the shape of the inner shell surface pushing against the DT, high energy x-rays are required. We will present initial results from experiments on the National Ignition Facility (NIF) utilizing the Advanced Radiographic Capability (ARC) measuring the shape of the inner shell.

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Structure of a collisional plasma shock front in an extended hydrodynamics frame

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The ions of the hot plasma inside inertial confinement fusion targets can sometimes be not collisional enough to be safely modelled by the Euler equations implemented in standard hydrodynamics codes. To treat the non-equilibrium features which can hence arise in the plasma, an extended hydrodynamics model has been developed, which includes higher moments of the ion velocity distribution function, together with physically justified closure assumptions and relaxation terms[1].

In this work, after refining the underlying distribution defining the closure for improved hyperbolicity, we apply the latter code to the classical problem[2] of the structure of a collisional plasma shock front. The non-equilibrium features found in a kinetic, Vlasov-Fokker-Planck, description[3] of the shock front are partially recovered: the very high ion heat flux in the embedded shock is satisfactorily reproduced, although the extended, high-velocity kinetic feature in the upstream region of the shock structure is not.

That encouraging result is a guide in further developments of the extended hydrodynamics model, e.g. for the design of an improved N-moment closure involving faster hyperbolic modes[4].

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Effect of small magnetic fields on stimulated Raman scattering in the kinetic, strongly-driven regime*

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We have previously shown how backward stimulated Raman scattering (SRS) in the kinetic regime ($k\lambda_{De} \approx 0.30$ for backward SRS scattered plasma wave) can be mitigated by weak external magnetic fields ($\omega_c/\omega_p << 1$, where ω_c and ω_p are the cyclotron and plasma frequencies, respectively) [1]. These results considered moderate laser intensities, on the order of those found in the average speckle of a beam at the National Ignition Facility (NIF). Speckles of up to an order of magnitude higher intensity also exist in a NIF beam and are important. In this work we explore the effects of small magnetic fields in this more strongly-driven regime, where 1D and 2D OSIRIS simulations that show that the magnetic field can enhance the SRS reflectivity, in contrast to what occurs at lower intensities. A number of mechanisms are responsible for this phenomenon, including enhanced resonance and suppression of rescatter with the magnetic field, in addition to competition between forward and backward SRS. Geometrical effects revealed by 2D simulations will also be discussed.

**Work conducted under the auspices of DOE through CMEC*

[1] B. J. Winjum, et al. *Phys. Rev. E 98*, 043208 (2018)

Implementing field ionization models in VPIC for laser-target interaction simulations

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X-ray radiography using a high-power short-pulse lasers to generate x-rays is of interest as this technology can create a spot $<$100 microns in size for energies up to 25 MeV. The development and design of laser-based radiography systems can be optimized with predictive simulations that include laser-target interactions, such as field ionization. We have implemented multiphoton ionization and the Ammosov-Delone-Krainov (ADK) model with the barrier-suppression ionization (BSI) correction into the particle-in-cell code, VPIC. This work investigates the implementation of field ionization into VPIC as well as simulations with field ionization enabled, which include benchmark tests that were run to increase confidence that the field ionization models are implemented correctly into the code.

*Work performed under the auspices of the U.S.~DOE by Triad National Security, LLC, and Los Alamos National Laboratory. This work was supported the LANL Laboratory Directed Research and Development program. High-performance computing resources were provided by LANL's Institutional Computing program. LA-UR-23-24874

X-Ray Spectroscopy of Mid-Z Tracers to Estimate Wall Mix in NIF Gas Pipe Experiments Relevant to MagLIF

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A major concern in Magnetized Liner Inertial Fusion (MagLIF) is the mixing of material from the Beryllium liner into the fuel. This mixture can radiate energy out of the imploding fuel, reducing the target's yield. Wall mix largely comes from the shockwave produced during the laser preheating phase of MagLIF. The laser produced shockwave can rip and transport material from the liner inward towards the center of the MagLIF target. At the Nation Ignition Facility (NIF), experiments are being performed to quantify the mix produced during laser preheating using tracer materials of Titanium and Vanadium in a MagLIF relevant target. The X-Ray spectroscopy of N230226 -002 and -003 has yielded potentially valuable measurements of the trajectory and behavior of the tracer wall materials that can be used to better inform simulations and future MagLIF experiments.

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Characterization of a plasma diffraction grating with equal pump and probe wavelengths

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The energy output of ultrashort lasers continues to increase, resulting in high-peak powers that necessitate an increase of the size of optics. However, large optics are expensive and undesirable for compact laser systems. Plasma optics offer a solution to this problem because their damage thresholds are orders of magnitude larger than those of traditional solid-state optics, allowing plasma-based optical devices to be much smaller. Diffractive ionization gratings, a type of plasma optic, can be created by crossing two laser beams within a neutral gas; the interference between the beams causes fringes of varying intensity that produce alternating layers of plasma and neutral gas, resulting in a modulated index of refraction[1,2]. We present experimental measurements of an ionization grating created and probed with 800 nm femtosecond pulses, where the pump and probe beams are separated by polarization. We find an average diffraction efficiency of up to 34%.

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Modeling of Halfraum-Driven Physics Experiments in an Eulerian Radiation-Hydrodynamics Code*

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The LANL double shell[1] platform consists of a low-*Z* outer shell and a high-*Z* inner shell that contains deuterium-tritium fuel. The outer shell is driven indirectly with x-rays produced inside a cylindrical hohlraum. It collides with and transfers its kinetic energy to the high-*Z* inner shell, which then compresses and heats the fuel to conditions of volumetric burn. As the high-*Z* shell is accelerated inwards, it is very susceptible to acceleration-phase Rayleigh-Taylor instability that can compromise the heating of the fuel and reduce the yield. Understanding and mitigating this instability growth is crucial to improving double shell performance.

Planar physics experiments have been leveraged to study proposed mitigation mechanisms for this acceleration phase instability growth, as they are more easily diagnosed than their spherically converging counterparts. In these experiments, lasers are directed onto the walls of a "half-hohlraum" or "halfraum" through one laser entrance hole. A cylindrical tube is mounted on the opposite side, and radiation inside the halfraum drives a physics package inside of the tube. The physics package consists of an aluminum ablator directly exposed to the radiation, which mimics the outer shell of the double shell, and a layer composed of a mixture of beryllium and zirconium that sits farther down the tube, which approximates the inner shell of the double shell.

The xRAGE[2,3] Eulerian radiation-hydrodynamics code has been extended[4,5] to include physics needed to model such indirect-drive experiments. We use xRAGE to model these planar physics experiments including the detailed halfraum geometry and laser beam configuration, representing an advancement over previous design calculations that utilized a frequency-dependent-source to approximate the drive. We explore the various sensitivities to electron thermal conduction parameters, halfraum fill density and fill gas, target component densities in the physics package, and the impact of the window in the laser-entrance-hole in our simulations. We also assess the resolution requirements for the halfraum material. [LA-UR-23-24904]

* This work was supported by the US Department of Energy through the Los Alamos National Laboratory, operated by Triad National Security, LLC, for the National Nuclear Security Administration (Contract No. 89233218CNA000001).

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Particle-in-cell simulations high-frequency hybrid instability (HFHI) dominated rescattering relevant to inertial fusion energy (IFE)

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In inertial fusion energy (IFE) plasmas, the scattered light from stimulates Raman scattering can undergo re-scatter and generate successively shorter wavelength electron plasma waves (EPWs) which can accelerate electrons to higher and higher energies [1]. However, in some advanced designs where the electron temperature is very high [2] and in direct drive scenarios, laser plasma instabilities occurs above 0.11 nc. For these densities, the scattered light cannot rescatter in-place and must propagate down the density gradient to the quarter critical surface of the scattered light where it will undergo the high-frequency hybrid instability [3] due to the high temperature of these plasmas. Because the primary LPI occurs at higher densities compared to those studied by Winjum *et al*, the wavelength of the scattered light (λ^2) can increase by a factor of 2 to 4, making rescatter much more likely even with very modest amounts of reflectivity.

The intricate interplay between the primary laser plasma instability and the secondary absolute instabilities is of fundamental importance, and it has potential implications in current and future experiments. We will present scenarios where HFHI rescattering is triggered by HFHI scattering near the quarter critical surface and by inflationary stimulated Raman scattering and discuss the relevance of these simulations to future target designs.

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* This work conducted under the auspices of LLE, CMEC and NNSA.

Development of a short pulse neutron source for multimodal radiography applications*

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Neutron sources are used in a wide variety of applications including material science, isotope production and radiography. Short pulse laser-driven neutrons have unique characteristics such as sub-ns durations and high peak brilliance. The peak flux that is often required to probe temporally evolving environments has not yet been demonstrated for these laser-driven sources. Here, we report on the platform development of a pitcher-catcher neutron source using the high energy short pulse lasers such as NIF-ARC, Omega-EP, and Titan. This presentation will report on scaling studies that explored neutron yield, spectrum, and directionality for a range of laser conditions. We will also present work to develop a simultaneous multimodal radiography platform designed to capture both an x-ray and neutron radiograph of a dynamic system.

* This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and funded by the LLNL LDRD program under tracking code 22-ERD-022.

Designing Thomson scattering diagnostics of unstable plasmas using particle-in-cell simulations*

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Optical Thomson scattering is commonly used to characterize the local density, temperature, and flow of laboratory plasmas. The analytical models used to extract plasma parameters from the Thomson scattered spectrum often require the assumption that the plasma is in local thermal equilibrium. Since this assumption fails for plasmas produced by ultrashort laser pulses before the plasma electron velocity distribution has time to thermalize through collisions, there is a need for analytical and computational methods that can reproduce the Thomson scattered spectra of nonthermal and unstable plasmas. We present a method for predicting the Thomson scattered spectra from any plasma directly from fully kinetic particle-in-cell (PIC) simulations. This approach does not require simulating the probe beam, and so one simulation of the plasma of interest can be used to optimize the scattering geometry to target specific features in the phase space of the plasma. We demonstrate nonthermal features in the Thomson spectrum for a bump-on-tail plasma using 1D PIC simulations. We then extend this method into 2D and demonstrate its application to simulations of a laser-ionized laboratory plasma and compare the simulated Thomson spectrum to experimental measurements.

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Wednesday, June 21

Morning session I – the Village Lodge
Chair: Mark Schmitt

8:30 – 9:00 am	Identifying mix in MagLIF experiments on the NIF using time-resolved spectroscopy and self-emission signatures (**invited**)	*Ellie Tubman*
8:50 – 9:20 am	High-Energy-Density Experimental Platform at OMEGA for Studies of Strongly Magnetized Inertial Fusion Plasma	*Arijit Bose*
9:20 – 9:40 am	Magnetized Hotspot ICF for High Yield	*Darwin Ho*
9:40 – 10:00 am	Exploring Axial and Other Imposed Magnetic Fields to Improve Layered Hohlraum-Driven Implosions	*David Strozzi*
10:00 – 10:20 am	Self-generated Magnetic Fields in Hohlraums: Uncertainties in MHD Modelling	*Chris Walsh*
10:20 – 10:40 am	**Coffee break**	

Morning session II – the Village Lodge
Chair: Eugene Kur

10:40 – 11:10 am	Benchmarking magnetized three-wave coupling for laser backscattering (**invited**)	*Yuan Shi*
11:10 – 11:30 am	Testing the Applicability of the WKB Method to Parametric Instabilities in Inhomogeneous Plasmas Using Stimulated Raman Backscatter in Steep Density Gradient Plasmas	*Mitchell Sinclair*
11:30 – 11:50 am	Predicting the growth of backward stimulated Brillouin scattering of smoothed laser beams	*Charles Ruyer*
11:50 – 12:10 pm	Measurement of the Filamentation Instability Growth Rate in Short-Pulse Laser Beams	*Kyle McMillen*
12:10 – 12:30 pm	**Business meeting**	

Lunch – the Westin

12:30 – 1:30 pm	**Lunch**	

Identifying mix in MagLIF experiments on the NIF using time-resolved spectroscopy and self-emission signatures.*

Eleanor R. Tubman[1], Bradley B. Pollock[2], Henry Meyer[2], David J. Strozzi[2], John D. Moody[2], Adam J. Harvey-Thomspon[3], Matthew R. Weis[3], Michael E. Glinsky[3], Stephanie B. Hansen[3], Ryan Lau[3], Evstati G. Evstatiev[3], David J. Ampleford[3] and Kristian Beckwith[3]

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Experiments are being undertaken at the NIF to investigate MagLIF, helping to understand the laser pre-heat stage that will be used in a full-scale MagLIF scheme[1,2]. Shock waves, launched from the heater beams propagating through the gas pipe, rebound off the walls and have the potential to cause mix, bringing material into the gas interior[3,4]. If the wall material is able to mix at early times the higher Z material would increase radiation losses, degrading the compression phase and decreasing potential neutron yields[5,6].

This talk will present recent results collected at the NIF, demonstrating both spatially and temporally resolved measurements of mix. Tracer strips of titanium and vanadium were attached to the gas pipe walls and the materials were tracked using both spectrometers and gated x-ray detectors (GXDs). A chromium backlighter was used to cause fluorescence of the gas pipe before two laser quads directly propagated through the gas pipe, reheating the gas interior. Spatially integrated but temporally resolved x-ray emission was recorded by a spectrometer. Additional measurements were made by taking ratios of emission from filtered GXD images so that the tracer material's location could be verified and measured over time. Indirect inferences of the wall material mixing can also be made using laser propagation through the gas pipe [7,8]. The propagation velocities of reheat beams through the gas pipe give indications of the densities at the different probing times. The various results from this platform will be discussed and corroborated with simulations from HYDRA.

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High-Energy-Density Experimental Platform at OMEGA for Studies of Strongly Magnetized Inertial Fusion Plasma

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External magnetic fields applied to an inertial confinement fusion (ICF) implosion make the fuel ions gyrate around the B-field lines, which can improve the probability for fusion and potentially boost fusion energy gain. With recent advances facilitating the generation of very high B-fields, it is essential to experimentally investigate and characterize the effects of strong magnetization on the dynamics and symmetry of an ICF implosion. This work discusses the first observation of how a strong, 500 kG, externally applied B-field increases the mode-2 asymmetry in shock-heated ICF implosions. Using an implosion with polar illumination and imposed B-field, the magnetization produces a significant increase in the implosion oblateness (a 2.5× larger P2 amplitude in x-ray self-emission images) compared to the reference case with identical drive but with no B-field applied. The magnetized implosions produce strongly magnetized electrons ($\omega_e\tau_e \gg 1$) and ions ($\omega_i\tau_i > 1$) that, as shown by simulations, restrict the cross-field heat flow necessary for lateral distribution of the laser and shock heating from the pole to waist of the implosion, causing an enhanced mode-2 asymmetry. Additionally, this work provides a novel experimental platform for producing unique plasma conditions where the electrons and ions are both strongly magnetized, and thus opens avenues for future studies of magnetized transport properties in high-energy-density plasmas.
This work was supported in part by the US DOE, the National Laser Users Facility and Laboratory for Laser Energetics.

Magnetized Hotspot ICF for High Yield*

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With ignition reached by N221204, the next milestone for ICF is to obtain a high yield. Magnetized hotspot ICF offers the possibility of reaching a high yield, e.g., > 20 MJ, with laser energy in the 2.0 – 2.2 MJ range. Magnetization improves implosion performance by reducing the transverse plasma heat conduction and the effective alpha particle range in the hotspot. Implosion performance can be quantified in terms of ignition margin, which can be expressed by the Generalized Lawson Parameter (GLP). We will show the extension of the GLP by including the *B* field. Based on 2D simulations and the GLP, the embedded field can improve implosion robustness, yield, and/or radiation symmetry and open the option of using DT-wetted foam targets for high yield. For example, yield can be increased using the same capsule configuration and laser energy but with a thicker fuel layer while maintaining the same GLP. The embedded B field does not impede the propagation of burn waves. The magnetized implosions for hotspot ignitions are in the favorable parameter range that the *B* field confines the alpha particles in the interior region of the hotspot, where the ratio of alpha gyro radius to hotspot radius $\widehat{r_\alpha} \lesssim 0.2$ and the electron Hall parameter $\mathcal{X}_e > 10$, to shorten the effective alpha range for enhanced energy deposition, but not at the outer region of the hotspot and the burn front, where $\widehat{r_\alpha} > 1$ and $\mathcal{X}_e < 10$, to impede burn propagation. The corresponding value of the alpha particle confinement parameter — the *B* field strength times the hotspot radius BR_h — around stagnation, is ~100 T×cm. This is about twice as large as the value of 42 ± 5 T×cm inferred from MagLIF experiments with deuterium on the Z machine at Sandia.[1] The ratio of inflight alpha particle to plasma particle density in general is < 10^{-2}. Thus, the *B* field strength degradation via enhanced Nernst-like magnetic flux advection[2] resulted from the azimuthal alpha particle drift current generated by the radial alpha particle energy gradient is not important.

*This work is performed under auspices of U.S. DOE by LLNL under contract DE-AC52-07NA27344 and LDRD 15-ERD-058

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Exploring Axial and Other Imposed Magnetic Fields to Improve Layered Hohlraum-Driven Implosions*

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We are investigating the design of magnetized, cryo-layered, indirectly-driven ICF targets that use an imposed magnetic field to improve their performance. This stems from the reduced electron-thermal and alpha-particle losses from the hotspot, and potentially reduced hydrodynamic instability. We build on the experimental demonstration at the National Ignition Facility (NIF) of increased fusion yield and hotspot ion temperature in room-temperature, gas-filled, hohlraum-driven capsules with imposed axial fields up to 28 Tesla[1]. One thrust is to impose a field on existing high-performing NIF experiments, such as the ignition shot from August 2021 and the breakeven shot from December 2022. Another is to push non-igniting targets into the ignition regime (which postpones the long-known issue of fields inhibiting burn propagation[2]).

We present early modeling for the first planned NIF cryo-layered experiments with imposed B field. These will be based on the sub-scale (1.3 MJ of laser) BigFoot[3] shot N190721, which is the highest yield to date at this reduced laser energy. We also study the benefits of magnetizing variations on this design.

We are separately considering if non-axial fields can do better than axial ones. These include mirror, cusp, and closed-azimuthal fields. The latter could be especially attractive: since no field lines leave the hotspot, electron and alpha losses are inhibited in all three Cartesian directions (as opposed to two for an axial field). A challenge here is the electrons can become too hot to couple well to the ions. Another is imposing an azimuthal field without degrading the capsule by e.g. running a wire through it. We discuss the potential of an "Omega" coil[4] to impose field of alternating direction in the capsule, which could form closed lines in the implosion due to magnetic reconnection.

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Self-generated Magnetic Fields in Hohlraums: Uncertainties in MHD Modelling*

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Simulations suggest that self-generated magnetic fields increase the hohlraum gold bubble and LEH electron temperatures by more than 1keV[1], bringing them in closer agreement with experimental data. However, the modeling is more nuanced than simply 'turning MHD on'. This talk will show how specific modeling decisions can change the predicted hohlraum conditions and discuss simplified experiments for improving the certainty in our modeling of self-generated magnetic fields.

It is widely known that a flux limiter must be applied to the classical heat-flow in hohlraum conditions; in the same way, a flux limiter must also be applied to the Nernst advection of magnetic fields down temperature gradients. The uncertainty in the value of this flux limiter changes the simulated LEH temperature by approximately 1keV. Thankfully, simplified experiments of Nernst cavitation in under-dense plasmas will help constrain the appropriate values for a Nernst flux limiter[2].

Biermann Battery magnetic field generation also has its own uncertainties. It is believed that the generation mechanism is suppressed in the kinetic regime relevant to hohlraums[3]. A reduced model for this suppression has been implemented into the extended-MHD code Gorgon and applied to simplified foil experiments on OMEGA EP, finding that kinetic suppression of Biermann Battery is required to simulate the magnetic flux generation rate[4]. The impact of this suppression on electron temperatures in the hohlraum is approximately 800eV.

Further uncertainties, such as magnetic field generation at the bubble-gas interface, will be explored.

*This work was 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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Benchmarking magnetized three-wave coupling for laser backscattering*

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Understanding magnetized laser-plasma interactions is important for controlling magneto-inertial fusion experiments and developing magnetically assisted radiation and particle sources. For ns pulses at non-relativistic intensities, interactions are dominated by coherent three-wave processes, whose nonlinear coupling coefficients became known only recently when waves propagate at oblique angles. In this talk, after briefly reviewing theories of magnetized three-wave interactions, we will focus on benchmarking analytical growth rates using particle-in-cell simulations [1]. Excellent agreements are found for a wide range of plasma temperatures, magnetic field strengths, and laser propagation angles when backscattering is mediated by electron-dominant hybrid waves. Systematic comparison between theory and simulations is made possible by a rigorous protocol: On the theory side, the initial-boundary value problem of linearized three-wave equations is solved, and transient-time solutions allow effects of growth and damping to be distinguished. On the simulation side, parameters are carefully chosen, and calibration runs are performed to ensure that comparisons are well controlled. Finally, the analysis is extended to lower-frequency waves, which affect backscattering as well as cross-beam energy transfer. Model predictions are being tested experimentally at the OMEGA facility.

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Testing the Applicability of the WKB Method to Parametric Instabilities in Inhomogeneous Plasmas Using Stimulated Raman Backscatter in Steep Density Gradient Plasmas

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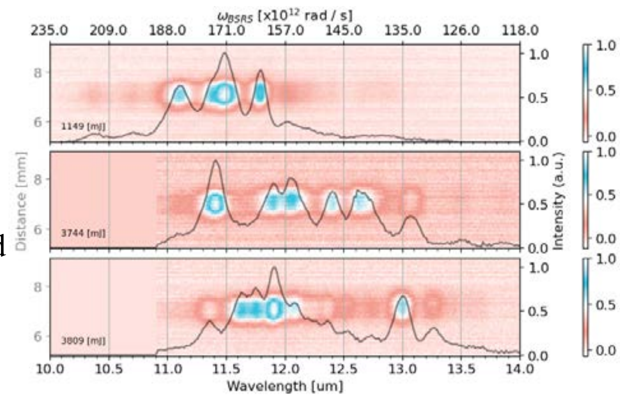

Figure 1: B-SRS Spectra from LWIR Spectrometer

We are experimentally testing the validity of the Wentzel-Kramers-Brillouin (WKB) approximation for estimating the spatial extent of the regions over which Stimulated Raman Back Scattering (SRBS) occurs in inhomogeneous plasmas with length scales of (L~70-200λ_o). The experiment uses a picosecond CO_2 laser drive with a normalized vector potential of a_0 of 0.4 – 0.8. We observe and diagnose the spectral amplitude of SRBS via a custom ZnSe long wavelength IR prism spectrometer that can cover the spectral range from 10-20 µm. SRBS is a three wave process described by $\omega_o = \omega_s + \omega_{EPW}$ and $\boldsymbol{k_o} = \boldsymbol{k_s} + \boldsymbol{k_{EPW}}$ where the pump electromagnetic (ω_o, $\boldsymbol{k_o}$) decays into a scattered EM wave (ω_s, $\boldsymbol{k_s}$) and an electron plasma wave ($\omega_{EPW}, \boldsymbol{k_{EPW}}$). We find that the time integrated SRBS generated in such steep plasma density gradients have distinct peaks riding on top of a weaker continuous background and that the spatial extent of these peaks is in reasonable agreement with that expected using the WKB approximation applied to SRBS by Lui, Rosenbluth & White, $dk_{EPW}(x)/dx = \omega_p/2k_{EPW}c^2 L_n \ll 2k_{EPW}^2$ [1], where ω_p, c, L_n are the plasma frequency, speed of light and plasma length scale, respectively. The spatial extent of which the instability at certain frequencies is the distance over which the pump wave can transfer its energy to the scattered daughter waves as described by $\Delta\Phi = \int_0^{\xi_{int}} \Delta K\, dz$ [2] where ΔK is the phase mismatch between the pump, plasma and daughter wave: $\Delta K = k_{EPW} - k_o - k_-$ [2]. In such a steep plasma density gradient this region may be just tens of pump wavelengths long, so short, that the B-SRS cannot self-adjust to the rapidly changing wave number interacting waves until they are detuned, i.e. $\Delta\Phi = 1/2$ [2] and the WKB validity condition is no longer satisfied. Fully self-consistent PIC simulations are used to reproduce our experimental spectra. These show that the weaker backscattered background, on which the more intense peaks reside, can arise from SRBS of the forward scattered Stokes and anti-Stokes radiation which can extend the spectral range over which downshifted radiation occurs, Fig 1.

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Predicting the growth of backward stimulated Brillouin scattering of smoothed laser beams

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Based on a previous work [1], we derive a system of equations describing the backward stimulated Brillouin scattering (BSBS) in the convective regime. This new model accounts for the polarization, temporal and spatial beam smoothing techniques used in most high energy laser facilities [2]. Quantifying the instability variability induced by the phase plates is shown to be crucial for understanding quantitatively the backscattering spatial growth as well as the reflectivity. An analytical correction to the plane wave spatial gain is extracted from our theory for a simple and effective reflectivity prediction that includes the impact of the most relevant smoothing techniques in inertial confinement fusion (ICF) conditions. Validated by a large number of three dimensional hydrodynamic paraxial (Hera) simulations [3] and experimental data [4], our model shades a new light on the long-time studied BSBS deleterious to many high energy experimental studies related to the physics of ICF [5]. Finally, the implementation of our model in a ray tracing scheme and the possible interpretation of ICF experimental results will be discussed [6].

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Measurement of the Filamentation Instability Growth Rate in Short-Pulse Laser Beams

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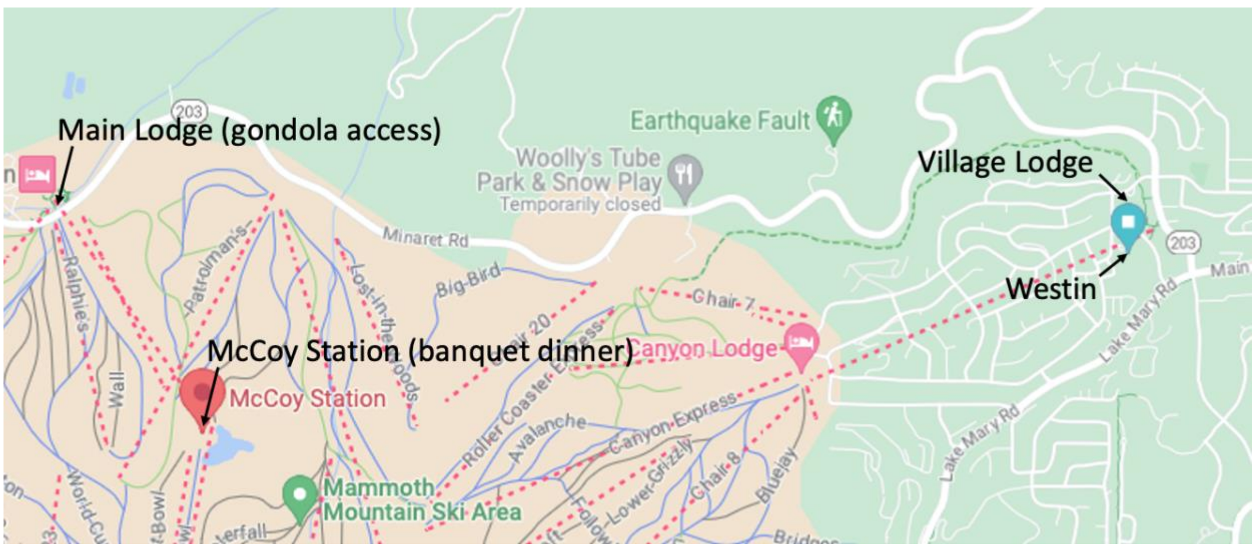
In the filamentation instability, the ponderomotive and thermal ejection of electrons from the high-intensity regions of a laser beam within a plasma create modulations in the plasma density and refractive index, which lead to self-focusing and filamentation of the beam. We present an experiment that utilizes the joint operation of the OMEGA 60 and OMEGA EP laser systems at the University of Rochester's Laboratory for Laser Energetics to investigate the growth rate of the filamentation instability. In our experiment, a 1ω short-pulse (1—100-ps) laser beam from OMEGA EP is coupled into a preheated plasma on the OMEGA 60 laser–plasma interaction platform. The resulting beam spray of the filamented short-pulse beam is recorded as a time-integrated 2-D image while plasma parameters are determined via Thomson scattering. By modifying the incident short-pulse beam pulse duration, we can limit the growth of the instability and record the beam spray at discrete steps in its temporal evolution. The inferred radial-growth rate is then compared with simulations, theoretical predictions, and scaling with incident beam intensity and plasma temperature. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 and the Office of Fusion Energy under Award Numbers DE-SC0016253 and DE-SC00215057.

Wednesday, June 21 (cont'd)

Banquet Dinner – McCoy station

5:30 – 7:00 pm	Reception
7:00 – 8:30 pm	Banquet dinner

The banquet dinner will be held at McCoy Station (elev. 9,600 ft), accessible via a (free) gondola ride from the Main Lodge (cf. map).
Dinner should be served around 7 pm but the bar and reception will open at 5:30 pm. Please plan to be at the gondola at 6:30 pm at the latest.



Access:
You can drive on your own to the Main Lodge (a 10- to 15-minute drive from the Westin, plenty of parking at the Main Lodge), or take a free shuttle from the Westin. The 40-person shuttle will make loops between the Westin and the Main Lodge throughout the evening (schedule below).

Shuttle schedule:

Departs from Westin (5:15 to 6:15 pm)		Returns from Main Lodge (8:45 to 9:45 pm)	
5:15 pm	Pick up @ Westin	8:45 pm	Pick up @ ML gondola
5:30 pm	Drop off @ Main Lodge (ML) gondola	9:00 pm	Drop off @ Westin
5:45 pm	Pick up @ Westin	9:15 pm	Pick up @ ML gondola
6:00 pm	Drop off @ ML gondola	9:30 pm	Drop off @ Westin
6:15 pm	Last pick up @ Westin	9:45 pm	Last Pick up @ ML gondola
6:30 pm	Drop off @ ML gondola	10:00 pm	Drop off @ Westin

Thursday, June 22

Morning session I – the Village Lodge
Chair: Jason Bates

8:30 – 9:00 am	Ray-based modeling of cross-beam energy transfer for broadband lasers (**invited**)	*Russ Follett*
8:50 – 9:20 am	Nonlinear laser-plasma interactions near quarter-critical density in plasmas	*Andrei Maximov*
9:20 – 9:40 am	Measurements of nonuniform distributions of unabsorbed light from OMEGA implosions	*Dana Edgell*
9:40 – 10:00 am	Quantifying the effectiveness of different laser beam smoothing techniques on mitigating inflationary Stimulated Raman scattering	*Han Wen*
10:00 – 10:20 am	Dynamic Control of the Spatial Frequency Content of an Intense Laser via Intra-Beam Energy Transfer	*Josh Ludwig*
10:20 – 10:40 am	**Coffee break**	

Morning session II – the Village Lodge
Chair: Russ Follett

10:40 – 11:10 am	Applying Differentiable Programming to Theoretical, Computational, and Experimental Plasma Physics (**invited**)	*Archis Joglekar*
11:10 – 11:30 am	Accelerating diagnostic parameter estimation for improved understanding of Thomson scattering using machine learning	*Avi Milder*
11:30 – 11:50 am	Heat Flux and Anisotropic Electron Temperatures in Laser- Driven Magnetized Gas-Jet Plasmas	*Zachariah Barfield*
11:50 – 12:10 pm	GPU acceleration of the particle-in-cell code OSIRIS with maximal memory utilization	*Roman Lee*
12:10 – 12:30 pm	Influence of the solid-to-plasma transition on the laser energy deposition in targets and subsequent hydrodynamics for direct drive inertial confinement fusion	*Romain Liotard*

Lunch – the Westin

12:30 – 1:30 pm	**Lunch**

Ray-based modeling of cross-beam energy transfer for broadband lasers*

R. K. Follett, A. Colaitis[1], A.G. Seaton[2], H. Wen, D. H. Froula, J. P. Palastro, and D. Turnbull
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Broadband laser drivers (>1% relative bandwidth) have the potential to mitigate many of the laser plasma instabilities that limit the performance of current direct-drive inertial confinement fusion implosions. To assess the impact of bandwidth and set the bandwidth requirements for future laser drivers, laser bandwidth models need to be included in the radiation hydrodynamic codes that are used to simulate implosions. Two different approaches to broadband ray-based cross-beam energy transfer (CBET) modeling (discrete and fixed spectrum) are developed and shown to be in good agreement with wave-based calculations. Implementation of these models into radiation hydrodynamic simulations shows that broadband drivers can mitigate CBET in OMEGA-scale implosions.

* This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 and ARPA-E BETHE Grant Number DE-FOA-0002212.

Nonlinear laser-plasma interactions near quarter-critical density in plasmas*

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In the direct-drive approach to the inertial confinement fusion (ICF), the importance of the plasma region near the quarter of the critical density is due to the two-plasmon decay (TPD) instability growing in this region, as TPD has the lowest intensity threshold among the laser-plasma interaction (LPI) instabilities. Nonlinear stage of TPD leads to the formation of the plasma region where a balance is achieved between a high level of plasma waves that grow in TPD, and a high level of ion-acoustic perturbations that are driven by plasma waves and saturate the TPD.[1] The threshold of TPD is usually exceeded in the plasma corona of direct-drive ICF experiments, and the laser light propagating through the instability region experiences additional absorption.[2]

Our model for nonlinear LPI in the plasma region with enhanced incoherent waves includes the interplay between the TPD, the crossed-beam energy transfer (CBET) and laser scattering and absorption. For the laser intensity profiles relevant to direct-drive ICF experiments on OMEGA laser system, three-dimensional modeling of nonlinear LPI have been performed using the laser-plasma simulation environment (*LPSE*). The scalings for nonlinear LPI processes in the plasma region near quarter-critical density have been obtained consistent with LPSE results.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856.

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Measurements of nonuniform distributions of unabsorbed light from OMEGA implosions*

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The primary method of diagnosing the absorption of laser light in a direct-drive implosion is the measurement of the unabsorbed light scattered from the implosion. These measurements have been critical to the implosion performance improvements on OMEGA. In particular, scattered light spectra were the key to identifying cross-beam energy transfer (CBET) as the primary source of absorption degradation on OMEGA.

Historically, the only absolute calibrated scattered light diagnostics were the two Full Aperture Backscatter Stations (FABS) and the scattered light was assumed to be isotropic over 4π. The FABS are located in neighboring beam ports near OMEGA's south pole and cover a total of less than 0.3% of the distribution. As more and different scattered light diagnostics were deployed on OMEGA, it became apparent that there were significant nonuniformities (10s of percent) in the scattered light distributions. There are several sources of low modes in the absorption and scattered light distributions for implosions, including: beam energy balance, beam mispointing, polarization effects on CBET[1], and possibly others.

There are now a variety of scattered light diagnostics[2,3] available to better diagnose the scattered light distribution and we can sample a much larger (~9%) faction of the distribution along with a better spread in sampling position. Once the diagnostic issues have been worked out, we aim to have a true constraint on the laser coupling during OMEGA implosions in order to refine modeling of absorption physics (e.g. Coulomb logarithm, Langdon effect, ion screening and TPD laser absorption).

* This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

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Quantifying the effectiveness of different laser beam smoothing techniques on mitigating inflationary Stimulated Raman scattering *

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Kinetic inflation exacerbates the threat of the stimulated Raman scattering instability (SRS) to inertial confinement fusion. Continued growth of the instability requires phase matching between the incident light wave and the decay products, a scattered light wave and an electron plasma wave (EPW). In principle, a density inhomogeneity can disrupt the phase matching by changing the frequency of the EPW along the gradient. In reality, electron trapping in the EPW produces a frequency shift that can compensate this change. This autoresonance, or kinetic inflation, can substantially enhance the SRS reflectivity. Here we demonstrate that laser bandwidth can mitigate inflationary SRS and limit the reflectivity to non-inflationary levels by rapidly moving the location of exact phase matching. While the instantaneous reflectivity depends on the local chirp of the incident light, the inflationary SRS threshold depends on the bandwidth format, for example random or smoothing by spectral dispersion. This leads to distinct scaling laws which can help guide SRS mitigation efforts.

*This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856.

Dynamic Control of the Spatial Frequency Content of an Intense Laser via Intra-Beam Energy Transfer*

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We present theory and simulations demonstrating that bandwidth-inducing optical smoothing techniques such as smoothing by spectral dispersion (SSD) can initiate Intra Beam Energy Transfer (IBET) within a single beam. IBET consists in energy transfer between the different frequency components of the beam, and results in a simultaneous and correlated redistribution of the temporal and spatial frequencies of the laser's electric field. We identify a threshold in bandwidth for IBET to occur and validate the theory with simulations. The bandwidth and color cycling of SSD can result in IBET in conditions relevant for high-energy density experiments at the National Ignition Facility and Omega Laser. We show that IBET could be used to manipulate a laser's spatial frequency content within a plasma. In particular, this technique could be used to increase a laser's effective f-number, with potential applications for self-guiding in plasmas.

Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344. Release number: LLNL-ABS-824293.

Applying Differentiable Programming to Theoretical, Computational, and Experimental Plasma Physics

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Modern deep learning relies on the paradigm of automatic differentiation (AD) to perform gradient descent and update the weights and biases of the underlying function approximators, typically neural networks of varying architectures. In contrast to finite-differencing, AD enables efficient and accurate calculations of gradients with respect to many parameters within a single function call, the most prominent examples of which are the gradients used to update the 100B parameter functions used in Large Language Models. In contrast to symbolic differentiation, AD is capable of calculating derivatives of arbitrary functions which do not have tractable symbolic derivatives as long as those functions can be expressed numerically, such as those resulting from the time-integration of a partial differential equation. In this work, we emphasize that the application of AD is not restricted to neural-network-centric programs. We discuss examples where

1. an AD-assisted simulation code expands plasma physics theory by enabling the discovery of parameter regimes where novel non-linear behavior occurs,
2. an AD-assisted simulation code enables efficient incorporation of kinetic physics into reduced models such as fluid codes, and
3. an AD-assisted model-based experimental diagnostic enables parameter estimation that was previously deemed impractical due to computation time requirements.

Accelerating diagnostic parameter estimation for improved understanding of Thomson scattering using machine learning

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Over the past 30 years Thomson scattering has become one of the premier diagnostics for temperature and density measurements at large multiple-beam laser facilities. With improved diagnostic expertise and modeling capabilities it is now possible to extract more information Thomson scattering such as the electron distribution function [1], heat transport [2], and local current fluctuations [3]. Speeding up diagnostic analysis allows deeper investigation of the data and more scientists to utilize the data in their experiments.

Thomson scattering is typically analyzed by matching a model spectral density function to lineouts of the measured data often using gradient-descent-based optimization. However, this approach suffers from the curse of dimensionality, making it increasingly difficult to extract more information. A new algorithm that leverages the use of GPUs and automatic differentiation allows for efficient gradient calculation and significantly increased computation speed. These techniques enable 10-100x faster parameter estimation from Thomson scattering in HED plasmas. This improved algorithm also allows estimation of additional parameters at minimal additional cost, resulting in more information from a single spectrum in less time.

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Heat Flux and Anisotropic Electron Temperatures in Laser-Driven Magnetized Gas-Jet Plasmas (*)

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Experiments at the Omega Laser Facility have utilized a single-beam gas-jet platform to infer anisotropic electron temperatures ($T_{e\parallel} > T_{e\perp}$) in a low-density Nitrogen plasma ($n_e = 5 \times 10^{18} cm^{-3}$). The temperature anisotropy persists when a 15 T magnetic field is applied to plasma. At these conditions the magnetic-field pressure is comparable to the plasma electron pressure ($\beta \cong 2$). Thomson-scattering analysis show the spectral density function changes relative to the axis of the magnetic field. The temperature anisotropy exists on a nanosecond timescale while being driven by a high-intensity 3ω beam ($I = 5 \times 10^{14} W/cm^2$).

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GPU acceleration of the particle-in-cell code OSIRIS with maximal memory utilization*

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Fully relativistic particle-in-cell (PIC) simulations are crucial in advancing knowledge of plasma physics. Modern state-of-the-art GPU supercomputers offer the potential to perform PIC simulations of unprecedented scale, but require robust, performant, and feature-rich codes to support users. We have addressed this demand by adding GPU acceleration to the PIC code OSIRIS. Our approach strikes a balance between preserving the existing CPU codebase and achieving high performance by accelerating only the particle pushing and sorting routines. Within this design framework we maximize performance by enabling high device memory utilization through tile-based dynamic load balancing and a pre-allocated, manually-managed memory pool for particle data. Additionally, the memory pool eliminates any cost of resizing particle buffers and enables complete fault tolerance during particle communication. We present detailed benchmarks for performance on Perlmutter, and demonstrate that GPU acceleration of only particle routines can yield high performance in a PIC code. Our approach may serve as a model for implementation of GPU acceleration on other mature PIC codes as they transition to full GPU support.

**Work conducted under the auspices of DOE, LLNL, NSF, LLE*

Influence of the solid-to-plasma transition on the laser energy deposition in targets and subsequent hydrodynamics for direct drive inertial confinement fusion

Presenter R. Liotard[1], A. Colaïtis[1], I. V. Igumenshchev[2], A. Pineau[2], S. X. Hu[2], A. Sollier[3], E. Lescoute[3], B. Canaud[3], G. Duchateau[4]
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Inertial Confinement Fusion (ICF) is a method of achieving nuclear fusion reactions by bringing a small mass of combustible material at high densities with the desired thermodynamic properties. To achieve this goal, direct drive ICF uses high power laser beams to implode a spherical target which consists of gaseous DT fuel surrounded by a thin shell of DT ice and an outermost layer of plastic ablator. The laser ionizes the plastic which is ablated and the target implodes due to the rocket effect. In radiation hydrodynamics codes, the plastic ablator is approximated as opaque to the laser radiation, i.e. an initial plasma state is assumed. The solid-to-plasma transition of the ablator is not modeled in the aforementioned codes, whereas it may have an important role in implosion symmetry, target compressibility, shock timing, and hydrodynamic instability.

This work is a continuation of a study on the effects of solid-to-plasma transition on direct drive ICF simulations. This study was carried out on simulations of experiments undertaken at the OMEGA laser facility. This work focus on the experimental validation of the coupling between the solid-to-plasma transition model and a hydrodynamics code. The transition model was developed in Ref. [1,2] and describes the solid-to-plasma transition of polystyrene (most ICF ablators are composed of polystyrene). It has been experimentally benchmarked for photoionization in Ref. [3]. This model has been coupled to the 3D radiations lagrangian hydrodynamics code Azathoth, a code developed at the CELIA.

I will present results from an experiment carried at CEA-DIF on the GCLT laser. The purpose of this experiment was to measure the transmission of a laser pulse (5ns with a peak intensity of 2.10^{12} W/cm^2) through a polystyrene layer. The comparison of these results with the simulation allowed us to validate the coupling of the transition model to the hydrodynamic code. It thus validates the results of the study of the effects of solid-to-plasma transition on the ICF simulation : the pre-heating of the ablator, the reduction of low mode of hydrodynamic instabilities and the increase of high mode instabilities.

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Thursday, June 22 (cont'd)

Plenary evening session – the Village Lodge
Chair: Tom Chapman

7:00 – 8:00 pm	Fusion power and the impact on planet Earth (**plenary**)	*Chris Young / Brian Spears*

Poster session – the Village Lodge
8:00 – 10:00 pm

Study of the X-ray drive deficit on hohlraums at the National Ignition Facility	*Nicholas Aybar*
Diagnostic signatures of thermonuclear implosions near ignition on the NIF	*Laurent Divol*
Modeling the effect of spectral phase shaping on laser-driven ion acceleration on ensemble scales	*Blagoje Djordevic*
Reaction-in-Flight Measurements using Neutron Time-of- Flight at the National Ignition Facility (NIF)	*Shaun Kerr*
Comparisons of Kinetic Effects on Heat Transport to Classical Fluid Models in MagLIF Gaspipes on NIF	*Ryan Lau*
Evidence of high-power laser beam ponderomotive filamentation when burning-through a gas-filled target	*Pascal Loiseau*
Multi-stage lasing in Ar atoms contained in a weakly ionized air plasma in the high-field regime	*Noa Nambu*
Developing high fluence bremsstrahlung x-ray sources enhanced by magnetic fields	*Patrick Poole*
The Role of Improved Hohlraum Efficiency in Indirect Drive Inertial Confinement Fusion Experiments on the National Ignition Facility	*Joseph Ralph*
Towards a General-Purpose Model of Inverse- Bremsstrahlung Absorption for Laser-Produced Plasmas	*David Strozzi*
Experimental Studies of SBS and CBET Mitigation Via Enhanced Laser Bandwidth at the Nike Laser	*James Weaver*
Particle-In-Cell Simulations of Nonlinear Electron Plasma Waves Propagating in Magnetic Fields	*Benjamin Winjum*

Study of the X-ray drive deficit on hohlraums at the National Ignition Facility

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Integrated models of indirect drive inertial confinement fusion (ICF) experiments often rely on the use of multipliers on the laser pulse or hohlraum plasma opacities to accurately match experimental bang times. The deficit between measured and simulated x-ray drive, known as the drive deficit, is pervasive in these experiments[1]. Several experimental campaigns carried out at the NIF allow investigation of the relevant parameters which affect the drive deficit including the hohlraum complexity and laser pulse shape. For example, the build-a-hohlraum campaign, where each shot in the series increases the hohlraum complexity (laser entrance hole size, laser pulse, gas-fill, capsule, etc.). These experiments provide data on the dependence of the X-ray drive on hohlraum features and complexity. The rise to peak power campaign employs a ViewFactor hohlraum to measure the X-ray drive as seen from the capsule to determine if the deficit begins during the rise to peak power of the laser pulse. These experiments use either a nominal 'fast-rise' laser pulse or 'slow-rise', where the rise to peak power was slowed by 1.5 ns. For all experiments, the time-resolved Dante diagnostic yields direct measurements of the X-ray drive across many spectral energy bands. In particular, the multi-layer mirror incorporated into a Dante channel designed to observe the 'M-band' region can be compared directly to numerical simulations due to its flat spectral response[2]. Here we present data from these experiments compared against a semi-empirical model[3] as well as numerical simulations to study the relationship between hohlraum designs, laser parameters and the observed X-ray drive deficits as well as the spectral dependence of the drive deficit.

*This work conducted under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. De-AC52-07NA27344

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diagnostic signatures of thermonuclear implosions near ignition on the NIF*

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Since the Y = 1.35 MJ layered DT experiment of August 2021, roughly 15 layered experiments have produced thermonuclear yields Y between 100 kJ and 3 MJ+ on the NIF. This talk will describe what is observed on a suite of Xray and neutron diagnostics, temporally, spatially and spectrally resolved, as the yield varies. Comparison with expectations from simple one-dimensional simulations will be discussed.

*** 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.** 1074714

Modeling the effect of spectral phase shaping on laser-driven ion acceleration on ensemble scales*

Presenter B.Z. Djordjevic, D. Mittelberger, T. Galvin, E. Grace, G. Zeraouli†, K. Swanson, P. Campbell, B. Sullivan†, J. Rocca†, R. Hollinger†, S. Wang†, R. Nora, A.J. Kemp, S.C. Wilks, J. Ludwig, R. Anirudh, J. Thiagarajan, T. Bremer, J. Kim*, T. Ma, J. Williams, and D.A Mariscal
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In this work was performed modeling of spectrally-shaped, laser-driven ion acceleration in a multi-fidelity framework that covered several orders of parameter space. Inspired by pulse-shaping at nanosecond timescales such as those found in inertial confinement fusion, spectral shaping by means of a dazzler allows us to modify the temporal shape of a short-pulse laser on femtosecond to picosecond time scales. An assembly of over 10,000 1D PIC simulations was used as the support for several hundred 2D PIC simulations modeling both Gaussian and shaped pulses based on experiments performed at the CSU ALEPH laser facility. The 1D dataset is used to inform a neural-network surrogate model which is then elevated to 2D fidelities via ad-hoc transfer learning, whereby the intuition and trends embedded in the 1D data is used to inform the surrogate model of the 2D data at accuracies not possible otherwise. More complex network architectures also allow us to synthesize non-congruent datasets in ways otherwise not possible and may allow for the integration of more realistic, experimentally-based data in future work. Pulse shaping suggests that we can not only achieve higher ion energies than otherwise accessible with just a Gaussian pulse but also that typical quantities of interest such as dosage, temperature, conversion efficiency may be partially tuned independently of one another to a limited degree.

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Reaction-in-Flight Measurements using Neutron Time-of-Flight at the National Ignition Facility (NIF)*

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The deuterium-tritium (D-T) reaction is utilized at the National Ignition Facility (NIF) to achieve high yield Inertial Confinement Fusion (ICF). The primary products of this reaction, neutrons and alpha particles, can elastically scatter with deuterons and tritons to produce up-scattered ions, which in turn can undergo fusion reactions. The resulting high energy reaction-in-flight (RIF) neutron spectrum is highly sensitive to stopping power losses, and therefore can act as a probe for key parameters of the hot spot and fuel shell, such as mix fraction, quantum degeneracy of the cold fuel, and the fuel adiabat. The NIF neutron time-of-flight (nToF) spectrometer suite consists of five different lines-of-sight, with detectors located at ~20 m from the chamber center. These spectrometers can span over six orders of magnitude in dynamic range, allowing them to measure both the primary D-T fusion and RIF spectra. This work will cover advancements in nToF-based RIF measurements, using improved diagnostic configurations, hardware, and analysis, and the ensuing insights that can be gained for implosion performance at the NIF.

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51ST AAC ANOMALOUS ABSORPTION CONFERENCE 2023

Comparisons of Kinetic Effects on Heat Transport to Classical Fluid Models in MagLIF Gaspipes on NIF

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We present simulations of heat flow relevant to MagLIF-related gaspipe experiments on NIF[1] to investigate kinetic effects on transport phenomena. These D2 and neopentane (C5H12) filled gaspipe targets are used to study the laser preheat stage of a MagLIF scheme where an axial magnetic field is applied to the target. Modeling these gas pipes is usually done with the radiation-magneto-hydrodynamic code HYDRA[2] with a collision-dominated fluid model. However, we find the Knudsen number, the ratio between the electron mean free path and temperature scale lengths, exceeds 0.01 in substantial regions of space indicating the regime where non-local effects are important for electron heat flow. Non-local effects are a primary candidate for why the observed heat flux is greatly over or under predicted by classical transport models such as Spitzer-Harm or Braginskii. Motivated to further study kinetic nonlocal effects, we utilize Hydra to initialize plasma conditions for the Vlasov Fokker-Planck K2 code[3] until a quasi steady-state heat flow is reached. We compare the kinetic heat flux from K2 to classical transport models, as well as the reduced nonlocal Schurtz model[4]. We do this in 1D and 2D geometry over realistic experimental volumes, which are usually not modeled kinetically.

*This work was 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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Evidence of high-power laser beam ponderomotive filamentation when burning-through a gas-filled target

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The propagation of a 351-nm 1-TW 3-ns laser through a 5-mm long gas-pipe is investigated using the OMEGA EP laser facility. The laser-plasma coupling strength is adjusted by varying the gas-pipe's backing pressure, giving an electron density range from 5 to 10% of the laser critical density. The laser transmission through the gas-pipe is inferred using a VISAR diagnostic, while proton deflectometry is used for probing the plasma at different times. Measurements show that in such configuration, where the high-power laser heats and propagates inside the gas, strong ponderomotive and thermal filamentations develop, breaking the laser beam in typically 100-µm large filaments. This is in agreement with simulations using the HERA paraxial code where ponderomotive and thermal forces are modeled at the speckle scale. Further analytical confirmation is also given when calculating the unstable filamentation's wavelengths [1]. In addition, our ponderomotive filamentation model is now implemented into the Troll radiative-hydrodynamics code [2]. Three-dimensional simulations confirm the development of filaments with wavelengths into the expected range. Those truly unique results quantitatively show that, in the early stage of the laser propagation, in conditions relevant to the indirect drive approach for inertial confinement fusion, beams' break-up is still a serious concern, possibly seeding defaults in the shell's capsule

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Multi-stage lasing in Ar atoms contained in a weakly ionized air plasma in the high-field regime*

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We will show that when atmospheric air is weakly ionized by multi-photon ionization of Ar contained in air, it can lase on several transitions either sequentially or simultaneously. When pure Ar is weakly ionized using a 261 nm, <100fs long laser pulse, 3 photon absorption leads to resonant excitation of the 3d level. By definition this level is inverted with respect to all the energy levels below it, and can lead to superfluorescent photon emission on cascaded transitions. We also find that when air is used instead of pure Ar a similar cascaded lasing is seen on nearby but different wavelengths, corresponding to different electronic transitions in the Ar atom. This wavelength shift effect is traced to the coupling of Ar with nitrogen in air. In addition, when a coherent beam with photon energy corresponding to one of the lasing transition energies is sent through the system, the beam can be amplified. Superfluorescence is observed in both forwards and backwards directions, which makes it useful for remote sensing. [1]

* This work conducted under the auspices of DOE Award No. DE-SC0010064:0011 , NSF grant No. 2003354:003 and Office of Naval Research (ONR) N00014-19-1-2517:P00002

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Developing high fluence bremsstrahlung x-ray sources enhanced by magnetic fields*

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The National Ignition Facility (NIF) laser is uniquely capable of generating large x-ray fluence with Ehν > 1 keV through high energy laser plasma interactions, most successfully by pumping atomic transitions in plasmas heated to He-like temperatures. A high fluence source of hard x-rays (30+ keV) is desired for extreme radiation effects testing but it is challenging to boost yields in this energy range using existing laser-driven K-alpha or pulsed-power bremsstrahlung capabilities.

An alternative scheme being developed enhances laser-plasma instabilities to generate hot electrons that convert to bremsstrahlung x-ray emission in high-Z target walls. Experiments on Omega and NIF have been performed varying hohlraum plasma conditions to strengthen and enhance plasma waves, most recently using strong external magnetic field (10's of T) to prolong favorable plasma conditions for x-ray generation and resulting in 6x enhancement over non magnetized outputs. The underlying physics of the magnetic field effects on these x-ray sources–flow confinement prolonging optimal thermal and density conditions as well as enhanced wave breaking will be discussed, as well as upcoming NIF shots testing high power laser pulses and novel target foam designs with MagNIF.

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The Role of Improved Hohlraum Efficiency in Indirect Drive Inertial Confinement Fusion Experiments on the National Ignition Facility*

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Indirect drive inertial confinement fusion (ICF) uses a hohlraum to convert laser energy into x-rays. Recent campaigns have demonstrated higher efficiency by reducing losses by (1) reducing the size of the laser entrance hole entrance hole and (2) by reducing the area of the hohlraum wall. These hohlraum efficiency improvements have translated into higher performance when used in DT layered implosions. In one series of experiments conducted on the NIF, a 420 TW, 1.7 MJ Hybrid E design 3-rise laser pulse and a pure gold hohlraum have demonstrated an increase in radiation temperature by ~18 eV from 292 to 310 eV. The experimental results show the systematic increase in radiation temperature with decreasing diameter of the laser entrance hole from 3.64 mm to 3.1 mm. A 1.1 mm inner radius high density carbon ablator filled with deuterium and Helium-3 was used to assess the performance gains and impact on implosion symmetry. Results show the higher radiation temperatures led to increases in velocity measured through in-flight radiography and peak x-ray core emission time, a doubling of the DD fusion yield and a 15% increase in hot spot temperature. The more efficient hohlraum developed in these experiments were than used with a 1.05 mm inner radius capsule contributing significantly to the recent ignition scale results[1]. Measured performance increases were also measured in higher efficiency hohlraums when using a 1.0 mm inner radius capsule. These results and preliminary results using very efficient hohlraums will be presented and compared with hydrodynamic simulations.

* This work was 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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Towards a General-Purpose Model of Inverse-Bremsstrahlung Absorption for Laser-Produced Plasmas*

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Inverse-bremsstrahlung (IB) absorption of laser light is a very old and important topic. Many practical models are in use, that attempt to include a broad range of effects, for the full range of plasma and laser conditions encountered in HED experiments. Motivated by the recent, quantitative absorption measurements by Turnbull et al.[1], we are revisiting this problem. The goal is a model that is comprehensive yet computationally lightweight enough to be implemented inline in the ray-tracing package of a radiation-hydrodynamics code. We specifically propose a model based on logarithmic approximations to the full quantum-mechanical, velocity-dependent Gaunt factor of Sommerfeld for the unscreened Coulomb interaction[2] - with proper order-unity numerical factors. To correctly handle non-Maxwellian electron distributions f(v) due to the Langdon effect[3], it is important to thermally average this Gaunt factor times f(v) rather than simply use the Maxwellian result[4]. The "vacuum" Sommerfeld result needs to be extended to include dielectric medium response, namely screening, which we are studying via quantum partial-wave calculations with screened Coulomb potentials. An approximate multiplicative factor to reduce absorption due to screening may be adequate, based on the quantum Born approximation[5].

Other effects we examine are ray-tracing envelope equations with finite damping, Fermi degeneracy following Meyer-ter-Vehn[6], and electron-neutral collisions for weak ionization. Future work will address partial ionization. We note that the physics of IB absorption overlaps with that of free-free x-ray opacity, even if discussed with different languages.

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Experimental Studies of SBS and CBET Mitigation Via Enhanced Laser Bandwidth at the Nike Laser

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Increased laser bandwidth is currently of great interest as a mitigation strategy for laser-plasma instabilities (LPI) in inertial confinement fusion. Experiments at the Nike laser facility have demonstrated that the laser output spectrum can be broadened from 1 THz to almost 5 THz with stimulated rotational Raman scattering (SRRS). Without the application of SRRS, the output spectrum for the Nike laser (λ_{peak}=248.5 nm) can be varied with etalons in the front end over a range of 0.3 to 3 THz. The fall LPI campaign will investigate bandwidth effects on stimulated Brillouin scattering (SBS) using the etalons to vary the laser spectrum. Additionally, a range of plasma conditions will be created with varied targets, including thin exploding foils and large scale (~1mm) low density CH foams. A development platform for using stimulated rotational Raman scattering (SRRS) for broader bandwidth (> 3 THz) in SBS/CBET experiments will be presented.

Prefer Poster Presentation
*Work support by DoE/NNSA

Particle-In-Cell Simulations of Nonlinear Electron Plasma Waves Propagating in Magnetic Fields*

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The kinetic evolution of nonlinear electron plasma waves (EPWs) is sensitive to the presence of magnetic fields, even magnetic fields with weak normalized amplitude ($\omega_c/\omega_p << 1$). Perpendicular magnetic fields can accelerate trapped particles across the EPW wave front, damping the wave and altering the wave-particle interactions that are responsible for the nonlinear damping and frequency of these waves. This can have significant consequences for laser-plasma instabilities like stimulated Raman scattering whose growth and saturation depend on the damping and frequency of EPWs. We present particle-in-cell simulations of externally driven electron plasma waves showing how the initial damping and frequency of the wave, the evolution of the wave after several bounces, and its long-time evolution after many bounce times are all effected by even weak magnetic fields.

*This work conducted under the auspices of the NNSA.

Friday, June 23

Morning session I – the Village Lodge
Chair: Benjamin Winjum

8:30 – 9:00 am	LPI comparison of foam and gas-filled hohlraum experiments on LMJ (**invited**)	*Mikhail Belyaev*
8:50 – 9:20 am	Modeling stimulated Brillouin scattering across multiple NIF hohlraum designs	*Andreas Kemp*
9:20 – 9:40 am	Impact of Stimulated Brillouin Backscatter on HYDRA Simulations of the Hybrid-E Platform at NIF	*Eugene Kur*
9:40 – 10:00 am	Ion acoustic instability driven by stimulated Raman scattering in picosecond laser-plasma interactions	*Christophe Rousseaux*
10:00 – 10:30 am	**Coffee break**	

Morning session II – the Village Lodge
Chair: Laurent Divol

10:30 – 10:50 am	Observation of ponderomotively driven bow shock (**invited**)	*Colin Bruulsema*
10:50 – 11:20 am	New Insight into Hohlraum Science from Recent NIF Experiments	*Hui Chen*
11:20 – 11:40 am	A comparison among the three platforms for ignition	*Baolian Cheng*
11:40 – 12:00 am	Towards new direct-drive facilities: comparison of novel chamber beam geometry robustness to mispointing, imbalance and target offset	*Diego Viala*

12:00 – conference adjourns.

LPI comparison of foam and gas-filled hohlraum experiments on LMJ

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Ultra-low density aerogel foams can be manufactured with average density down to 1 mg/cc. We report results from two shots on LMJ that studied the effect of replacing a substantial fraction of the fill gas with a 1 mg/cc SiO_2 aerogel foam. The first shot was a control, which used a standard C_5H_{12} (neopentane) gas-filled hohlraum with a gas fill density of 0.55 mg/cc. The second shot used a hohlraum with a 0.305 mg/cc C_5H_{12} gas fill in addition to a 1 mg/cc SiO_2 aerogel foam insert. The foam insert was a cylinder that radially spanned the width of the hohlraum.

The average hohlraum ne/nc (fully-ionized) was equal for both the foam and control shots. The foam insert was strategically placed at the same axial position as where the outer beams strike the wall of the hohlraum. The local overdensity at this position due to the foam mitigated the ballistic gold-bubble expansion, occurring in the time interval between the foot of the laser pulse and peak power. A reduction in gold bubble size was observed in both simulations and experiments, although the effect was more pronounced in the simulations. A smaller gold bubble allows better propagation of the inner beams to the waist. This improves capsule symmetry and potentially allows for an extended laser pulse.

We assess backscatter in the foam and control shots by performing time-dependent LPI simulations with the code pF3D. We compare the pF3D results to steady state gain calculations along rays using the code FLIP. One surprising result is the pF3D prediction of high outer beam SRS, which is observed experimentally, but not supported by the gains calculations. The experimental data also show an inner beam SBS reflectivity that is roughly constant through peak power for the foam design but decreases steadily from beginning to end of peak power for the control. We see similar trends in pF3D simulations, which may be indicative of enhanced inner beam propagation to the waist in the foam design.

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Modeling stimulated Brillouin scattering across multiple NIF hohlraum designs

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Stimulated Brillouin backscatter (SBS) is a potential risk for laser damage in experiments at the National Ignition Facility and by altering the energy deposition pattern in hohlraums, it affects the symmetry of indirect-drive ICF implosions. We have surveyed SBS backscatter on outer-cone quads across ten NIF integrated hohlraums of various platforms numerically, using three-dimensional simulations with the backscatter code pF3D and ray-based gain calculations with FLIP. Measured reflected powers and energies, drawn from two separate diagnostics, as well as the spectrum of reflected light all compare favorably with pF3D simulations. Ray-based calculations of exponential SBS amplification ("gain"), which assume a strongly damped plasma wave and steady-state response, are performed using a novel method that includes the 3D speckled field of the laser that drives SBS. This approach is useful for understanding qualitative differences between hohlraum designs and identifying regions susceptible to SBS within hohlraums. However, gains are in general not found to correlate with SBS reflectivities in 3D, necessitating time-dependent calculations using pF3D.

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Impact of Stimulated Brillouin Backscatter on HYDRA Simulations of the Hybrid-E Platform at NIF*

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During inertial confinement fusion (ICF) experiments at the National Ignition Facility (NIF), 192 laser beams drive a hohlraum to produce x-rays, which in turn drive a capsule implosion that leads to a fusion reaction. During laser propagation in the hohlraum, stimulated Brillouin scatter (SBS) can lead to backscatter of the laser light out of the hohlraum before it has a chance to couple to the hohlraum walls and contribute to capsule drive. In modern low gas-fill-density hohlraums, the measured SBS is generally small (less than a few percent of total energy)[1] so SBS losses are typically ignored when simulating the experiments. In this talk we show that although total SBS losses are small, their strong dependence on polar angle is enough to impact drive symmetry and implosion shape. We present simulations of two Hybrid-E[2] experiments, N210808 and N211024, using the HYDRA[3] radiation-hydrodynamics code, and compare their results with and without SBS subtraction. The SBS subtraction on these shots reduces incoming beam power by as much as 25-50% early in peak power on the innermost (21.2°) beams. We show that starting from simulations tuned to match experimental conditions, such SBS subtraction creates a more oblate implosion, introducing a negative P2/P0 shift as large as 20-35%. This suggests SBS should be included in future simulation modeling efforts, and we briefly summarize ongoing efforts to facilitate better SBS modeling.

*This work was 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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Ion acoustic instability driven by stimulated Raman scattering in picosecond laser-plasma interactions

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We have investigated experimentally (at LULI's ELFIE facility) the unstable propagation of a laser pulse of ~ 1.5 ps duration, $\sim 10^{15} - 4\times10^{16}$ Wcm^{-2} intensity and $1.059\ \mu$m wavelength through a preformed undercritical ($\sim 0.01 - 0.09n_c$) He plasma. By means of space- and time-resolved Thomson scattering, we have characterized with unprecedented detail the dynamics of the electron (EPWs) and ion plasma (IPWs) waves excited along the laser path. Our main findings are as follows:

- Strong IPWs are observed to arise following the onset of backward stimulated Raman scattering (B-SRS).
- Their spatial location coincides with that associated with strong B-SRS activity.
- They are excited within a broad range of wavenumbers, extending at least from $\sim 0.8k_0$ to $\sim 3k_0$ (k_0 is the laser wavenumber in vacuum), that is, including the $\sim 2k_0$ wavenumber of backward stimulated Brillouin scattering (B-SBS) at laser intensities that can be lower than B-SBS threshold.
- Their lifetime (a few tens of ps) largely exceeds that of the B-SRS-driven EPWs.
- Their level scales linearly with that of the B-SRS-driven EPWs over several decades.

We have performed large-scale 2-D particle-in-cell (PIC) simulations to interpret these measurements and, more generally, to illuminate the intricate sequence of processes triggered by the laser-plasma interaction. These simulations reveal that, under our conditions, the electric current carried by the electrons trapped in the nonlinear EPWs induces, so as to ensure current neutralization, a backward drift of the bulk electrons well surpassing the ion acoustic speed: there ensues an ion acoustic instability that excites IAWs in a broad wavenumber range, as observed experimentally. Interestingly, those waves are predicted to accelerate backwards a fraction of the plasma ions to 10 keV–range energies.

Observation of ponderomotively driven bow shock

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By crossing beams at the intensity of 1.4e15 w/cm2, in an ablating plasma flowing near Mach 1, we observed the formation of a shock upstream of the beams. The upstream plasma had a sharp density increase after the flow velocity reached the sound speed, while the downstream plasma also had a reduction in density at a similar timing. These effects are consistent with simulated laser induced shock behavior. The formation and propagation of this shock had a large effect on the plasma's properties, which could be relevant for laser propagation.

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New Insight into Hohlraum Science from Recent NIF Experiments*

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Recently, focused experimental campaigns have been carried out to study various aspects of hohlraum science on the NIF with the goal of improving the model predictive capability that is critical to the ICF program. The focused topics included radiation drive, symmetry and plasma conditions [1]. The results presented here are from two subset experiments, one on the "outer beam glint" that addresses the radiation symmetry and the other on the "rise to peak power" that addresses the drive deficient as well as laser-entrance-hole (LEH) physics.

The "outer beam glint" experiments use a similar experimental setup as that of the "inner beam glint" experiments [2], a half hohlraum with a witness plate at back to measure the glint. In a NIF cylindrical hohlraum any specular reflection off the wall from the outer cone laser beams (incident angle of 50° and 45° relative to the hohlraum axis) glints onto the capsule. If the glint power is sufficiently large during the picket (early time) of the laser pulse, it may seed high-mode perturbations that can grow during the implosion. We found that the measured glint power is lower than predicted by simulations which use a low electron conduction flux limiter ($f = 0.03$), indicating the glint from the outer beams play a less important role in capsule asymmetry.

The "rise to peak power" experiments use view-factor hohlraums (a hohlraum cut off ~ 2 mm beyond the waist leaving an open end at full diameter) to eliminate LEH closure effects in measurements of the x-radiation drive thru the open end using the Dante diagnostic. This measurement of x-radiation drive from the "capsule-point-of-view" is compared with traditional measurement through the LEH [3, 4]. The data through the open-end show that while the radiation-hydrodynamic code LASNEX, using the flux limiter of $f = 0.15$, agrees with the measured radiation flux time history when the rate of "rise to peak power" is 2-3 ns, the code predicts a faster rise than in data when the rise rate is fast (~ 1 ns). The model's disagreement with data for >2 keV photon flux persists using both laser pulse shapes, which could indicate inaccuracies of the non-local thermodynamic equilibrium atomic model used in the simulation.

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A comparison among the three platforms for ignition*

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In this work, we have studied three platforms currently available for achieving burning plasmas under inertial confinement fusion: 1. NIF hot-spot ignition design; 2. Pushered-single shell implosion design; and 3. double-shell implosion design. The necessary conditions for achieving ignition for each platform have been derived. The advantages and disadvantages as well as critical challenges of each platform are discussed. The significant challenge for the NIF hot-spot ignition design and pushered-single shell capsule design is to achieve a sustainable thermonuclear (TN) burn propagation in the cold fuel after the hot spot is ignited, for which fuel ignition and robust burn rely on. For the double-shell capsule designs, the major challenge is control of the implosion symmetry of both the outer and inner shells. If the implosion symmetry is controllable and the energy transfer coefficient is optimized, the double-shell capsule design would demonstrate some attractive advantages of achieving a burning plasma/ignition with the least driving energy among the three platforms. (LA-UR-23-24420)

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Towards new direct-drive facilities: comparison of novel chamber beam geometry robustness to mispointing, imbalance and target offset.

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A decade of experiments at the National Ignition Facility[1] (NIF) has proven that inertial confinement fusion (ICF) is a credible approach to energy production, with experiments having exceeded the ignition regime[2]. However, the indirect-drive approach is not suited for high gain implosions and reliable energy production. The direct-drive ignition approach is favored for energy production as it features simpler target designs and couples more energy to them. There are currently no ignition-scale laser facilities configured for the standard direct-drive approach. Integrated direct-drive experiments have mostly been focused on understanding the physics at reduced scales, with the ultimate goal of demonstration of necessity and feasibility of construction of an international direct-drive laser facility.

In this talk, we will present studies about the irradiation and low-mode perturbations in 3D at NIF scale (also called “ignition scale”). While the stability of direct-drive targets to low mode was analysed in the past on the basis of 2D simulations, only 3D simulations can capture correctly the effects of beam imbalance, beam mispointing and target offset errors. We first perform optimisation studies of innovative chamber designs[3,4,5] (where the beam ports are arranged differently) using a solid sphere illumination thanks to the inverse-ray-tracing code IFRIIT[6]. We sample and select free parameters – the super-gaussian order and the spot size of the laser that reduce the most the initial laser perturbations on target. Robustness to systematic low-mode asymmetries is then evaluated between the chamber geometries using gaussian sampling and statistical methods. We will also assess how the in-flight stability of the target is affected for different ignition schemes.

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